Advance Power Electronics and Control
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Lecture – 05
Device Physics - III

Welcome to our lectures of advanced power electronics and control now, we have already discussed actually, thyristors.

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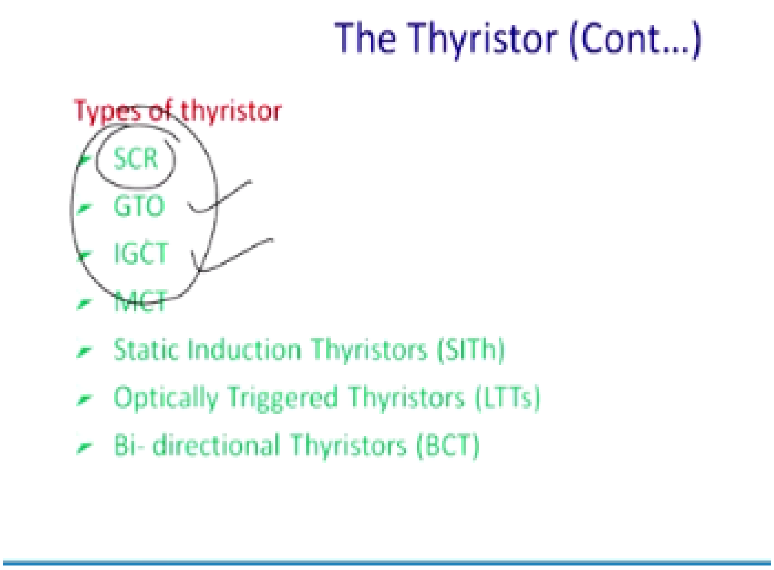

And we have discussed basically, SCR there after we shall discuss actually with the other member of this family, so GTO, IGCT, MCT and other these are the main 3 members are very frequently used in the thyristor family, apart from that static induction thyristors and optically trigger thyristors and bi directional thyristors also we will try to give a brief descriptions but most of the application is applied to this 3 segment; SCR, GTO, IGCT and sometime MCT.

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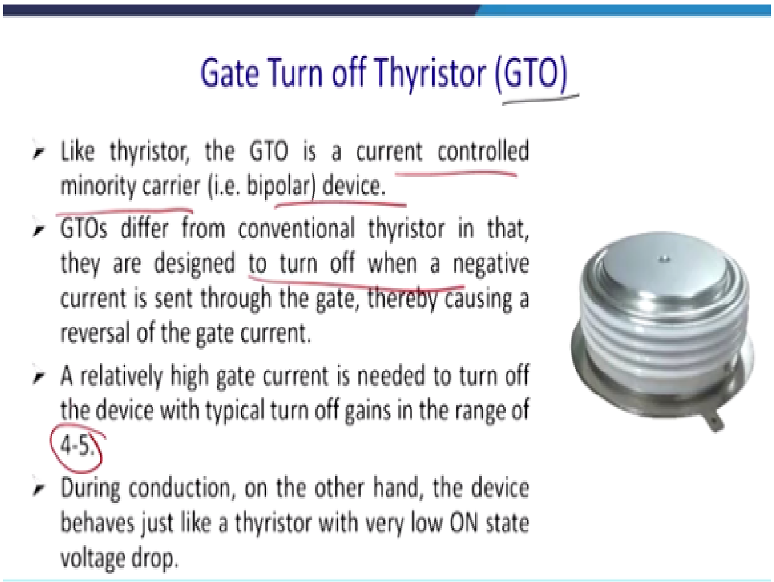

So, we shall today discuss one of the very important members of the thyristors that is actually gate turn off thyristors or GTO. GTO is actually get turn on thyristors, so it is essentially a thyristors which has a capability to turn off by gate; this is the basic difference of it. So, like thyristors GTO is a current controlled device, current control minority carrier that been a bipolar device.

Same thing, it is combination of PA to PN junction that can be think and we will come at with the structure little later. GTO differs from the conventional thyristors in that they are designed to turn off when a negative gate current sent to the; that mean we have actually discussed briefly that 2 transition energy in case of the thyristors, when thyristors are conducting we believe that both this actually transistors are in a saturation regimeS.

But then again we have to bring it one of the thyristors in a cut off region to turn it off and subsequently other thyristor will turn on. A relatively high gate current is needed to turn off because there is a trap charges in that P2 region and typical turn off gain in the range of actually 4 to 5, so we require larger negative current to turn it off let us say if you are turning off 10 ampere current through the GTO, you require a -2 ampere of current something like this kind of values will come.

So, huge negative current you require to sink to operate a GTO, during conduction on the other hand device behaves like a thyristors and with very low constant voltage drop, this is a one of the advantage where other device will find like you know in case of the IGBT and all those things.

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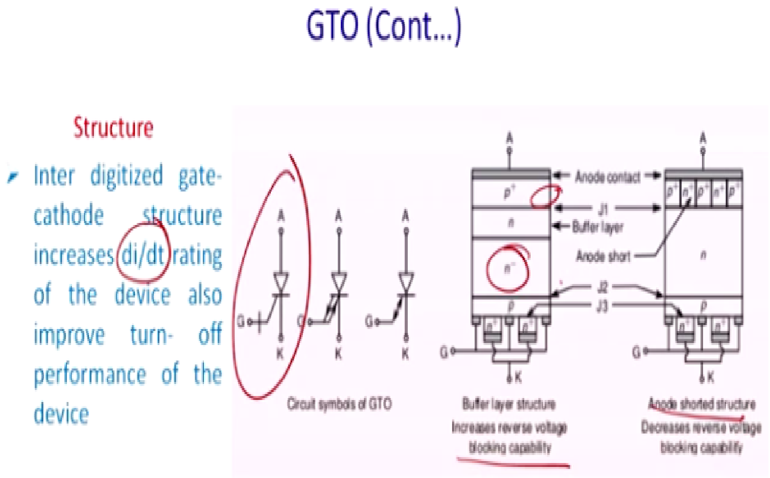

So, this is a symbol of it and we can draw any of it actually, so bi-directional gate current and we show like this ultimately, inter digitized gate cathode structure actually increases the di/dt rating of the device also improve turn off performance of the device, so essentially you have this is an anode, this is actually junction j1 same as that actually thyristors, there after you have a buffer layer, there after actually you got a in junction, there after P junction.

So, this buffer layer is there to actually sustain high forward and a blocking voltage, so there after you got a P junction and followed by gate M cathode, so you can see one thing that you know this is the junction j2 and this is junction j3, buffer structures is there to increase the high blocking potential in reverse as well as the forward direction and in this case, anode shorted structure to decrease reverse voltage blocking capability.

So, this is basically little difference from the conventional thyristors, how does it work, we have to go back again the two transistor analysis.

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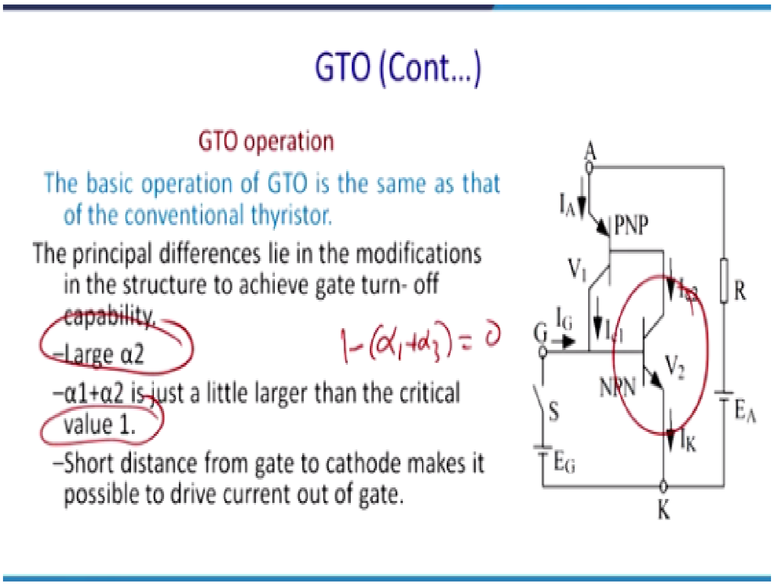

A basic operation of the GTO is same of the thyristors, principal difference lies the modification of the thyristors structures, we shall ever discussed in the previous slide to achieve the gate turnoff capability, it will have large alpha 2, so alpha 2 corresponds to this NPN transistors and it will have large alpha 2 and you know that I have to make it in a connection more than in a model, alpha 1 + alpha 2 should be = 0.

So, alpha 1 + alpha 2 is just little larger than the critical value of 1, short distance from the gate to cathode makes it possible to drive this current from the gate, so this is upper one is the in-plane transistors and you can turn it on and so it will have a first turn on and thereafter what happens, they have turn off it but then you have to change the signal and change the alpha 2 and you have to make transistors since in the structure inside this GTO into the cut off region then you can achieve this turn off of this device.

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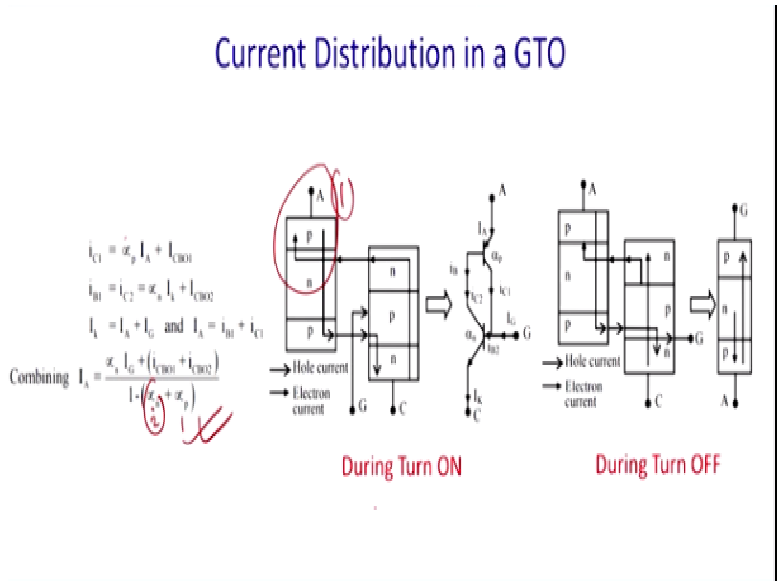

So, essentially when turns on, then equation becomes this; IC1 = alpha P that is alpha P actually corresponds to the PNP transistors, upper one transistors + ICB1 and similarly you can write this equation from the KCl you can boil down the same equation which you have this is in case of the thyristors, so you can see that this corresponds to alpha 2 and this corresponds to alpha 1 same as here it is when you present by alpha M and alpha P upper transistors as alpha; as transistor 1.

And this transistors has transistors 2, so gate turn on operation is same as of the conventional thyristors, so whole current will flow, electron current will flow ultimately this is the direction of the current and ultimately when alpha 1 + alpha 2 = 1, then the current and not current basically goes to the conduction mode and what about actually turn off? Once turned on takes place you have to inject negative gate current.

And thus what happen actually this transistor required to be in a cut off stage; cut off mode and for this reason we inject the trapped charges and we have to take the base into the cut off mode by applying the negative gate current and the structures; the leakage current will be flowing only through the PNP transistor and this portion will be block and thus this is a turn of operation of the GTO.

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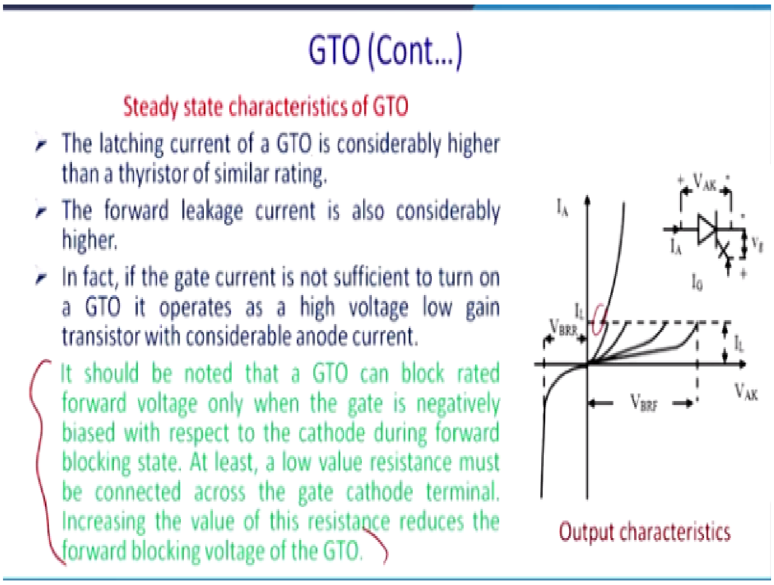

So, steady state operation of the GTO, it is something almost same for the thyristors, the latching current of the GTO is considerably higher than the thyristors of the similar rating, so due to the structure actually you require to take this value little larger then only actually you can put up the gate otherwise, you required to put gate. Forward leakage current is considerably also higher, so that you required to take out the trap charges from that region.

In fact, the gate current is not sufficient to turn of GTO, it operates as a high voltage low gain transistor and with a considerable anode current, so for this is we require to do something, so this is IL; IL value will be higher than the corresponding rating of the normal thyristors, it should be noted that GTO can block rated forward voltage when gate current is negatively biased with respect to the cathode during the forward blocking state.

So, you require to dissipate some amount of the energy to achieve also its blocking stage at least a low value of resistance must be connected across the gate and cathode terminal increasing the value of the resistance will reduce the forward blocking voltage of that issue, this is very important point, so while you have a forward blocking mode and you require to put little amount of the negative gate current to keep it in active plane forward blocking mode.

So, this is something you require to design for it, we shall discuss the gate driver circuit of all the entities starting from thyristors, GTO, MOSFETs and IGBT, these are the 4 major component we generally use in the power electronics, IGCT and other components are now venturing and the ages yet to come for normal application because of the high costs and the technological up gradation till continues.

So, all those 4 gate driver circuits will be design and we will see that what require what, what actually fit to do this associate, what kind of performance.

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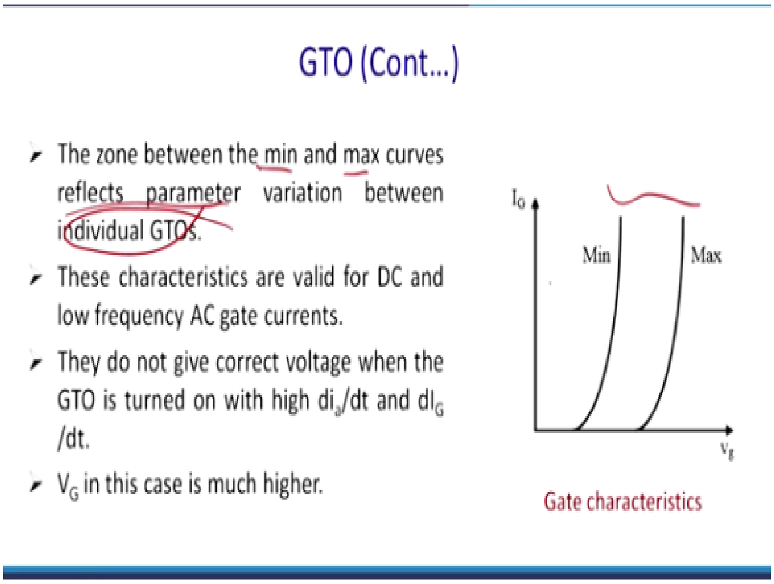

Now, the zone between the minimum and the max curves reflects the parameter variation during the individual GTO, so it is not that you have a single curve, so ultimately depending on the IG, the value of mean and max can be changed, this characteristics valid for the DC as well as the low frequency gate current. They do not give a correct voltage when GTO is turned on with high di/dt.

So, you require to actually take care of the high di/dt issue in the gate current and for this is you require to put a small inductor into the circuit of the gate devices to block it, so this is a new features that require from the thyristors and this VG in this case of the GTO much higher than the SCS of the same rating.

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GTO (Cont...)

Symmetrical versus Asymmetrical GTOs

Type	Blocking Voltage	Example (6000V GTOs)	Applications
Asymmetrical GTO	$V_{RRM} << V_{DRM}$	$V_{DRM} = 6000V$ $V_{RRM} = 22V$	For use in voltage source inverters with anti-parallel diodes.
Symmetrical GTO	$V_{RRM} \approx V_{DRM}$	$V_{DRM} = 6000V$ $V_{RRM} = 6500V$	For use in current source inverters.

V_{DRM} - Maximum repetitive peak (forward) off-state voltage

V_{RRM} - Maximum repetitive peak reverse voltage

And you know based on the applications or the operations, we can classify as symmetrical operation and asymmetrical operation that means when let us say C application, it blocks same forward, it made equal to block same if it is triggered let us say alpha more than 90 degree, so what happened you know it will be blocking forward peak inversion voltage as well as in a reverse also the same voltage.

So, we have discussed in previous slides you know actually, this is a peak repetitive voltage and asymmetrical GTO; VDRM is much, much greater than VRM, the repetitive voltage, then we say that it is asymmetrical and mostly this is use for the source inverter with the anti-parallel diode that is in case of the VSI; voltage source where VDRM can be as high as you know 600 volt and reverse voltage can be as low as the same value.

And GTO can be used for CSI that is we shall come across this topology after this that is called current source inverter where these 2 values are almost same and this is called a symmetrical operation and there VDRM and RRM you will find that actually it is 600 volt and it is almost close to 600 volt, it is 6,500 volt and so it is used for the CSI, of course we have discussed in the graph in a previous class, students are requested to actually see my previous class where have discussed different terminology while discussing the thyristors.

VDRM is a maximum repetitive peak forward offset voltage and maximum repetitive peak reverse voltage.

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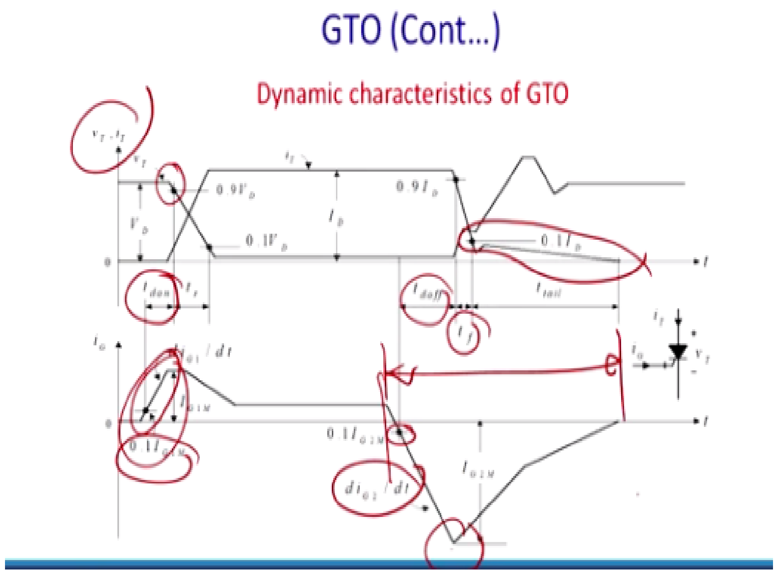

Now, this is dynamic characteristics of the GTO, so this is the voltage and current across this device, so once you initiate to turn it on so since there is a junction capacitor it is just like a charging a capacitor, so it will be actually a ramping on, so what happened due to that; so voltage across this device will gradually fall and it will gradually come to the conduction mode and you know, once you initiate it, till IG rises its value to 1% from that point you will see that actually what was a voltage.

And voltage that time will be the forward blocking voltage, then you ramp it on to the maximum value and by that time, you will see that actually there will be a drop in voltage across the thyristors will be around 90% and current also through this CTO will rise by 10% maybe, so this time basically it is called a delay time in a turn-on, so thereafter it is called rise time where basically you know IG it still which is get rating.

And voltage across this device falls 90% to 10% and current also rises to the maximum value to 90%, this time is called actually the raise time that we will continue, same will happen here you initiate basically the change and here also actually it is a 10% of your IG and you have to see that this IG and this IG here is a huge difference generally, this IG is around 4 times negative current has to be more than 4 times than the forward triggering current.

So, it will continue to rise for this reason there is a problem of high di dt or so it will reach to this value till that time, it will be off and still it is actually not grown up the capability and thereafter, there will be a forward blocking stage, there after what happened current will continue for a huge time, it has a got a current trail, so this is the current trail or the T tail time.

So and you required to continue to give, once you see that actually this value reaches, this actually 90% of a rated current, then you gradually decrease the value of the gate current but you continue to give current once it reaches the actually current generated as prescribed by your leakage current, so huge - negative gate current is required to achieve commutation or turning off. For this reason, GTO is quite slow device than the ICBT, so let us just go through the one of the data sheets of the GTO for better understanding of its phenomena's.

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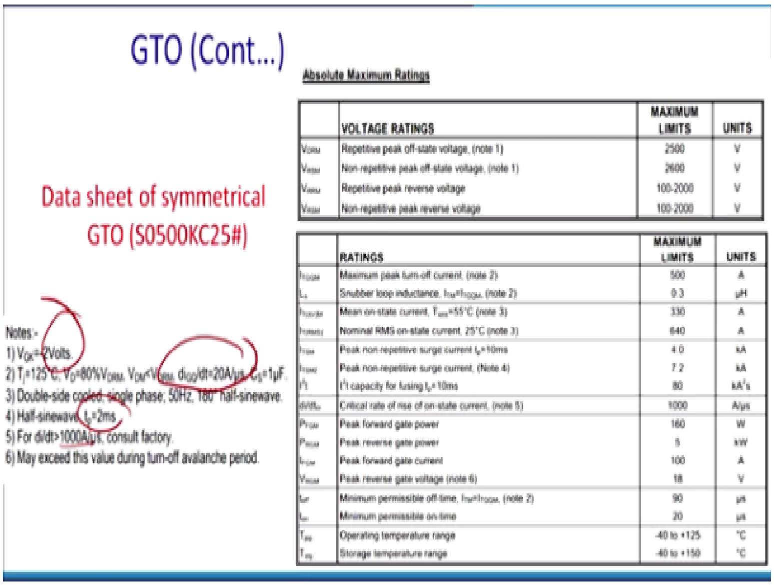

So, VEK, it is actually around 2 volt, so this one a voltage difference required, so T junctional voltage can go as high as 125 degree centigrade, VD should be actually 80% of the VDRM and VDRM should be actually more than the VDM and this thing, rate of change of gate current should be around 20, you have seen that is around in a range of 1 ampere per microsecond, it require to be little higher that is around 20 ampere per microsecond and CS = 1 micro Fahrenheit double side cooled single phase for 50 hertz 180 degree sine wave application.

And since that tp is basically of 2 and for di/dt is basically you know for this device as high as 1000 ampere per microsecond, so let us see, so VDRM, so it should be around 2500, a non-peak repetitive voltage will be more than that so it is 2600, (()) (19:07) peak reverse voltage, it is actually 100 to 2000, so it can be used symmetrical as well as asymmetrical, non-repetitive peak reverse voltage, it is 100 to 2000.

So, what is important you know this is the snubber part that is comes into the protections, so we shall discuss this zone, mostly you know T off permission turn off time, it is basically quite high that is basically 90 microsecond, so generally switching frequency should be you make it around 100 micro second, if you reciprocal it will be a 10 kilo hertz, so at least this turn off time should be around 5 to 10% of the total timing.

So, for this is in this device is required to operate below 1 kilo hertz and possible turn on time is 20 micro second.

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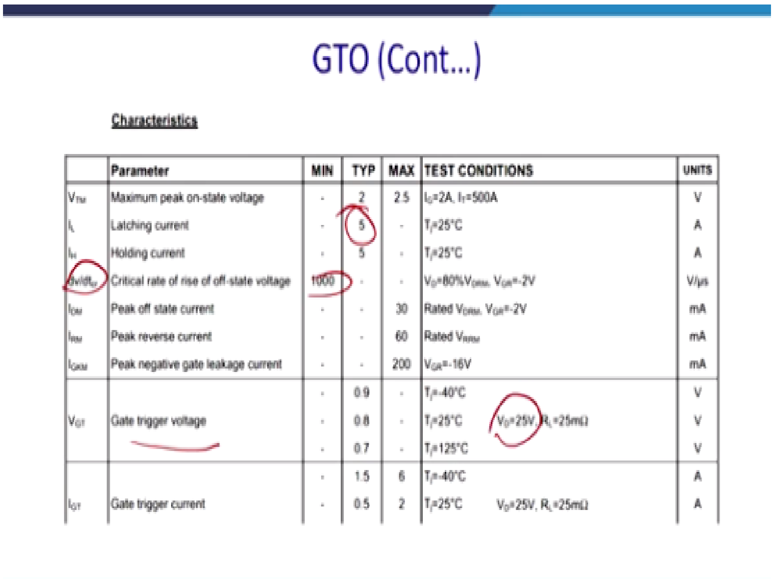

GTO (Cont...)

Characteristics

	Parameter	MIN	TYP	MAX	TEST CONDITIONS	UNITS
V_{TM}	Maximum peak on-state voltage	-	2	2.5	I_G=2A, I_T=500A	V
I_L	Latching current	-	5	-	T_j=25°C	A
I_H	Holding current	-	5	-	T_j=25°C	A
dv/dt_{cr}	Critical rate of rise of off-state voltage	1000	-	-	V_D=80%V_{DRM}, V_{GR}=-2V	V/μs
I_{DM}	Peak off state current	-	-	30	Rated V_{DRM}, V_{GR}=-2V	mA
I_{RM}	Peak reverse current	-	-	60	Rated V_{RRM}	mA
I_{GRM}	Peak negative gate leakage current	-	-	200	V_{GR}=-16V	mA
		-	0.9	-	T_j=-40°C	V
V_{GT}	Gate trigger voltage	-	0.8	-	T_j=25°C V_D=25V, R_L=25mΩ	V
		-	0.7	-	T_j=125°C	V
		-	1.5	6	T_j=-40°C	A
I_{GT}	Gate trigger current	-	0.5	2	T_j=25°C V_D=25V, R_L=25mΩ	A

And what else, so this thing is quite critical dv/dt, so it has to be actually within 1000 and latching current you know it is quite high, latching current required to be 5 ampere, consider that then actually it is something like in a milli ampere region in case of the actually, same rating thyristors, holding current will be also same here there is no difference between the latching current and holding current.

Holding current generally less in case of the thyristor but in GTO, generally latching current and holding current both are remain same, so they are at a peak off state current, it is 30 ampere, so thereafter you have to understand the gate triggering voltage once it is trigger, so these are the typical values which are actually 25 volt and RL considered to be 25 milli ohm and gate triggering current; gate triggering current is required to be generally1.5 or 0.5 amperes.

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GTO (Cont...)

		-	0.1	0.4	T_j=125°C	A
t_d	Delay time	-	1.5	-	V_D=50%V_{DRM}, I_{TGQ}=500A, I_{GM}=10A, di_G/dt=5A/μs T_j=25°C, di/dt=300A/μs, (10%I_{GM} to 90%V_D)	μs
t_{gt}	Turn-on time	-	3.5	5	Conditions as for t_d, (10%I_{GM} to 10%V_D)	μs
t_f	Fall time	-	0.8	-	V_D=80%V_{DRM}, I_{TGQ}=500A, C_S=1μF, di_{GQ}/dt=20A/μs, V_{GR}=-16V, (90%I_{TGQ} to 10%V_D)	μs
t_{gq}	Turn-off time	-	10	11	Conditions as for t_f, (10%I_{GQ} to 10%I_{TGQ})	μs
I_{gq}	Turn-off gate current	-	185	-	Conditions as for t_f	A
Q_{gq}	Turn-off gate charge	-	1200	1330	Conditions as for t_f	μC
t_{tail}	Tail time	-	50	75	Conditions as for t_f, (10%I_{TGQ} to I_{TGQ}<1A)	μs
t_{gw}	Gate off-time (see note 3)	150	-	-	Conditions as for t_f	μs
R_{thJK}	Thermal resistance junction to sink	-	-	0.065	Double side cooled	K/W
		-	-	0.24	Cathode side cooled	K/W
		-	-	0.09	Anode side cooled	K/W
F	Mounting force	4.5	-	9.0	(see note 2)	kN
W_t	Weight	-	120	-		g

And this is for this actually junction, temperature, now delay time, so delay time of the there is a 2 delay time, so this is quite important. Delay time will be actually 1.5, please recall the graph what we have shown, so this is basically TD on so that is required to be 1.5, turn-on time that is actually fall of the voltage across the thyristor; across the device 90% to 10% that is 3.5, fall time is 0.8, turn off time you see that actually it is quite high, this is what is important here the trailing time.

Tail time is as high as 50 microsecond or 75 microsecond and turn off gate charges basically you require this is amount of the charge it has been trapped, you have to take it out, so this tail time is quite large and due to that you require actually this devised higher turn off time, so this is the weight, weight is also little bulky than the thyristors. So, what is the difference between the thyristors and the GTO?

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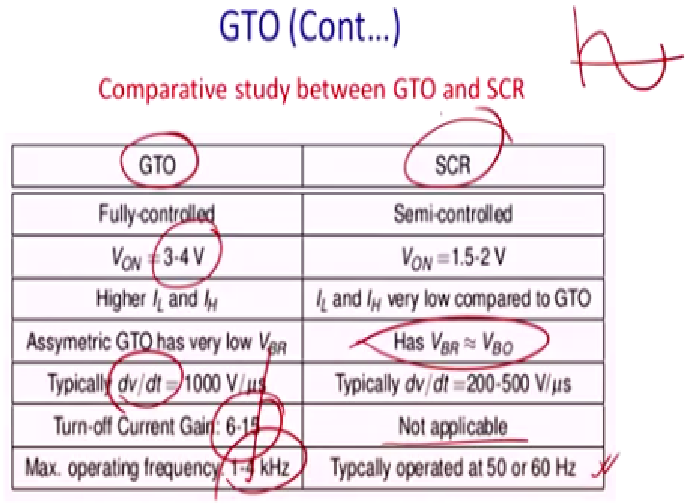

GTO	SCR
Fully-controlled	Semi-controlled
$V_{ON} = 3\text{-}4$ V	$V_{ON} = 1.5\text{-}2$ V
Higher I_L and I_H	I_L and I_H very low compared to GTO
Assymetric GTO has very low V_{BR}	Has $V_{BR} \approx V_{BO}$
Typically $dv/dt = 1000$ V/μs	Typically $dv/dt = 200\text{-}500$ V/μs
Turn-off Current Gain: 6-15	Not applicable
Max. operating frequency: 1-4 kHz	Typcally operated at 50 or 60 Hz

Problem of thyristors that it is difficult it to put off except you have a line commutation in AC, so naturally commutated, otherwise you have to find some means to actually take the current through the thyristors below its holding current to put off either by having an LC oscillations, so that you put actually a medicare auxilary thyristors, you may require a bypass path, so that current actually bypassed and you trigger another thyristors.

This is a different kind of commutation technique or the running of the thyristors, what you require essentially either extra thyristors or you require an LC circuit, so that you can (()) (23:38) circuit, so that you can have a oscillation but commutation failure may occur in a high current within the small interval of time, where you are applying the negative voltage.

If thyristor current does not goes below the holding current, so its forward blocking capability will not be there but GTO has an advantage that you can put off that where you require.

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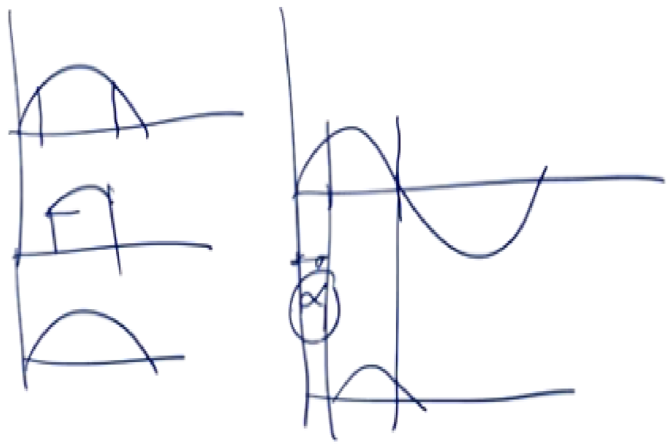

So that is the one of the biggest advantage of it you know, you I can take an example you know in case of the thyristors, let us say for the rectifier operation, you can turn it on here and you will automatically turn in off here depending on the kind of load you are having, if you have a resistive load you are having, so essentially what is your fundamental current that will be lagging yes, this is the displacement power factor comes to the picture and current will be lagging like this.

But you know in case of the GTO, you have an advantage, so here you have you; you may trigger it on here and you can also trigger off here and ultimately you get a this kind of voltage and what happened then; the fundamental current will be this in the same, same, so you can have a unity power factor or leading a lane you can chop it here and this way you can control the power factor of the system.

This is one of the biggest advantage of it and in between you can go further, if you require we will discuss about the selective harmonic elimination and all those things that can be achieved here but in case of the thyristors, you can only control alpha thus you can only control only one angle, so thus you can eliminate only one harmonic that will come later, so let us go back what are the difference of the GTO and the thyristors.

GTO is essentially, this is the one of the major feature otherwise, this is infinite device considered to the thyristors in all the aspects, GTO is fully controlled you can turn in off as turn in on at the wheel of the user but it is a semi control device, when on state drop in case of the thyristors of the same rating will be around 2 to 3 times higher, so for this is on state drop is around 3 to 4 volt.

But you will be having this around 1.5 to 2 volt, it is because of if you go back so we have seen that there is a negative blocking state, so here this buffer layer is there for the higher forward blocking voltage, so for this just in to incorporate it, you also incorporate higher losses, higher holding and latching current we have seen that it is around 10 times higher than the actually the normal corresponding rating of the thyristor.

So, lower holding and the latching current so generally, it has same forward and the reverse blocking voltage and you will have a symmetrical operation but here you have can have a asymmetric operation also all the symmetric operation and you can control and modify it according to the gate current, so you can apply a little bit of negative gate current to put it off to increase its power blocking capability.

These are the few flexibilities is provide and typically, it has high dv/dt, so it will be have a 1000 volt per microsecond but it will have a lower dv/dt for this GTO can to be designed properly for dv/dt and da/ dt protections and turn off gain is actually 6 to 15, so this is a wide range of variation how fast you want to turn off, see you can require to put a more gate current.

If you give a small gate current it will current trail will be much larger and you will require to take much longer time to put it off, so since there is no provision by gate turn off, so that is not there in case of the GTO and as I have shown you that actually current trail is of a typical GTO is in the range of the 50 microsecond, so for the season we are restricted to operate it in the range of 1 to 2 kilohertz.

So, we have maximum you can take it to the 4 kilohertz but it is quite difficult to actually operate and therefore, this is an actually back will be pass on basically on this actually, turn of the gate current, so you require a gate current to turn of these devices and this is typically operated in a 50 hertz supply and mostly in a converter operation where do you have a SCS operated for the and the name suggests is rectification as you can understood that is applicable for the natural commutations.

And it will commute this actually at it operate in a normal power frequency of 50 and 60 Hertz, so these are the differences of the GTO and we shall see that where if possible definitely, the take away from this classes if possible use thyristors, if possible use SCR but if you cannot you require to turn off in between for many reasons for the selective harmonic elimination, for improving the power factor or any other region then we require to GTO, so thank you for your attention, we shall start with another device in next class.