Advance Power Electronics and Control
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Lecture – 07
Application and Analysis of Switches - I

Welcome to the NPTEL courses on advance power electronics and control, this is a seventh lecture, today we shall continue with the application of the analysis of the switches, so we shall discuss about the switches in detail, so based on this actually viewpoints, so we cannot actually consider a physics point of view that is device physics that doping level, kind of material we are using, whether a high band gap material or the low band gap material and from there, we try to explain different features.

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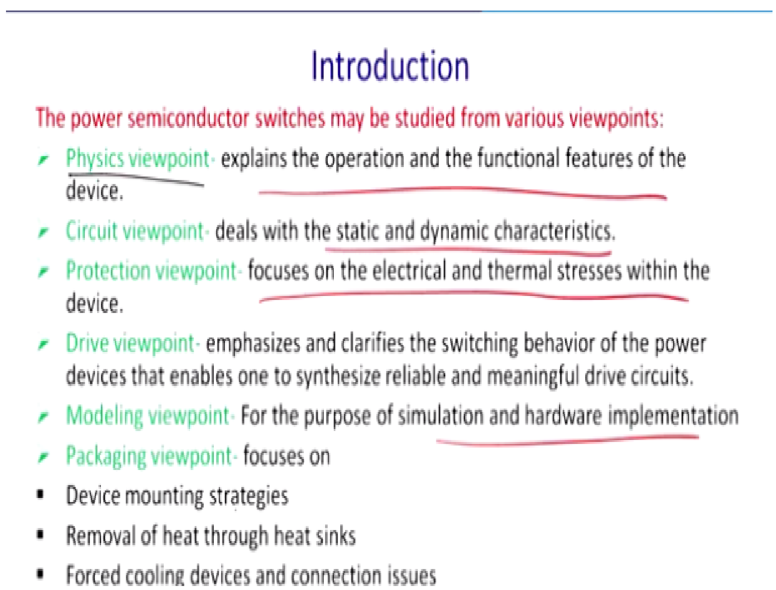

Then, explain the operation of the fundamentals switches of the devices, then we shall take it a physics point of view, so that is called device physics and same way we talk about a switching characteristics and its turn on characteristics, turn off characteristics, deals with the static and the dynamic characteristics; IB characteristics, now required to understand how also to protect the device from unnecessary disturbances, surges and the hazards, unnecessary disturbances and surges and we require normal protections like high dv/dt protection, da/dt, thermal runways.

So, focus on electrical and the thermal stresses within the device, drive viewpoint that is actually emphasis all the behaviour of the power electronic device which can be applied to the different kind of driver circuits, modelling viewpoint we have a different kind of model, we have a spice model of the power electronic, so it is as state space model, so we can write a; we can have a different kind of modelling viewpoint, what kind of simulation tool should be used.

Based on that we have a different kind of approaches, so simulations and the hardware implementation or hardware in the loop applications kind of thing, we have various kind of hardware interfaces like RTDS, (()) (02:37), so there we try to find it out the solutions of a few systems and we try to model the power electronics switches, so we will modelling more realistically, so that is actually the modelling viewpoint.

And packaging; so, it comes under different kind of packaging, so because you want that the device has to be compact, may be comes across in the ceramics packaging, in may comes across the plastic packaging depending on the thermal runaway and different kind of cooling systems and the compactness and so it comes at the device mounting strategies, removal of the heat sinks and how you will dissipate the heat in different way.

And force cooling devices and the connection issues, these are you know different criteria to choose a particular device because please understand that modelling of the viewpoint is also important because once you before put in a hardware, we generally simulate a system, so if it is not very authentically simulated, then actually the fragility of this model is in a questions, so all those aspects has to be consider while actually taking a consideration of a switch.

And when you are considering a switch we always assume this is the ideal conditions that no resistance or zero forward voltage, obstruct resistance is infinity when it switches off, no current flows, when on, conduct; it can carry infinite amount of the current, both in forward and the reverse direction, it comes under some kind of mechanical switches like SPST and all those things.

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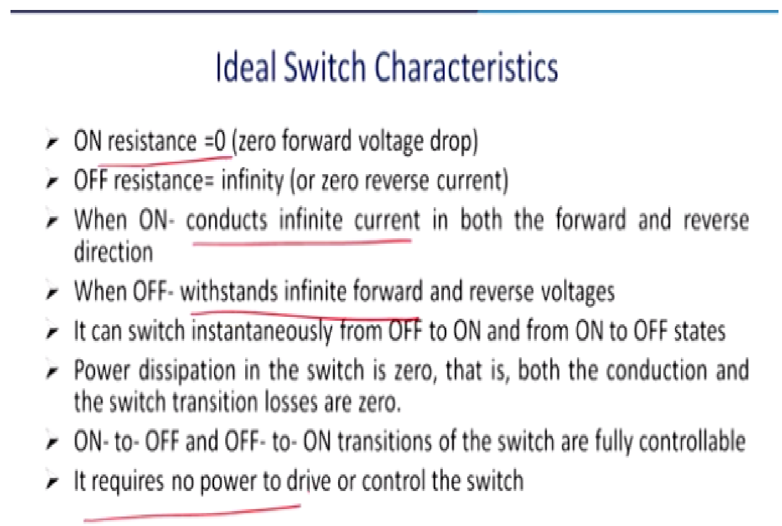

When off, infinite forward and the reverse voltage, so you have studied the forward breakdown, reverse breakdown voltage but in ideal consideration of the switches, this is not being considered, it can switch instantaneously that is also not the case because it has a finite turn on time, we have referred to the reduction of the different device and we have seen that different turn on and turn of time.

Instantaneous off and on time and from on, off states, so transition between on and off states is basically does not take any time that is resilient, it is instantaneous phenomena, power dissipation of the switches is 0, why; because when voltage is high, when it is blocking the voltage, no current flows and when it is conducts current, there is no voltage stop across it, so both conduction and the switch transitions losses are also 0.

On to off or off too on transitions of the switches are fully controllable, so we can wish to turn on and turn off wherever is required but we will come in to such picture that even if actually in a different kind of topologies in future, even if you are triggered, current due to the direction of the current, switch will not take the conduction till current through that other device goes 0, then only transitions comes into the picture.

But in ideal condition we assume that whenever I wish, I can turn it on, whenever I wish I can turn it off and it require no power or to drive or control the switch, so power losses in a driver circuit is 0, these are the ideal characteristics of the switch and ultimately, we will see that all switch deviates from it and so we required to have; we have to find a closer approximation to this ideal conditions while we are analysing and discussing about the switches.

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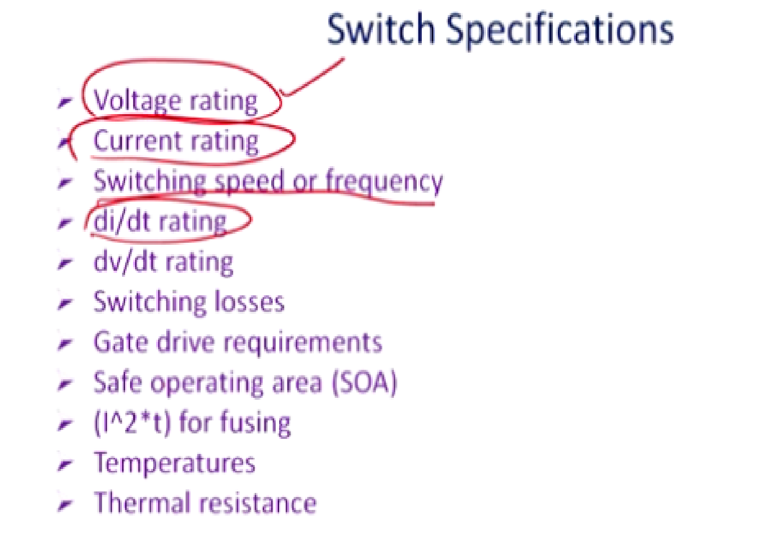

So, for this reason, we have few ratings and specifications, so this is what we are saying that you know are its forward blocking and reverse blocking capability is infinity ideally but actually you have a voltage rating that will pacify your forward and the reverse voltage blocking capability, the switch should have ideally infinite current carrying capability but the data sheet will prescribe the current rating of the device.

Transition from the switching on to switching off and vice-versa is infinitely small or it is instantaneous, this is ideal characteristics but switching speed and the frequency will have a limitation on it, same way di dt protection, so that is also comes into the picture in transitions, so high di dt leads to the damages of the switches, so we require to protect from it, same way; high dv dt also leads to the damage of the switches.

We require to give a protections, what we assume that that will ideal characteristics, there is no switching losses but there will be a switching losses, so requite to calculate it accordingly we have to choose the switch, gate drive; we have said that gate drive does not require any power, actually it requires power and gate driver requirements are many things, what should be the amount of the current sink into the system.

And how; what will the pulses can generated, these are the issues, same operating zone of the devices which voltage and which current it can operate separately, so that does not go for the thermal runaway and high square rating for the fuse and other devices, temperature; different functional point have different temperature, you should ensure that it does not causes the thermal limits and also the thermal resistance from the heat sink to the body.

So, what are the actual path of heat dissipations, so these are will be specified we have seen already in the data sheet, this data has been specified.

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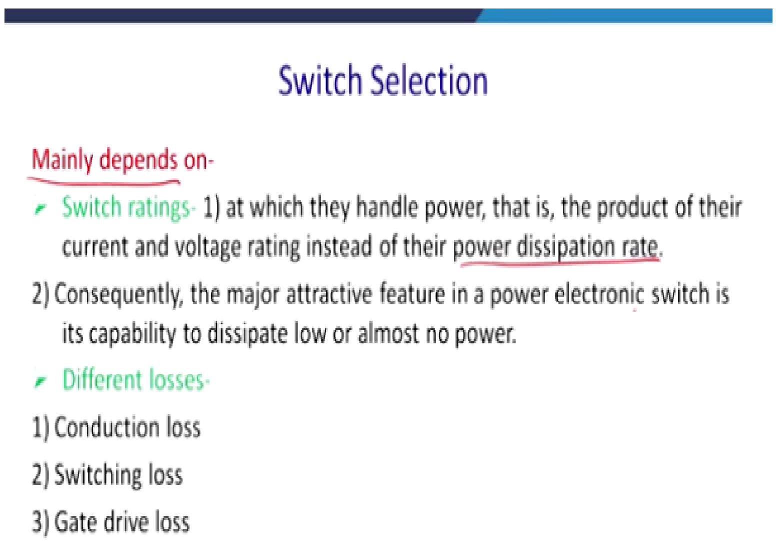

So mainly, switch depend on switching rating, that is which they handle power and the product of their current and the voltage instead of their power dissipation rate, so higher the power dissipation rate, we say that switch rating will be higher and we shall find that you know thyristors is actually the first person in that category, first entity in that category, consequently the major attractive feature in the power electronic is its capability to dissipate low power or the no power.

So, there are different kind of loss, if it is on even though we assume that the power losses across the switch is 0 but it is not 0, so thus we have a conduction loss and thereafter when there is turn on and turnoff takes place, so there is a switching loss and also there is a loss at the gate driver, so these 3 losses we have to actually accommodate, switching loss comes with a turn on and a turn off losses and conduction losses is depends on sometime it is (()) (10:23) * I square for the MOSFET.

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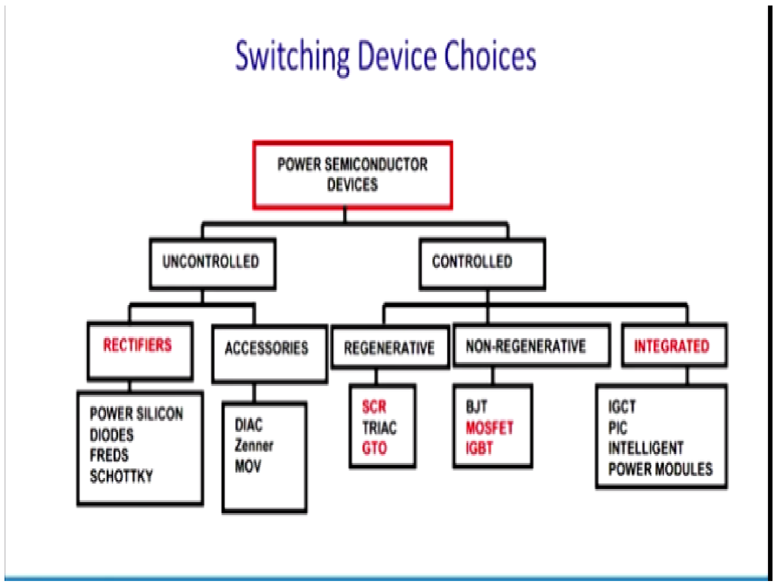

And other device is a constant voltage drop into the current, so from this discussion we can come out to the switching device choices, one is semiconductor device, so it can be uncontrolled and controlled, so under uncontrolled, it comes to the rectifiers and the accessories, thereafter it comes to the power silicon diodes, short key diodes, fast recovery diodes and there is a accessories like you know this is the used mostly in the protection and the regulations.

These are Diac, Zinner, MOV, thereafter within a control, we can classified broadly into 3 categories; one is regenerative, so you want that power to be feedback from the load to the source like for example, when you are using electric vehicle and you are breaking or you are going to downslope, then power should fit it back to the source for the better utilisation of the power and if you wish that regenerative braking from the we use the device like SCS, TRIAC, GTO and if you are using because it is current control device.

So, as long as current as high, it can be a bidirectional and you can have a non-regenerative that is BJT, IGBT and MOSFET, generally MOSFET with the body diode and thus also have a regenerative braking capability. And to make IGBT and BJT regenerative, we require anti-parallel diode parallel to it, so and thereafter it can have an integrated packages that is IGCT, so the packages actually the MOSFETs and the IGBT together, thereafter intelligent power module, PIC, this kind of entities are also there.

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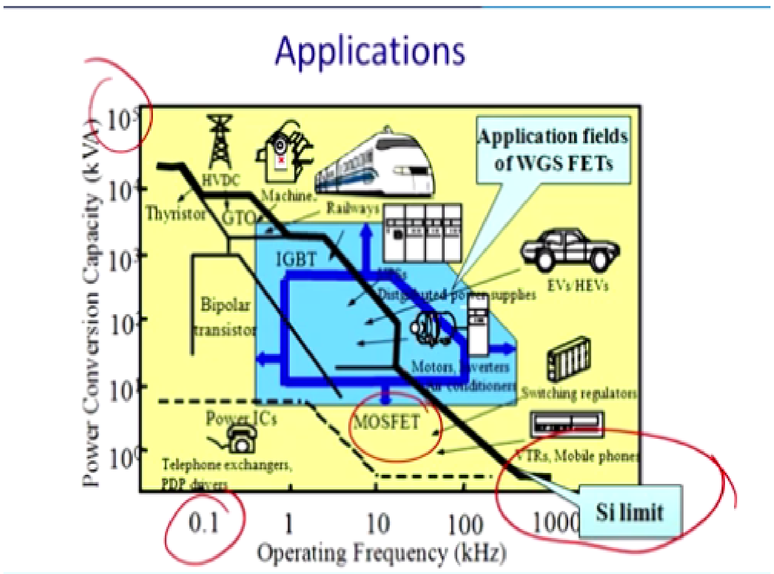

So, you see that actually power conversions capacity and the switching frequency, so different kind of power handling capability is been used, so far low frequency applications, you can have a thyristors and where power handling capability as high has 100 of megawatt, so it find its applications in HVDC, thereafter you got GTO, so while it is a little high frequency and quite high-voltage or high-power, so for this is a high power tribes and relevance.

Thereafter, whole zone comes under IGBT, so IGBT is basically fitting you can see the actually very big portion of the power electronics, so it can handle power to some level up by paralleling hundreds of kilo watt, thereafter for this is an application is a UPS distributed power supply, small motors invertor, small drive or medium voltage strength drive, electric vehicle applications.

There after it comes, there after you go to the higher frequency and little less power, then it comes to the MOSFET, here the bipolar transistor has seen a lowest duration nowadays due to the advent of the IGBT, so generally a bipolar transistors is have phased out most of the cases, MOSFET will have a very high frequency but low power handling capability and that finds the application is switching regulator is MPS, VTR modules of the phones and power ICs and all those things.

So, these are the power ratings and the frequency ranges that is available for the existing device and what kind of device we will choose based on those criteria has been discussed here and new entrant is basically the you know, this is the SI limit and the SIC and SIC is a material instead of the silicon and SIC will have an advantage of; they are pushing the power obtained to the power three.

So, if it is a power MOSFET of SIC, so that can come into IGBT range, so if it is actually an IGBT can come to the GTO range and GTO can come to the easily the thyristor range, so this is a advantage of the SIC devices. So, we have discussed about actually power diodes and power diode you know we have classified that is based on of its recovery time, so this is called pin diode.

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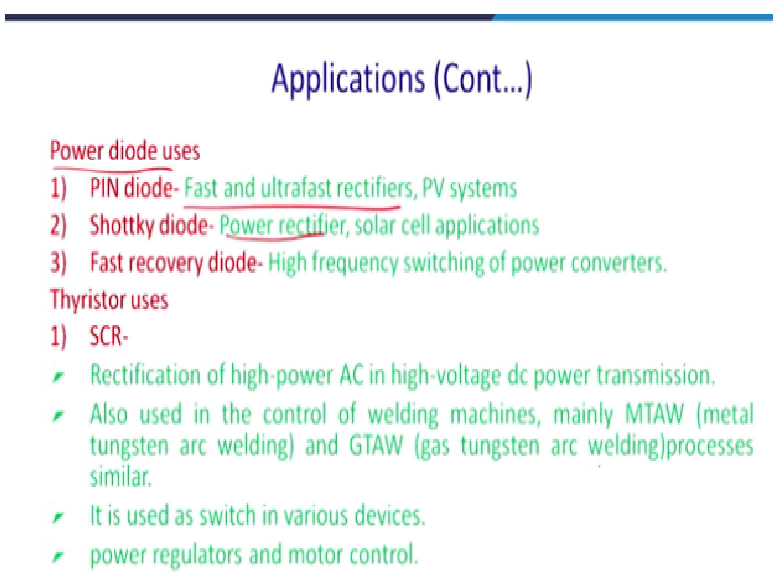

And it is used in fast and the ultra-fast rectifiers, mostly in which the DC to DC applications, isolated DC to DC or non-isolated DC to DC applications and the PV systems and thereafter, we have a Shottky diode, this is used for the power rectifier mostly, in case of the active rectifier where you are making AC to DC keeping (()) (16:22) limit low and then after, solar cell applications so that as a fast recovery.

Mostly, fast recovery diode is used mostly in SMPS, where actually switching frequency required to be high and it is mostly use in a parallel with the MOSFETS. Thyristors; mostly used in high power rectifier, rectification of high-power AC in high-voltage DC power transmissions, all are actually (()) (16:56) those who are actually (()) (16:58), still they use actually use high voltage rectifiers, used to control the welding of the machine mainly MTAW, metal tungsten arc welding.

And the gas tungsten arc welding, this kind of thing they are actually it finds the applications, it is used as a switch for different devices and power regulators and the motor control because it is uncontrolled device based on this actually, voltage polarity, it will conduct and sorry, it is a semi-controlled device and for this reason quite actually high power requirement is there and we can make the current leading then it is will automatically commutated.

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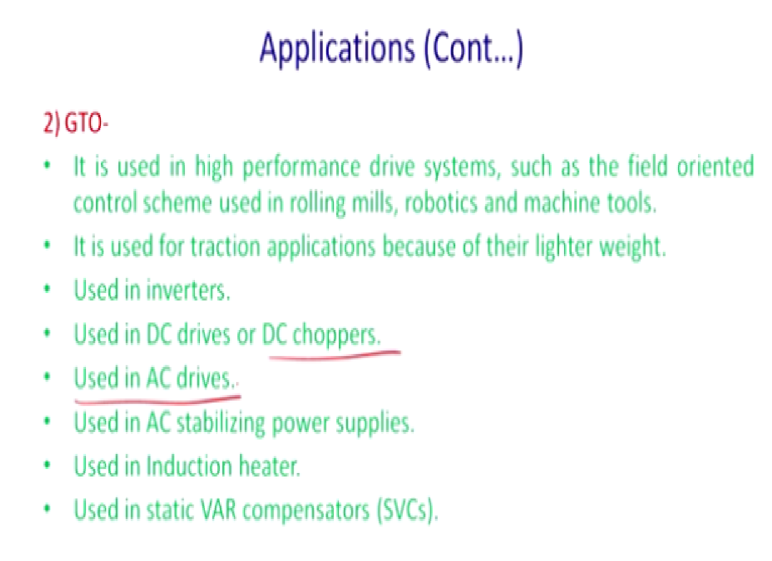

And thus in this kind of applications you know, thyristors point is suitability, now comes to the GTO, is uses in high performance drive system such as a field oriented control scheme that is vector control for the high power motor drive, robotics, machine tools, it is used for the traction application because of the lighter weight and it used in high power inverters where GTO's cannot fit the power, they have to use in the DC drive and fax devices and DC chopper, used in AC drives.

Or rectification operation of the high power application used in stabilised power supplies, used in high-power induction heaters and used static VAR compensators or different kind of fax devices.

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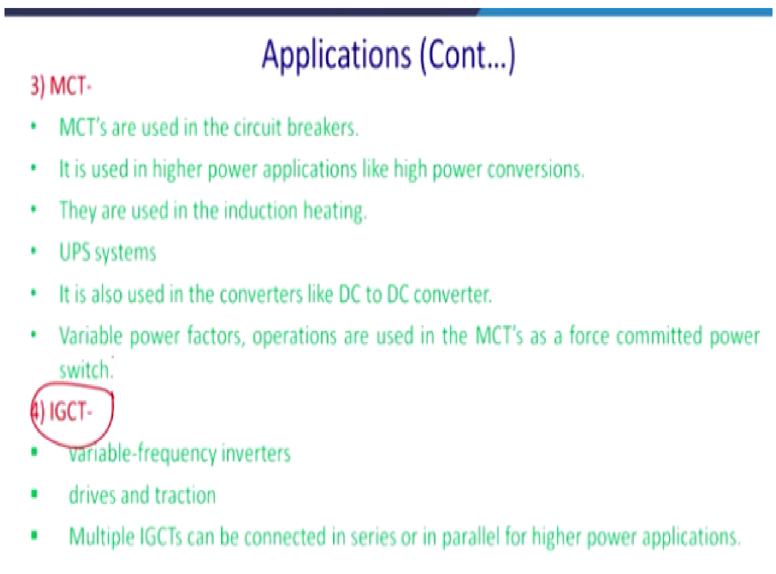

MCT; mostly it founds an application in a circuit; high power circuit breakers, it uses high-power application like high power conversions, their use for the induction heating, UPS system, is also used for the convertor; DC to DC convertor, high power DC to DC convertor, mostly use for this actually harvesting power from the offshore, wind plant or something, power handling capacity can go as higher megawatt level.

Variable power factor operations are used as the force commutative power switches, now IGCT is the new entrant, one of the application of the IGCT; it can handle around 100 times or 1000 times more power than the IGBT, the same actually the frequency range, variable frequency inverters is definitely a preferred choice for it because we can go to the high-voltage applications and if we run at a high frequency since you have heard about the VYF control.

And you can track the switching frequency little higher then we can have a high-power gearless operation that is one of the challenge we are facing, because once we have a very high power drive, if you wish to go for the higher power rating, then torque compromises, so keeping torque same if we wish to go to the high-power, high speed, so this kind of application where IGCT has been preferred.

Drives and tractions, so it is a preferred choice and multiple IGCT can be connected in parallel in series to actually increase the power handling capability of the line.

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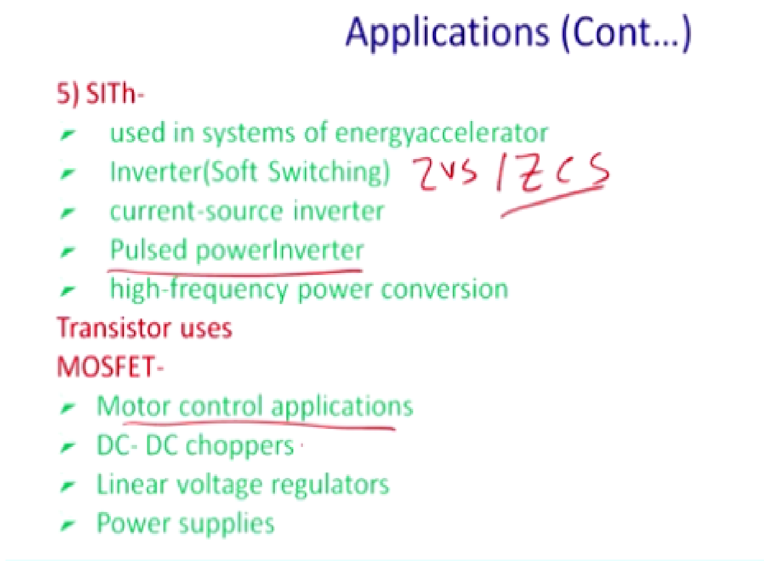

Same way, SiTh, we have discussed already used for the system of the energy accelerators, so inverter with the soft switching that is actually we can make the switching losses low or 0, that is called soft switching that can be ZVS or ZCS that mean, ZVS is 0, voltage switching or ZCS or 0 current switching that can be easily achieved by this SiT and it is one of the member that find very good applications for the current source inverter.

We will come across this voltage source and current source, different kind of topology and we shall discuss about it with that the switches, pulse power inverter; so this kind of application is quite natural for this in case of the pulse mostly in actually welding kind of application now, let us come to the MOSFETs. MOSFET used for the high frequency low power drives, motor controlled applications, there are DC choppers, linear voltage regulators, power supply etc.

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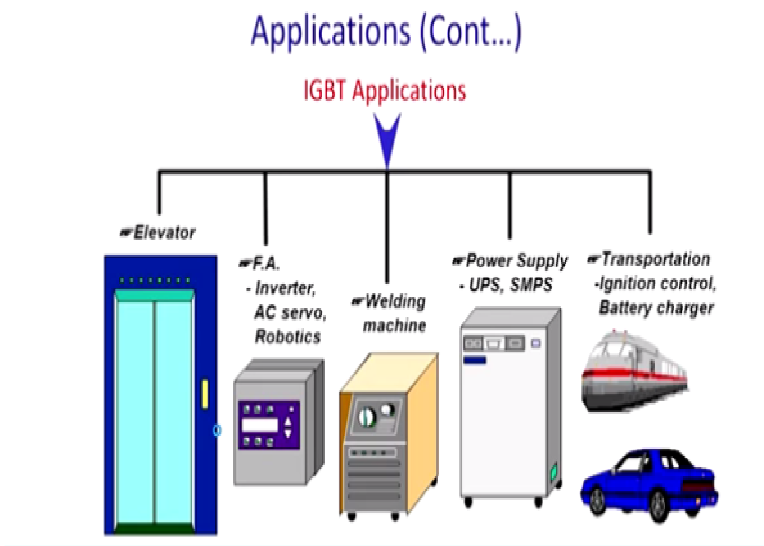

So, you can see that these are the different applications of the IGBT, I have seen that IGBT fit into this actually day to day application quite well, so we have a modern elevator that is having an adjustable spring type and these are run by the IGBTs, so power goes to 100s of the kilowatts, there after you may have a inverter servo robotics, so that we use for the different kind of mining operations mostly.

They have to arc machine or arc welding where we want to maintains a power quality better, power supply is UPS, SMPS for a highly data bank kind of applications, transportations for the railways and all those things and battery charger, electric vehicle, these are whole area is of IGBT.

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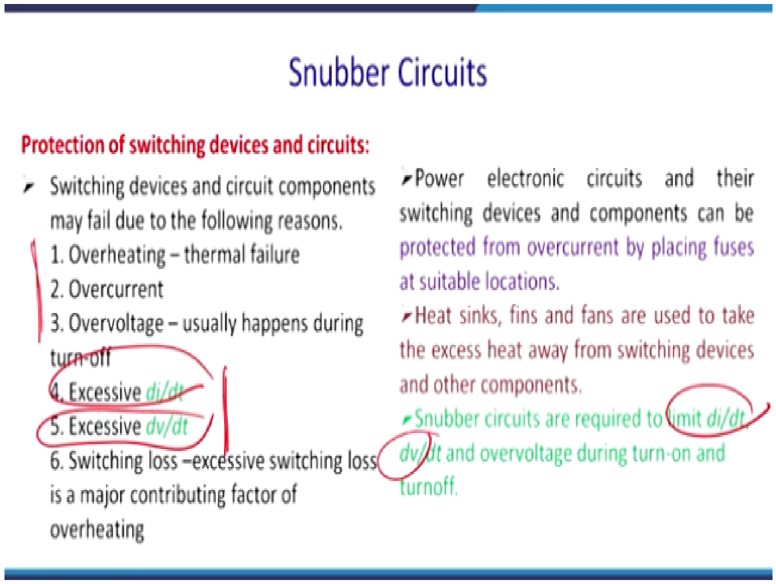

Now, let us come to the protections, we have talked about dv dt and di dt protections, now let us and how you can achieve that; we achieved by snubber, due to the shortage of time we shall take it out for the thyristors and this concept can be extended to the all the switches we have talked about, the switching device and the circuit's component may fail due to the following reason, so failure may come due to the thermal failure or this is called thermal runaway.

Overcurrent and overvoltage, so these can be controlled by the supply site but you know and also you know it may cause with the excess di dt and the dv dt, so that may actually cause failure or reduce the life time of the switches and also excessive switching loss while conduction, so we required to reduce this 2 losses mainly, by snubber directories. Power electronics and switching device and the component can be protected from the overcurrent by placing the switch will fuses or the MCB or now different kind of circuit breakers.

Heat sinks; over the different kind of cooling technique fins and fans are used to take out the excess heat and what snubber will do; snubber circuit required to limit di/dt and dv/dt and overvoltage during turn on and turn off of the switches.

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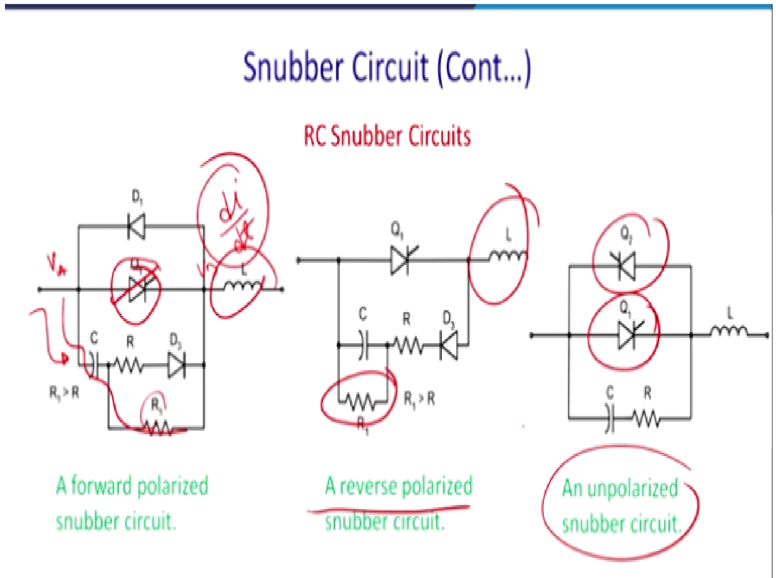

So, there are different kind of snubber, so this is the device you know we required to protect; to protect that device we require so many device, so anyway so this L will be in a series with the device and this will ensure the protection over di/dt, it will limit the di/dt protection and this RC rate work will come while turning on because you know once actually, correct flows if it is an off and this is the actually, voltage across VA is > VB so and you are triggering.

Then, this this will come for high dv/ dt protection and also while actually taking off this capacitor will ensure that actually current flows through it through this R1 and ultimately, it gets the capacitor charge in a reverse manner and it will ensure that really over the dv/dt, same way we can have us different kind of circuit here, value of R1 is more than R and mostly it is comes into the picture.

Because if you see that actually it is a RC network that is searching and this is the time constant of the circuit and will ensure the time constant of the circuit in such a way and that time stress across the switch does not comes, once capacitor is fully charged, whole stress will come across the switches and if we used reverse polarity, inductor will be in the same position and what happened here actually, this R has to be set beside and R1 will be here.

So, it comes into the picture of this circuits while actually it did not turn off and it is called a reverse polarised snubber circuit and it will actually protect for the dv/dt protections and same way we have a unpolarised snubber circuit, so it can operate both the connection it is with the, this is the RCD snubber, this is RC snubber and your time constant will require to choose in such a way that stress dv/dt stress across the switches get reduced.

Since it is unpolarised, it can operate for the bidirectional thyristors, so where snubber finds its applications?

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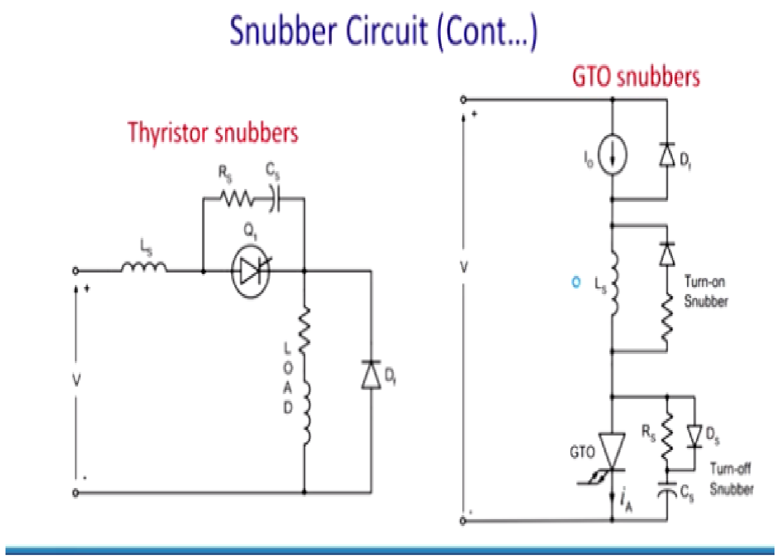

So, let us consider the simple chopper kind of operation and you have a high source inductance, then you will have to provide the diodes as a snubber to have a you and since it is a high and we can assume that load is a high current source, in this conclusion you know you have to allow flow of current continuously and thus it will find this path like while turning off, so this diode comes into the picture while turning off.

And similarly, power MOSFETs turn off, once the gate pulses is been withdrawn and negative; little negative gate pulses, so ultimately you know the switches does not have any voltage, so to short, so gradually it is actually getting up forward blocking voltage capability and thus capacitor will be charging, so what will happen; since capacitors will start charging this way, so automatically actually current through this MOSFET will go low and will have a high dv/dt protection.

So, this is thyristors snubber what we have discussed here and so this is the RCT snubber and it is used for the thyristors and this is the snubber used for the GTO, same snubber and it can be used for the GTO, this is the turn on snubber and this will be the turn off snubber. So, we shall continue to the requirement of the gate drive, we have talked about the protections and in next class, we shall talk from the gate driver circuit and we shall looking forward to start about the different features of the gate driver circuit in our next class, thank you.