Advance Power Electronics and Control
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Lecture – 08
Application and Analysis of Switches - II

Welcome to a second lectures on applications and analysis of the switches, we left we have discussed till the protection parts number, now we shall now take into considerations of the control that is a gate driving circuits.

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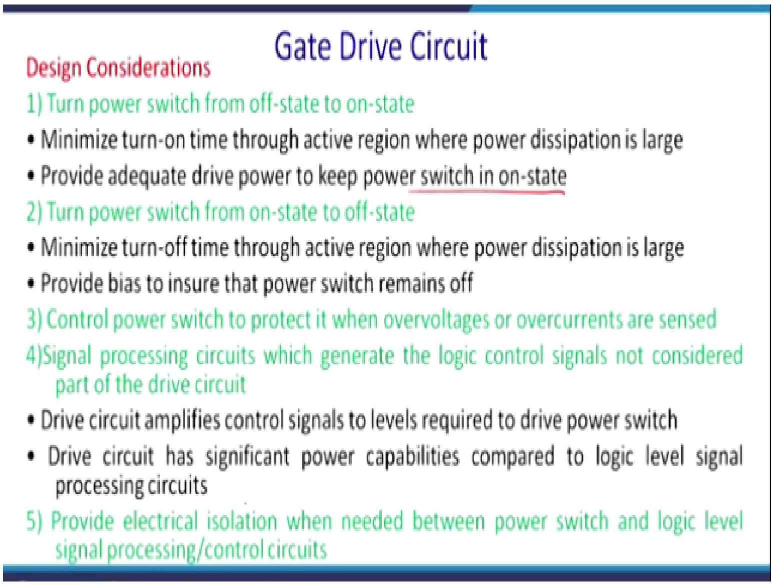

So, what does it do gate driver circuit, it turn on and turn off the switches, so these are the design consideration, turn power switch from off state to on state and vice versa, while transitions power losses should be minimized and if there is a thermal heat generation that should be evacuated, so minimum power on turn-on time through via active region where power dissipation is large provide adequate driver power to keep power on the switch on state in case of the MOSFETs and other devices.

Turn power switch from on state to off state to minimize turn off time through which the active region where power dissipation is large provide bias to ensure that power switch remains off. Third entities that control power switch to protect when over voltage over current or any unnecessary phenomena comes are sensed, signal processing circuits which generates the logic control and control is not considered a part of the device circuit.

Drive circuit amplifies control signal to the level required to drive power switch, drive circuit has significant power capability compared to logic level signals processing circuits provide electrical isolations where needed between the power switch and logic level signal processing and control.

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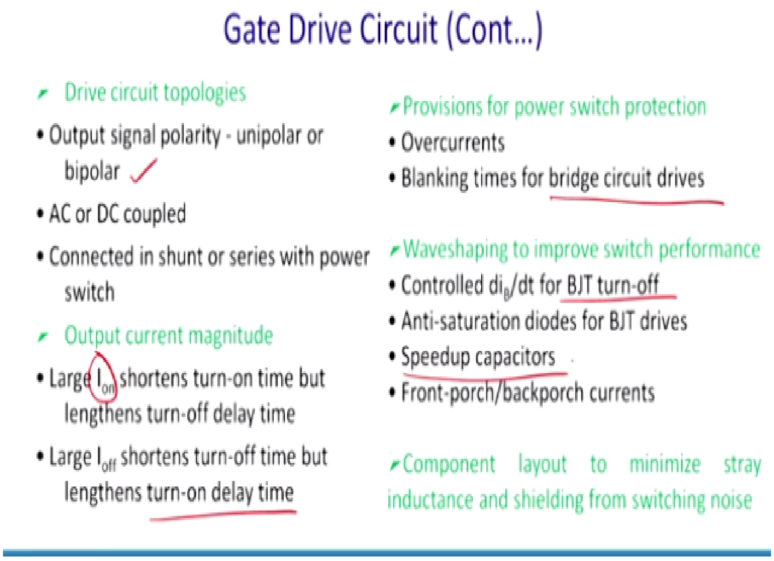

Drive circuit topologies; output signal polarity it can be unipolar or bipolar, some drivers circuit require plus minus some voltages, mostly in IGBT require a bipolar supply, so and the bipolar polarity, signals can be bipolar or the unipolar and we required to have a different kind of coupling, it can be DC coupling or AC coupling connected in shunt or series power switches.

There after provision for the power switch protections once it is over current like you know in case of the IGBT, we sense that VC voltages; VC's voltages is actually comes down to a certain value then gate pulse is withdrawn, blanking time for the bridge circuit a drive, so we can ensure that there is no actually, short circuit among the lags in case of the inverter drives.

Output current magnitude, large on current shortened turn on time but lengthen the turn of delay time, this is one of the requirement, large off shortened turn of time but lengthened the turn-on delay, these are the contradictory features and we have to optimize these features while designing, wave shaping to improve the switch performance, control di/dt for BJT turnoff.

So, you have to see that actually base current of this BJT is actually within a controller, anti-situations diodes for the BJT drives, so once we have to ensure that it does not go to the saturation regime, then gate loses its control, we want that actually all the device to operate in an active region especially BJT otherwise gate losses its control, speed up capacitors; so it will make the turn on faster.

Capacitor is something like electrical mass, so we have to or electrical inertia, so we have to take control over it, front porch or back porch current that is also something we have to take care of, components layout to minimize a stray inductance and the shielding of the switching noise, this is very important while designing it, so we have a strain inductances into the PCB; printed circuit mode.

We have to have a such a PCB design that stray inductance will reduce otherwise, you will have a problem of high frequency because it will access a low pass filter and will truncate some portion of your frequency and it will also some time leads to give some unwanted noise into the system, apart from you know in digital system limit cycle oscillation and all those nasty feature may come.

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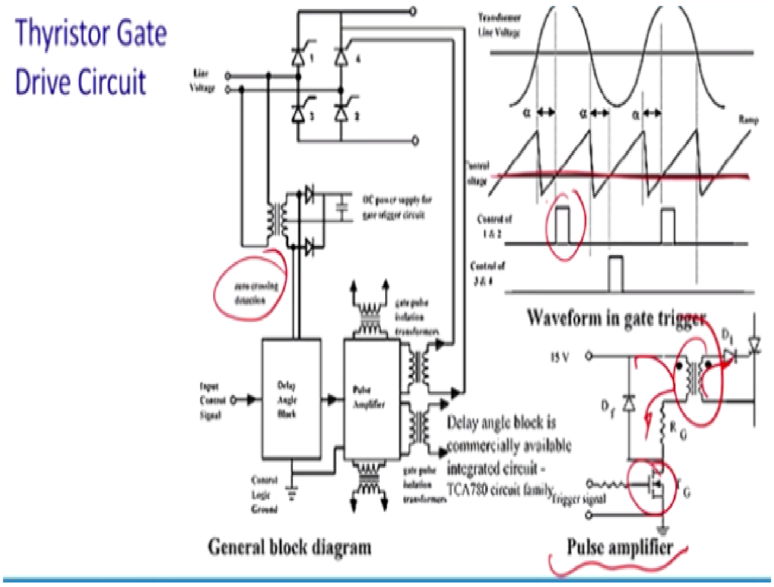

Now, let us take an example of the thyristor gate drive circuits, so here we have a zero crossing detector, from there we have analog control and then from there, we will have a pulse amplifier and pulse amplifier will have an isolation because it is a high voltage for this reason, we require galvanic isolation between gate driver and the thyristors power circuit and this isolation is provided by this isolation transformer mostly, this is called pulse transformer.

So, pulse transformer has been shown here, this is a feature once actually it will be in pulsed, so current will flow through it and this will be turn, once this MOSFET is turned on, so current will flow and ultimately, current will flow in this direction and it will turn on the thyristors. So, generally power dissipations will be in impulses, so for and this core of this pulse transformation is ferrite for very good power linkage and for the highest switching frequencies.

So, what happened you know, this is a line voltage and we required to delay by alpha, so alpha delay been actually done by shifting this DC voltage, so the moment it cuts, so this will be the delay alpha and at that point actually, it will be trigger so we got a actually high pulses and these high pulses will actually give fed to the pulse amplifier, pulse amplifier will generate necessary triggering pulses.

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GTO Gate Drive Circuit

- A GTO gate drive has to fulfill the following functions-
  - Turn the GTO on by means of a high current pulse (I_{GM})
  - Maintain conduction through provision of a continuous gate current (I_{GM}, also known as the "back-porch current").
  - Turn the GTO off with a high negative gate current pulse.
  - Reinforce the blocking state of the device by a negative gate voltage.

Now, let us come to the GTO driving circuit simply, as driving circuit of course you have a different kind of pulse triggering circuits and you can have a thyristors with the UJT for different device itself was actually used and invented for the triggering thyristors but anyway dam based thyristors triggering is quite useful and it has been used in practice for a long time, so we can refer to the book of another methods of the thyristors.

Of course you can go into the actually brief discussions of all the circuits of the thyristors because lack of time we cannot do that so, GTO gate drive circuit has to fulfill few functions apart from the thyristors because there is an issue of turn it off, turn of the GTO means that high current from the current pulse, maintains conduction through the provision of the continuous gate current.

And there is a continuous power dissipation because unlike thyristors once it trigger, it is finished we required to maintain little bit of gate current to make it on, GTO make it on and turn off of the GTO with a large negative gate current pulse that is also a requirement of the GTO, so it has quite complex gate regarding features compared to the thyristors and reinforce blocking state by the device by a small negative gate voltage.

So, ultimately it can be for the HVDC applications, so and for this is we require an isolations from this decayed gate driver part and where a operator is operating and the high voltage sites for this, we can have a optical fiber cable or any isolations microwave optical to the electrical conversion will be done, there were control logic and this is basically, the high frequency DC to AC conversion.

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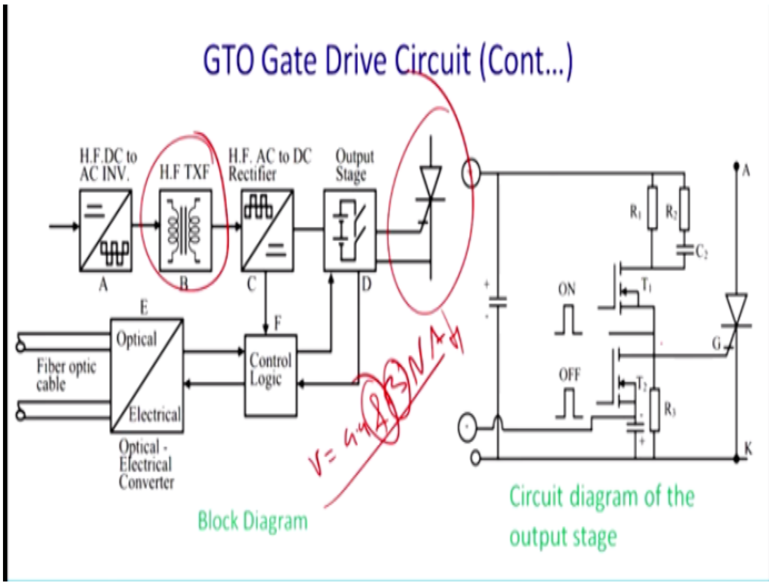

So, you have a high frequency transformer, this high frequency transformer used for its compactness once we go for the higher switching frequency, size of the device will be less since you know that actually V = 4.44 for fBN into so, this what happened you know if frequency becomes higher then basically, you can sustain higher rating with a low voltage because into A will come so ultimately, B something is constant.

So, if you increase the frequency then size of A can be reduced, for this reason we go for the higher switching frequency to reduce the size of the core and we have a high frequency AC to the DC rectifier, then we have a output stage and there actually you got a GTO, how GTO is triggered; so this is the supply of the GTO and it has been triggered by the 2 MOSFETs, conducted in these fashions.

So, once it is on, so upper MOSFET is triggered, so then what happened it will give to the forward pulses to it, once it is required to be off then lower MOSFET is triggered and please understand that it is given a bipolar voltage, so negative; high negative gate current is required to be applied followed by a little bit of negative gate voltage, so make it off state, so this is achieved by this features. However, current carrying capability of this device is required to be higher and sometime instead of this thyristor, we use IGBT's.

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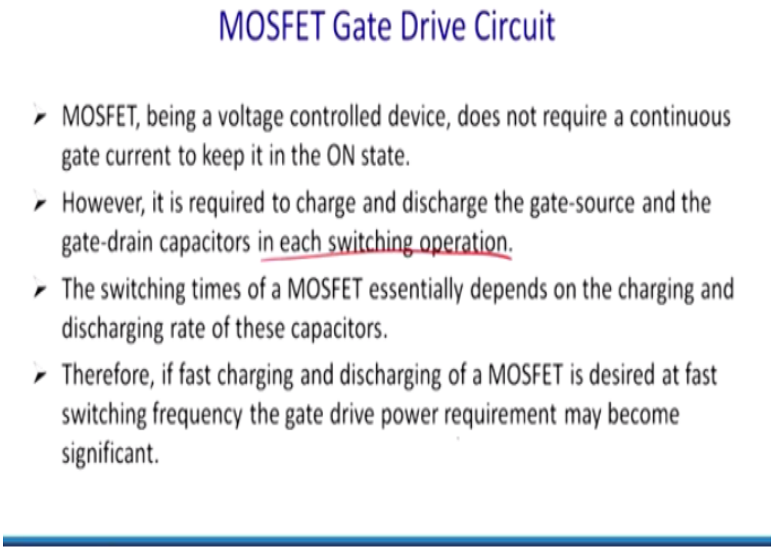

MOSFET gate reverse circuits; MOSFET is quite versatile device for the low voltage high frequency applications, MOSFET being a voltage controlled device does not require a continuous gate current to keep it on state and since it is the insulated gate, so gate current is quite low and power dissipation in the circuit MOSFET circuit is quite low compared to the GTO.

However, required to charge and discharge the gates and source and the drain capacitor in each switching operation, so every time the capacitor across gate and source that is CGS has to be filled by the charges fed from the gate drain, the switching time of the MOSFET is essentially depends on the charging and the discharging rate of the capacitor, so it will turn on when CGS is filled and it will totally discharge and have a forward blocking capability , when this capacitors will be fully discharged.

Therefore, fast charging and discharging on the MOSFET is desired fast switching frequency and higher current handling capability of the gate driver, for this reason to operate in a high frequency.

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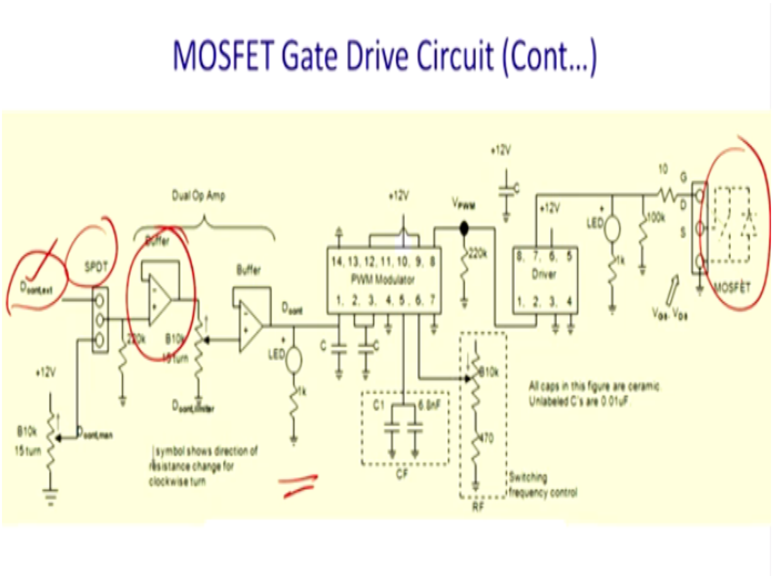

So, this is one of the small example of the gate driver circuits of the MOSFETs, it comes with a package, so this is the MOSFETs this has been shown as a switch, so you know this is a drain and this is a source of the MOSFET and it comes with the body diode and upper one is the gate, so what happened you know actually you have a, actually the connector from connector you have a SP DT and a single-pole double-throw switch.

So, from there you can actually control, so this is the external control of the pulses and you have a buffer that buffer will ensure that no loading takes place of this external circuit, otherwise this current is so small that you know if you have a resistance and all those things then it cannot support the loading of this current, from this buffer actually you have apart from’ part you got an LED.

So that will ensure that actually we require, we get a pulses, from pulses we have a PWM modulators, so that will actually have a generate the PWM by sine triangle comparison, from sine triangle comparison that will go to the driver and driver will actually drive the circuit, let us see what is actually happens to all this blocks in one by one.

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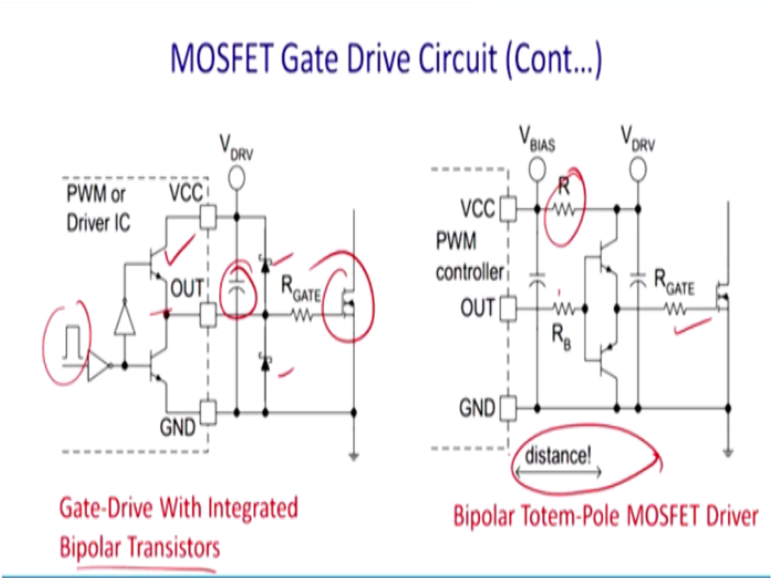

Essentially, one aspect is that gate driver circuit with the integrated bipolar transistors, so what happened you got an imprint transistors, once you have a pulses we have a inverting logic, so what happened if this pulses is on, then this transistor will go off and this will go on, so what happens essentially you know when it is on, then actually the current, then this device will get a high voltage and it will turn on and you will have a very small resistance to turn in on to dissipate the power drop across this gate.

So that this is basically the gate resistance and to block the actually the IGBT, you have a blocking capacitors and that and we have a very fast or short key diode, so that we require a very fast recovery, so for this reason we prefer a short key diode or ultra-fast diode for this purpose, now this is one of the configuration gate driver or integrated bipolar transistors.

Simply your version is definitely the totem-pole configuration here and that the same is used, so you have a RB, you got a totem pole configurations, so this is; this configuration is called totem pole configuration and you have a resistance to block the current through this actually this transistors and once it gets pulse upper thyristor is on, then actually MOSFET is turning on depending on the RG and the CGS, so this will be the RC time constant of the devices.

And mind it you know actually, we have to provide, if it is a huge distance that is leads to the stray inductance of this gate driver circuit and that will post trade on noise also high frequency application, so this distance should be as close as possible for this reason, we have modular time entities that will reduce the switches, so discrete component definitely will give you a stray inductances.

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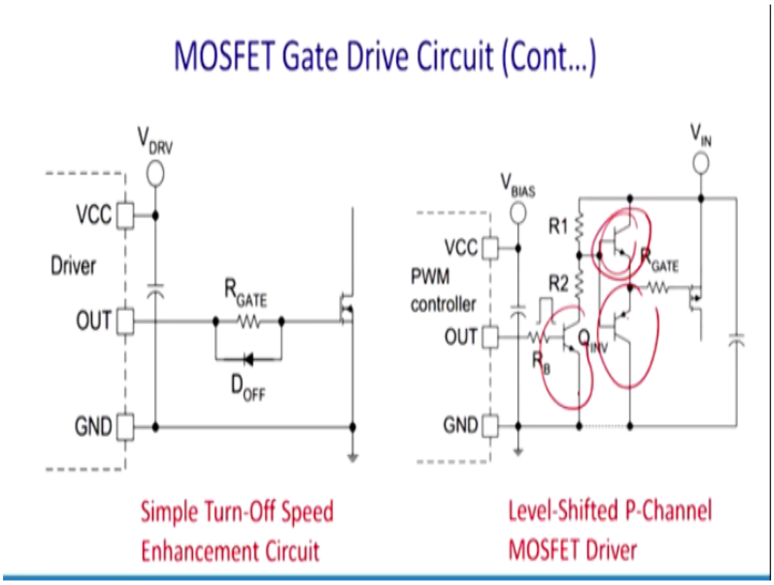

So, and also while turning off, we want that actually to bypass this resistance, so we have a fast turn it off and for this reason, we turn it off by this diode that is a very fast recovery diode is used and so once you turn in on it actually current flows to the lower transistors and little bit of negative biasing may be preferred to take it to the off state, so this is the one of the way to do that otherwise, you may have a which is a n-type, if you have a p-type, it is level shifted p type MOSFET driver is used.

So, MOSFET driver p-type is turned on by the negative voltage for this is we required to be actually even though you have positive pulses, then this kind of configuration is used to use the MOSFET driver with the p channel and for this reason here what we will find that actually this is the n channel MOSFET, so this is a NPN transistor, this is a PNP transistors and you have this actually these configurations once you get a pulse, this NPN transistors becomes on.

Once it is on, then basically then this voltage becomes 0 automatically, this voltage goes low this will be in a conduction mode, ultimately negative pulses or a zero pulses will be applied to it and it will come to the conduction mode.

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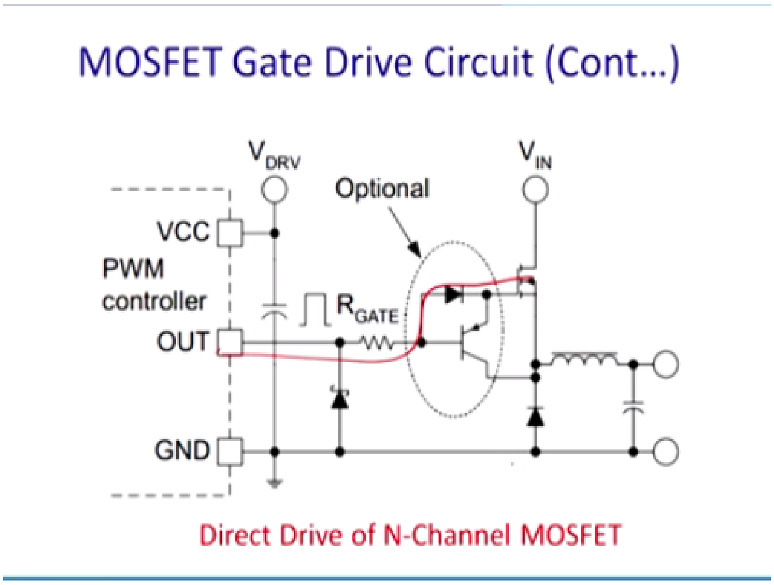

So, we have a different kind of configuration depending on a different kind of requirement, so you can see that if you have a pulses and if you have these n channel MOSFETs and this kind of configuration after RG you can provide to have a faster conduction, what happened while turning on you know path will be through it, while turning off so it can go through this, so what happened actually, you can ensure that faster turn of operation by putting this whatever we have put an optional that will leads to the faster turn off.

Because turn off if you have; you mentioned in the data sheet in 2 class earlier, you will see that is a biggest challenge, so we required to faster turn off by this kind of applications.

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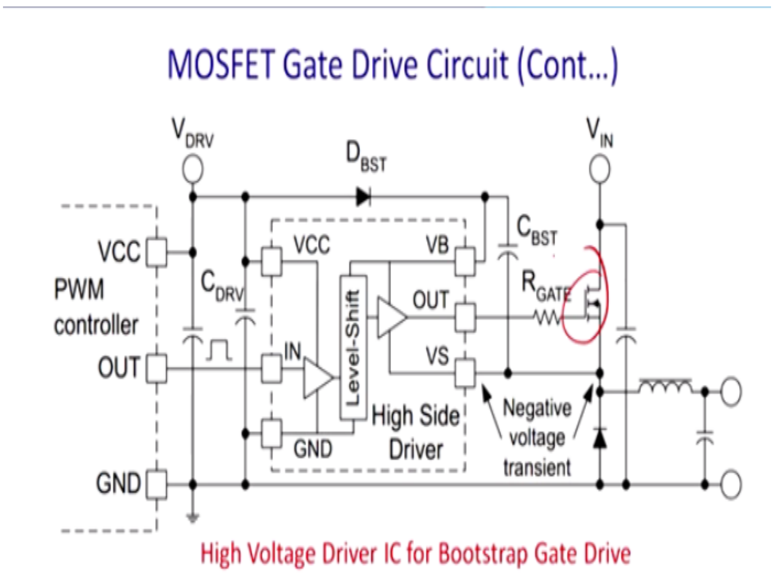

Another aspects comes into the pictures; bootstrapping, this issue comes once we require to once actually, this MOSFET is turning on, then what should be a level of the voltage, once if it is inverter a lake, lower MOSFET does not have that problem, once it is standing on so that voltage of this drain goes to 0 and thus and source is always 0 but the worse happens for the upper MOSFETs.

But or any kind of application when you were triggered that in voltage goes to the plus VCC, then what happened then gate voltage is lower than they actually the source voltage then the no voltage, then they actually the voltage polarity reverse in VGS and thus it will find difficulty to turn it on that MOSFET when this condition is fulfilled, so for this reason we require to do some kind of modification into the circuit.

And we provide a capacitor that is called bootstrapping capacitor and this method is called the bootstrapping, principle is same but we have a level shifting entities, this level shifting entity will ensure that actually and this is a high voltage site or the high timer site of the devices and ultimately it will give a pulse, once it will give a pulse this capacitor basically come into the picture between the driver and this actually VIN since it is short.

So, this voltage and this voltage will be same and this voltage and this within this voltage, there is a capacitor, so what happened then due to this actually capacitor, so there will be a voltage across this point and this point and this voltage required to be this voltage actually, maintain the higher driver voltage than this actually VIN, actually gate voltage required to be little higher than this source voltage is fulfilled.

And this kind of actually, this is called bootstrapping and it is required for the switching on the upper MOSFET in inverter or any kind of application when you turn it on these devices and the source takes the voltage of the forward voltage and which is more than the gate voltage of the source. Now, let us come to the IGBT; IGBTs are very important features when it required a bipolar power supply that is one of the difference with the MOSFETs.

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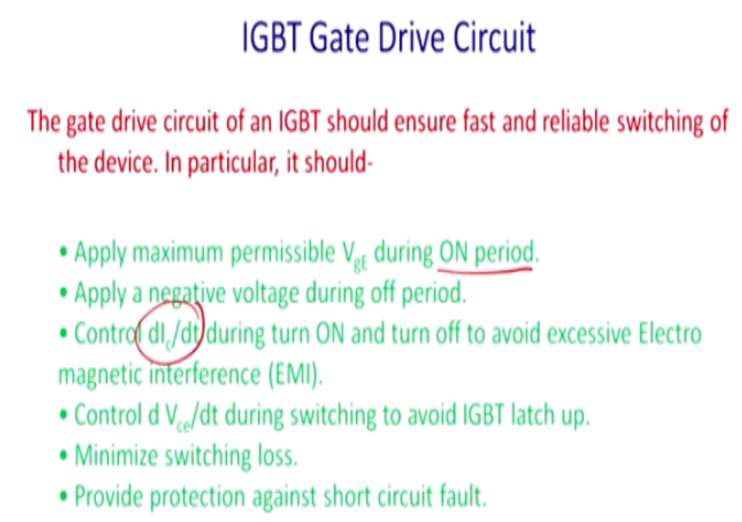

So what happened you know applying maximum permissible VG during the turn-on period, apply a negative voltage during a turn off period, control di dt during the turn on and turn off, excessive electromagnetic interference and that will cause this control of dv dt during the switching off and to avoid the latch up, minimizes the switching losses and provide protection against a short circuit and fault, these are the requirement.

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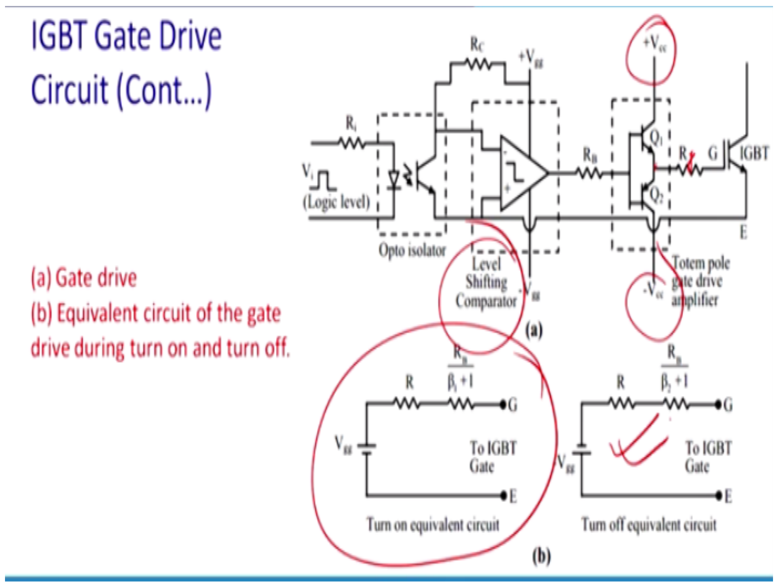

So, now this is the example of the IGBT circuit, so you got a logic pulses and you require a optical isolations and this is called opto couplers and you have to choose the frequency of the opto coupler accordingly and once we will get a pulse, we have a level shifted or comparator, so we will shift that level and ultimately fit to the totem-pole configuration, it is the same thing for the MOSFETs.

But here you require a bipolar supply, you have to be plus minus 15 volt or anything whatever require and this value of the RG should be very small otherwise, it will slow the process, so this is the totem pole configurations and accordingly, it will turn it on the IGBT, so the gate equivalent of it is basically this, this is VG + R, this is basically RB/beta 1, where beta 1 is a current gain of the IGBT, so this is the circuits come into the pictures.

And once you want to off it, so negative voltage comes into the picture, so this becomes off and this become on and antimony negative voltage applied to the system and that is what happened you know this voltage become negative, so this becomes the circuit, so extra trap charges will come and will dissipate, so this is the gate driver circuits for the IGBT. Now, let us consider the generic switching converters.

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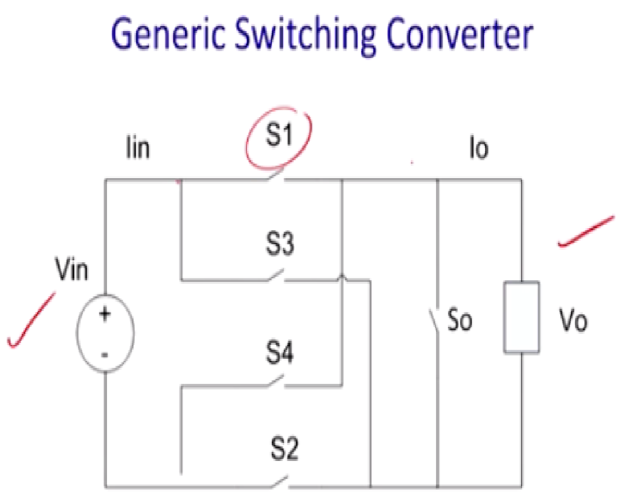

We want to send power to this point to this point and in different kind of applications, we will find a different switches on, you see that you know S1 is connected between this pole and this pole, it can be a simple SPST switch, single pole single source switch and it can be a mechanical switch, so let us realize it in that way then we say replace it by the different switches that we have discussing for a switches.

So, this switch is 0, this switch is S3 and this is S4 and this is S2, so let us see that what kind of switches comes into the picture, rectify inversion and different kind operation.

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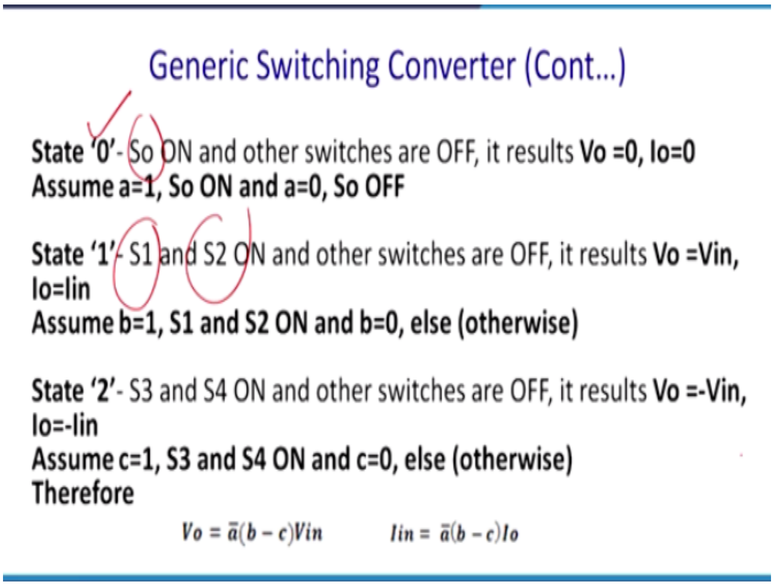

Now, let us take state 0, what is state 0; S0 is on that means, this switch is closed and other switches are off and results output voltage = 0, this is basically the freewheel action and it is called freewheel action in power electronics, next state 1 where actually load gets a power from the source, state 1 S1 and S2 is on, let us again see, S1 and S2 are on, so these are closed, so power will flow like this.

And it results since there is no losses across the switches, so V0 = V, so you can take; if you wish to have a chopper operation, so you are bucking, sometimes you may choose the state 0 and sometimes will state the choose 1, once you take a state1 output voltage should be equal to input voltage and once you take a state 0, so output voltage should be equal to 0, neglecting the diode up.

Because it freewill is essentially a diode but it is in a switch, so it is 0 and assume b = 1, S1 and S2 is on, so b will be 0 otherwise and state 2; it is S3 and S4 is on, other switch is off, so and you get the reverse voltage that is basically – V.

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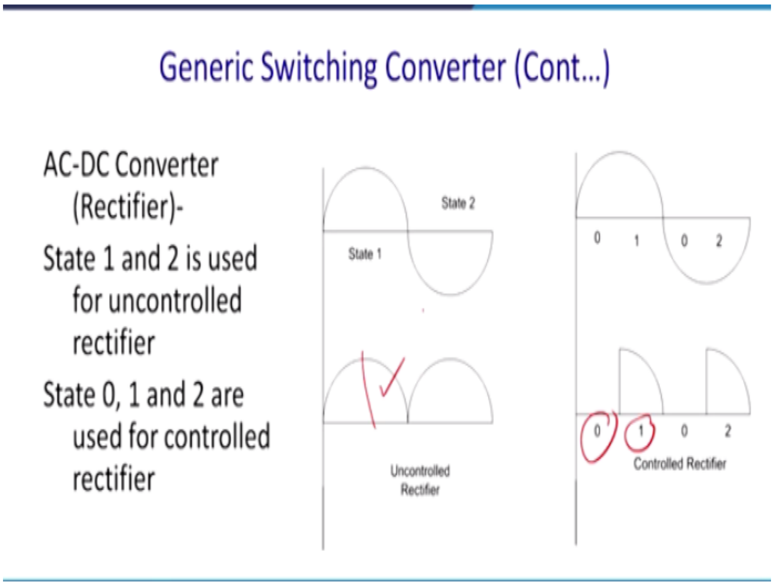

So, let us see how what happened, so for the AC to DC conversion, this is a state 1 and state 2 it and this is uncontrolled operation, so what kind of switch you will operate now, in this case what will happen; you will get the same thing state 0 and 1 is operated but this kind of operation you know when it is 0, it is not getting any load, so it will have a few elections, so you will get zero voltage.

Once you have connected this state 1, you get this part of the voltage, so depending on your application you will get a different kind of voltages.

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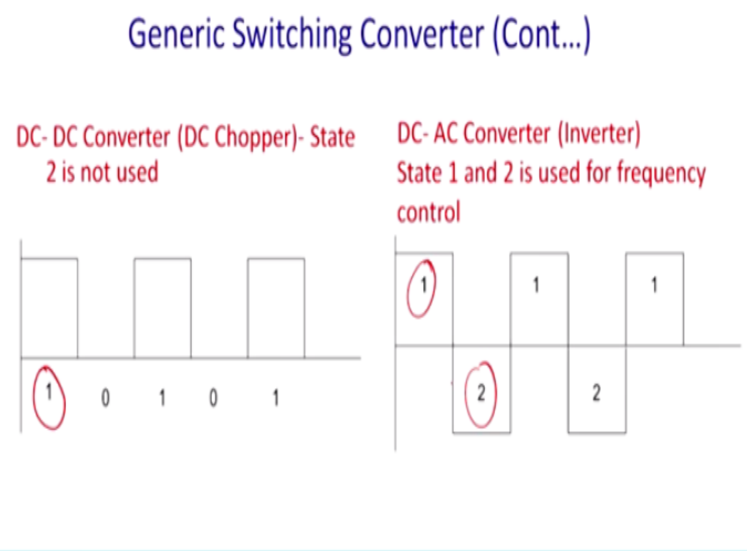

Now, let us take an example that you have a constant DC supply and you have chosen the state 0 and 1, 0 and 1, so that is just chopping operation and even taking a time out, so once it is input is connected 1, once it is not connected it is 0 and so on like that it will continue and so this is the inversion operation, if you choose 1 and 2, so once you choose the switch S1 and S2, you get 1 and you get minus once you choose the 3 and 4.

So, thus it is a inversion operation, so from same circuit we can realize a different kind of operation, we simply SPST switches, so now we can we have to go back and ultimately implement the actual switches, so what happened then?

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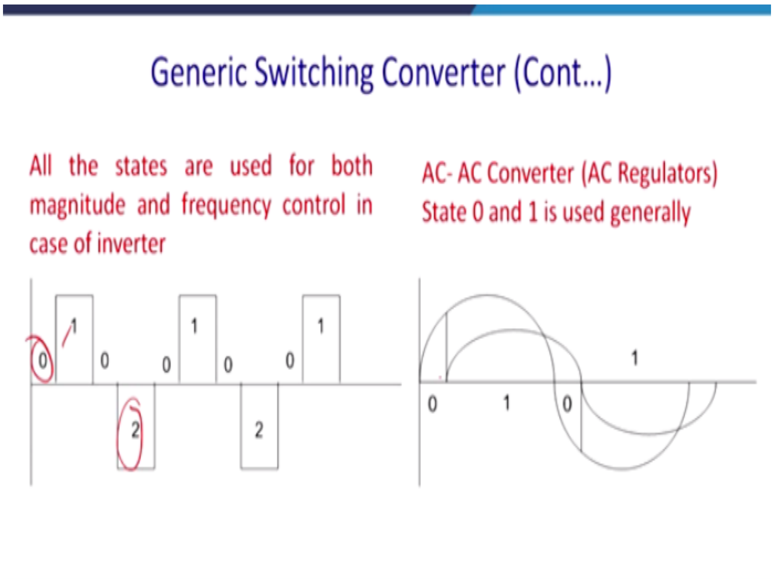

So, if you have a; this kind of chopping waveform in PWM, so it is 0, it is 1, this is 0, this is actually 2, again 0 and so on, this will continue and same way this example of the AC to AC conversion that is it is the one of the important feature now it is coming into the pictures with the advent of the IGBT, so we call it is matrix converter, so these can convert AC to AC, so accordingly you can choose a different kind of states and different voltages can be generated.

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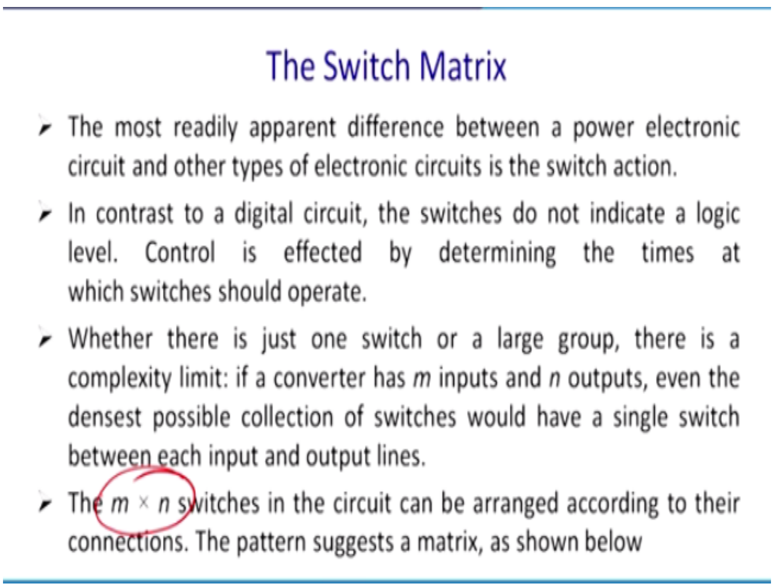

So, this is directly AC to AC conversion, DC to AC conversion now, this is a matrix converter, what matrix converter do; we have to realize it, the switching matrix, so that it gives you direct AC to AC conversion otherwise it is possible to convert AC to DC there after DC to AC, so if you wish to have a direct there is a different way to convert it, so AC to AC, one variable AC to fixed AC and vice versa. So, we require some kind of thing called matrix converter we shall discuss in later how it has been realized in practice.

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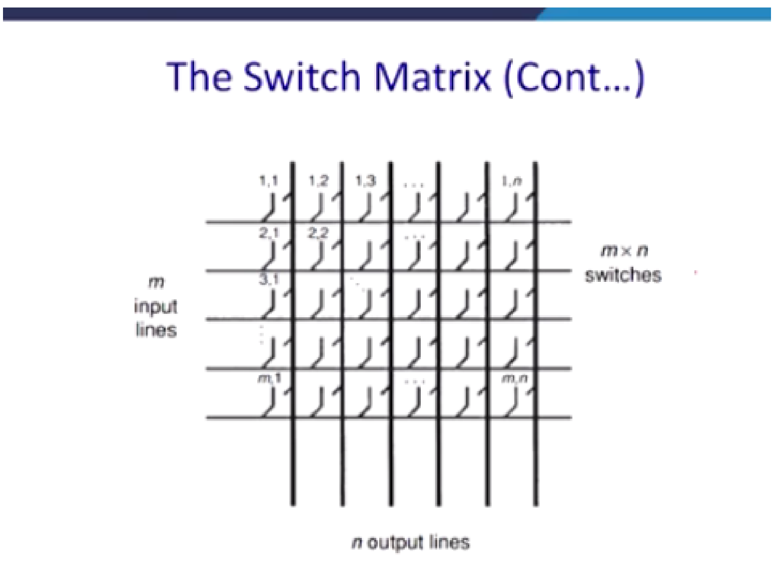

So, this is the combination, so you have a M input, so you have studied into the digital electronics basically MPGA or PLA this same logic has been incorporated here, you can actually close different kind of switch in a different way and ultimately, you can have a combinations of the voltages, please understand now, now you have, it is not necessarily power electronics we talked about three phases voltages.

But now we have a multi-phase voltages also, multi-phase means 5 phase, 7 phase, these machines also nowadays used or the special kind of machines, so their matrix converter heavily fit to it, so we shall this is an actually some part of our discussion regarding analysis and gate driver protections, so that student may find it is useful for the future course of studies, thank you very much for your attentions, we shall look forward for our next class with the devices, thank you.