Advance Power Electronics and Control
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Lecture - 02
Basic Concept of Switches

Welcome to our second lecture on advance power electronics and control and this class we will discuss about the basic concept of switches. First, let us understand why power electronics is preferred? You know let us see that there is a very one simple example you know.

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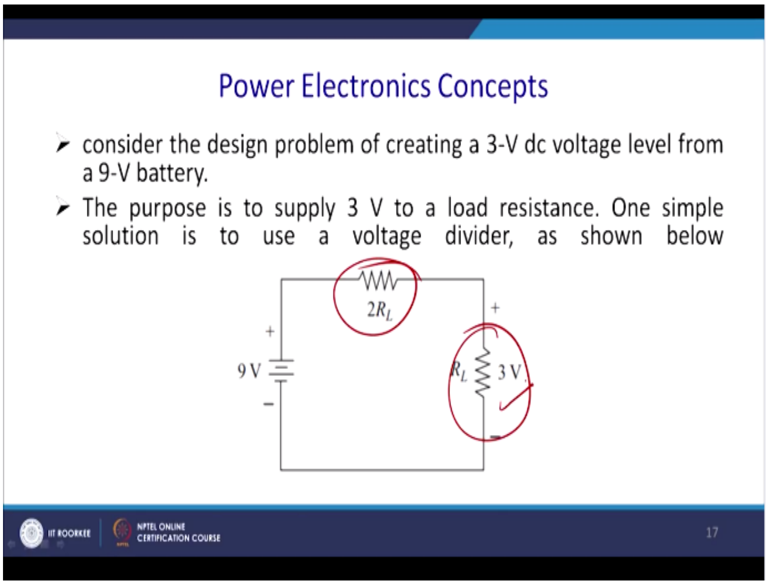

We want actually a buck operation 9 volt to 3 volt. Of course, you can use a voltage divider circuit and we can calculate actually what is the amount of the actually power to be dissipated here and accordingly we can choose the resistances and that will give you the desired actual dissipation but what happen you know this solution is quite lossy. So you require to put this resistance.

Since current will be the same so 33% will be actually dissipated here, 66% will be dissipated across the internal resistance. So efficiency of the system only will be close to 33% maximum and so what you can understand it is quite disadvantageous. Now let us consider a switch, mechanical switch let us first conceptualize and which is getting on and off.

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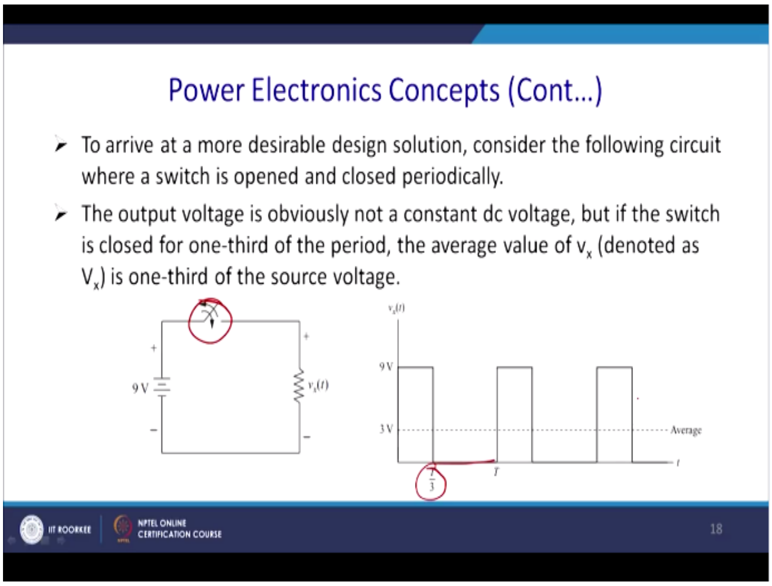

So we will on for the interval of T/3 and will keep it off for the rest of the interval. So what happen you know you can take the time average of it and you can get the voltage. So that voltage will be around 3 volt. So what happened here, why it is advantageous, it is because one switch is on so across the switch there is no power drop and just reverse because voltage across the switch idealized to be 0.

Though power electronics devices will have some losses, that is different issue and this reverse happens when actually switch is open. Total voltage will come across the switches, so no current will flow and also power losses to the switches is 0. So for this reason, you know of course is not possible to mechanical switch to operate in such a fast fashion and for this reason we require to use a power electronic switches and if operated very fast, then we can see that we can get an average value of it.

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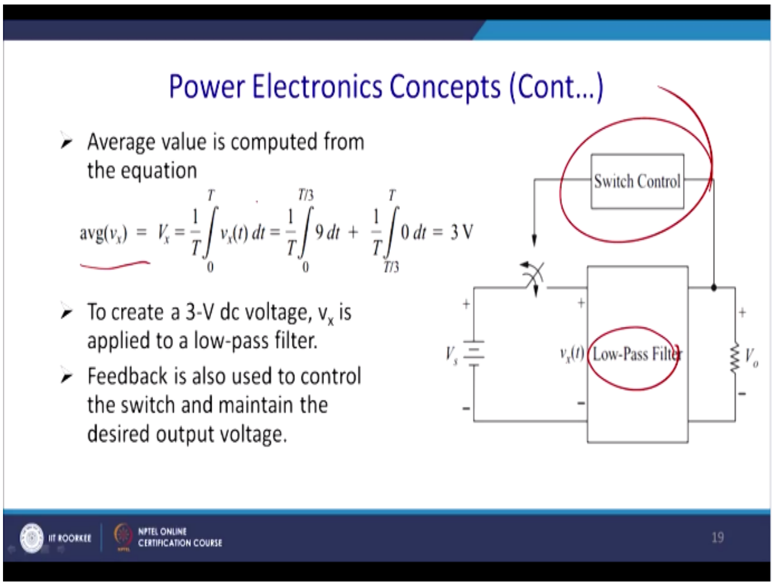

So for this reason and whether it will give precisely 3 volt, that is also a very big challenge and therefore this control aspects comes into the picture, you will have a control mechanism that will ensure that you are getting a that is a voltage level what has been prescribed up to a precision which the customer asked for and of course here since there is a lot of switching will have a high frequencies and that can be easily smooth out by putting a low pass filter.

Since these frequencies can be as high as in the range of the megahertz in case of the soft switching converter, that we will come later what we mean by the soft switching converter. So this is the average value of it, this is a time interval and to create 3 volt will be actually passing to the low pass filter to suppress the high frequencies and feedback is also required to give a precise control of this actually the converter.

Now same way when you require a wide range of speed variation, so think about electric locomotives.

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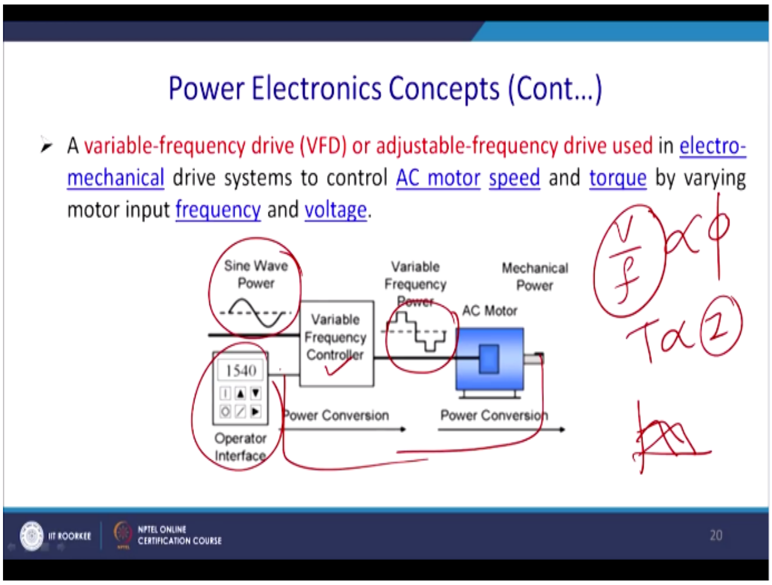

And now what we can do is basically you know that actually one control is called V/f control. So what happen if you control V/f essentially you make flux constant. So torque will be proportional to only the current. So if you keep the torque constant current also remains constant, so what happen you know you can keep this ratio constant and why the frequency. So you can get for the induction machine a various rated speed at different frequencies, in that way you can change.

So what you can do here, first of all you have a constant supply, constant frequency supply 50 Hertz then you will be fitting to the front end converter that will give you the DC. Thereafter, you will have a variable frequency converter and that will give you a AC with a variable frequencies ranging from 10 to let say 50 Hertz and of course it is possible to go higher, that discussion will be taking later.

So then that will be fitted to the AC motor and AC motor itself is a low-pass filter because it has a huge amount of the inductor present into the system and that will actually truncate the high frequency ripple and thus you can get a wide range of variation of the speed from this putting a variable frequency controller. So it will can precisely actually you can set that speed and precisely you can operate by a basically it can be a commanded system.

This is an open loop operation, if you take feedback of it, then you can ensure that it is actually rotating at the desired speed.

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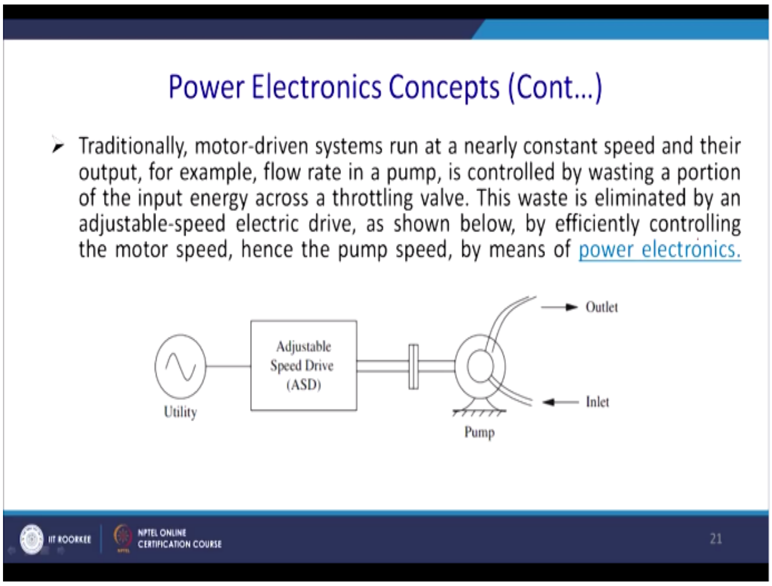

So traditionally motor system run nearly at a constant speed that is what I was saying because you have a constant frequency supply and for example flow rate of the pump is controlled by actually by wasting a portion of the input energy across a rotating or throttling valve. This waste is eliminated by adjustable speed drive, adjustable pure electric dive as shown below by efficiently controlling this motor speed.

Here is the pump speed by means of the power electronics and we control and energy is saved that is more important. When you require to have a reduced throughput, you can give a variable frequency supply and V/f ratio can we control accordingly, so it will run less and the throughput will be less, in that way you can control it. So instead of wasting energy, you will be feeding less energy to the motor. Now what are the desired characteristics of the electronics or the power electronic switches?

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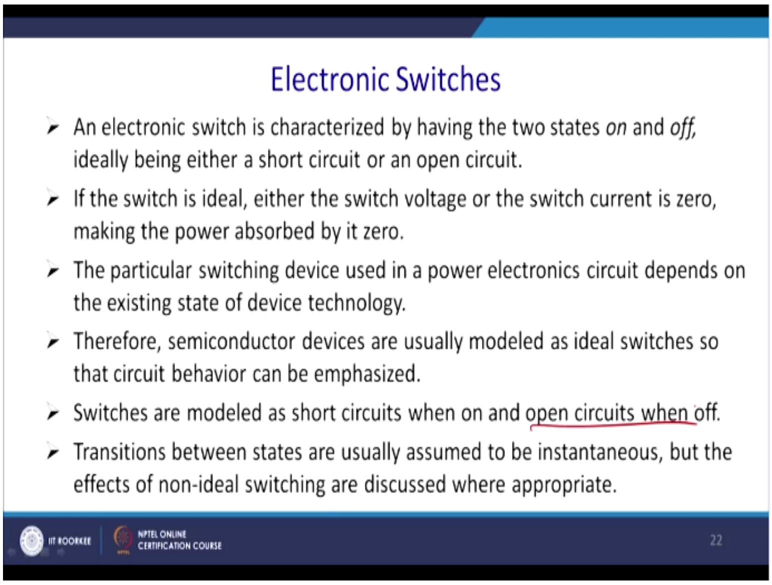

So an electronic switch, what is the difference between mechanical switch and electronic switch, mechanical switch is basically a switch we have metal conductors and is slow in operation and an electronic switch will be in a fast in operation. Electronic switch is characterized having two states, on and off state. Ideally, being either short or the open circuit. When it is closed, it is short. When it is open circuit, so no current flows when actually it is open circuited.

And when the short circuited, voltage across the switch should be equal to zero. That is the ideal characteristics of the switch. If switch is ideal, either the switch voltage or the switch current is zero making the power absorption to the switch is zero. So we should try to achieve that. Unfortunately, power electronic devices actually lacks this feature.

The particular switching devices used in a power electronic circuit depends on the existing state of device and the technology, that we will see little later what does it mean by that. Therefore, semiconductor devices are usually modeled as ideal switches. So the circuit behavior can be emphasized. Switches are modeled as short circuit when on and when off it is open circuit.

Transition between the states are usually assumed to be instantaneous but effects of non-ideal switching are discussed and it will be actually put into the appropriate application later. So of course first power electronics device is essentially is a diode that we are using pretty long time that you use for the rectifier operation.

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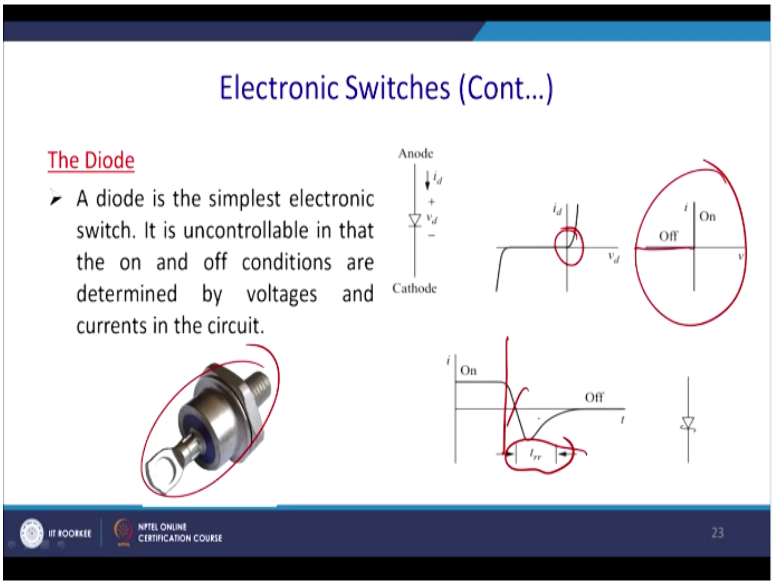

This is actually the diode and generally it is put into the heat sink. So for the power dissipations and generally it will have a voltage stop but something please keep in mind power diode will have a power drop more than 0.7 volt because it has a one extra positive n layer. So this is actually actual figure of the diode. This is the symbol and this is actually the V-I characteristics of the diode.

And you know that actually it will almost conducting for the 0.7 volt considering that it is a power diode. So this rating is almost close to zero and this is actually the coordinate of operation, it will block in reverse direction and current can flow in either in this direction. So it is a one quadrant operation and this is the signal its turn-off characteristics. Once it is on, current was flowing thereafter you initiate a change in voltage.

So then what happened, gradually current will come to zero but still it does not have a voltage breaking capability. How fast is getting a voltage breaking capability based on that there are different kinds of diode. So this is called trr reverse recovery time, shorter the reverse recovery time fast will be the diode put into the operation. Now this is the thyristor, this is actually one small thyristors.

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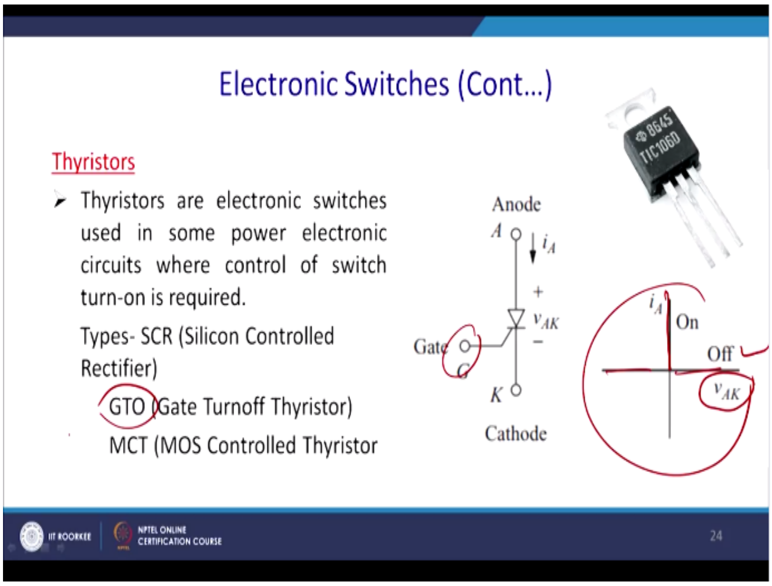

Thyristors and diodes are almost same features but thyristor has got a control. So what happened here, once actually it has been triggered by the gate then only current flows, otherwise it has got a forward blocking capability which was absent in case of the diode. Diode crosses this threshold voltage then only it start conducting but it has got a forward blocking capability for this is an operation almost same. It conducts i in this direction.

It can block this direction as well as this direction but this direction is controlled blocking forward direction. So we have another variant of the thyristors that is called gate turnoff thyristors, since turn on can be done by the thyristors, so turnoff in different manner but there are possible solutions given by this another device called GTO. So there what happened if by injecting negative current you can also turn off these devices.

So for this reason this is called GTO and similarly you got a MCT and it is MOS controlled thyristors. So there also you can turn it off.

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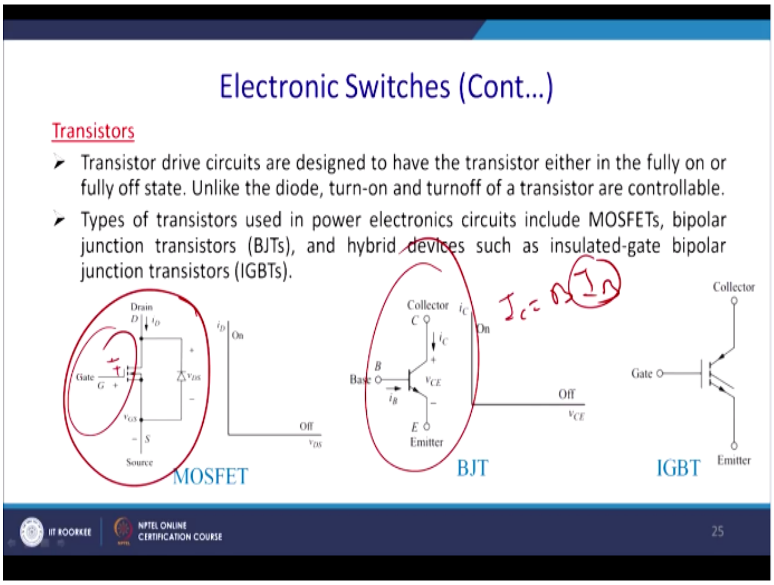

Now there is a transistors, transistors basically BJT, it has seen a lowest power BJTs. Signal level BJT has shown lot of applications for many years but in power electronics it is quite short lived because you know actually BJT will have same characteristics of this actually normal signal BJT but what current flows basically you know in active region IC=beta*IB but problem lies you know since value of the IC is quite high.

And beta's value is around 50 to 100, so IB also require to be quite high and it is very difficult to get that huge amount of the power dissipation in the actually the base part of the circuit. It has to sink that amount of current and for this reason you know actually for the high frequency applications and the low power applications, we found one solution that is basically MOSFET.

Different kind of MOSFET is possible, one advantage is that actually here charge is introduced is that MOSFET is essentially a voltage controlled current device. So what happened you know when actually you got positive pulses so you have a induced negative charges, so it make a channel and through this channel current will flow and there can be a normally on MOSFET and normally off MOSFET.

And one of the basic advantage of is that actually if you applied the DC voltage, so there is a capacity (()) (15:02) the current should be very low and due to that actually there is a less consumption of the gate driver circuit but however the current carrying capability depends on the channel width and thus you know we have found that you know actually current handling capability of this MOSFET quite low.

And gate part of this MOSFETs and the BJT has been combined by Baliga one of the Indian scientist (()) (15:36). So he came out with a solution of the IGBT. So IGBT has an advantage of huge current carrying capability and also the advantage of the actually the MOSFET gate driver circuit. It incorporates both and thus it becomes a quite famous and that itself actually phase out the BJT.

Invent of the IGBT basically the cause of phasing out of the BJT. So BJT we would not be discuss very much. In high frequency lower power application, we will be discussing MOSFETs for that control devices and for the little low frequency and high power devices we shall talk about IGBTs.

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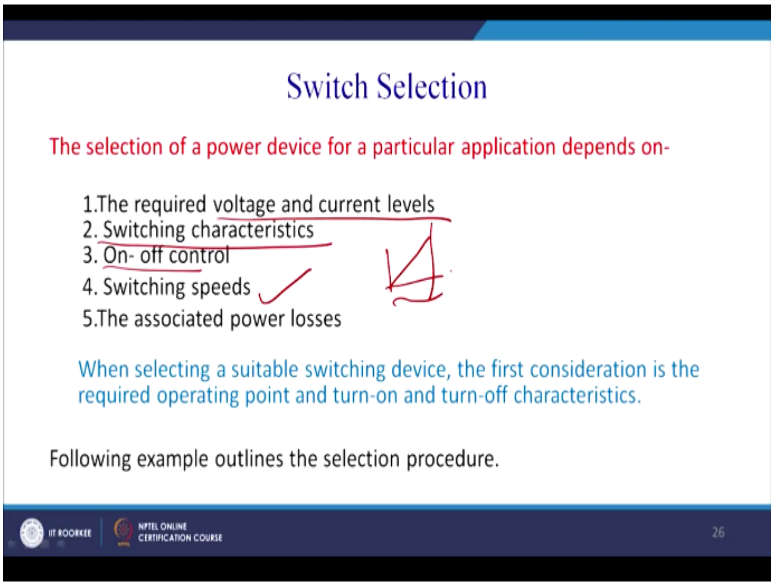

Now switching selections that is quite important. In previous class, I have shown that you know what are the different voltage level and the power level, from there what are the devices we will choose and here also this features quite important. While selection of the switch, we require the voltage and the current level. There is a safe zone of operation that will be prescribed in your data sheet.

Unless you are walking with a device say you are starting working with SIC, it does not have a data sheet and somehow you managed from the manufacturer to get the devices. So that is different issue, otherwise we will have a data sheet. So from there actually voltage and the current levels will be prescribed and we required to choose actually we have to see that what are the desired voltage and current level.

And accordingly we have to choose a factor of safety, more the factor of safety you will find that actually more will be the mean breakdown time that means actually it will be expected to leave longer but of course the penalty have to pay by the cost. Since the rating will be higher, the cost of the devices is going to be higher and also switching characteristics. If it is a high frequency applications, then you know diode trr required to be considered, we require to choose a fast diode that is fast recovery diode, so that has to be considered.

And also on-off control, for example if you have actually line commutated devices like you are applying for the line voltage to the rectifier or line voltage converter operation where your devices like thyristors will be naturally commutated without external circuits that is one of the features.

So whether the device has on-off control or it has only on control or off control, what is a stress coming out across the switches when you are actually turning on or turning off the devices so and it required to be smoothened in wide manner. So then snubber comes into the picture to actually reduce the stress across it. Switching speed, so every device will have a prescribed dv/dt and di/dt.

Please understand that once you track it on, it is not an instantaneous phenomena even if it is a microsecond or nanosecond. So there is a speed to ramp on. So this ramp on time you know so there will be a dv/dt as well as di/dt. So maximum value of dv/dt and di/dt will be prescribed in your data sheets by the kind of devices you are choosing.

You have to find it out what is the rate of dv/dt in your circuit and di/dt in your circuit accordingly you will select the switch. That is also one of the important parameter to absorb unassociated power losses. So that is the important feature we want an efficiency to be more than 90% for the power electronics devices. So accordingly we required to choose that particular device that gives you the least power drop.

Now once a power electronic devices is operating, full control devices will have a three losses, turn on loss, turn off loss and the conduction loss and we have to find it out which loss predominant in these sector and we have to attack that part of it and get it reduced and we will get the desired efficiencies. When selecting suitable switching devices, first consideration is the required operating point of turn on and turn off characteristics.

So we will find out the safe operating region in between and from there we will be deriving the switches. I am giving one example here.

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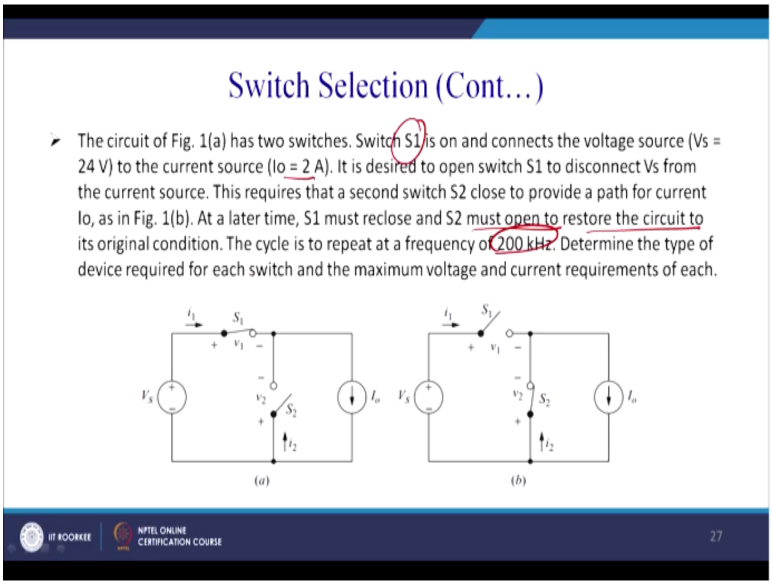

Let us see in the figure 1 has 2 switches, S1 on and connects the source Vs as 24 volt to the currents of that is it is carrying a load current of 2 ampere, it is desired to open switch S1 to disconnect Vs from the current source. This requires a second switch S2 to close to provide a path for current of i0 as in a figure B. At the later time, S1 must reclose and S2 must open to restore the circuit to the original condition.

This cycle will repeat in some frequency, we require for the compactness and other issues that frequency to be around as high has 200 kilohertz. So determine the kind of device required for the each switch and the maximum voltage and current required for the each of the element.

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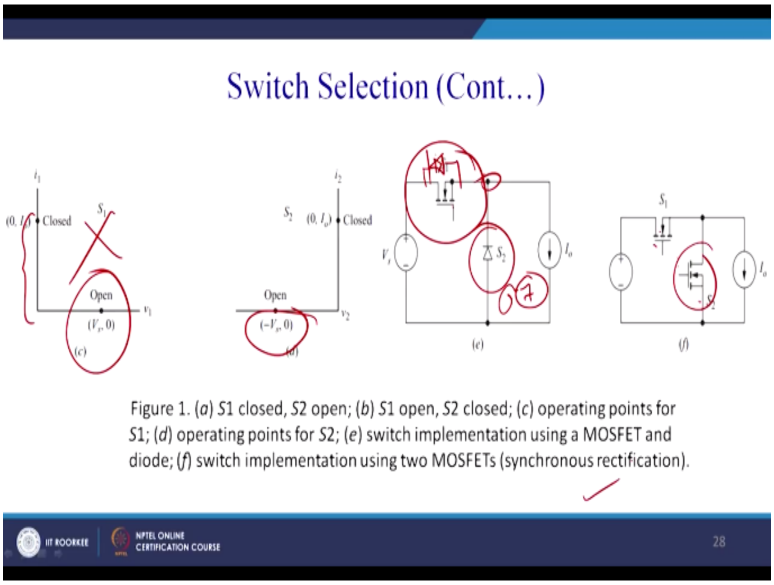

You can see that actually for switch S1, we require to when it is closed it has to carry a current of i0 but you take some factor of safety. Similarly, when it is off, it has to block that voltage. So it has to block the voltage Vs and similarly for S2, what happened, S2 is opened then it has to block the voltage of -Vs and it will carry the current of i0. So thus what we can visualize you know from these characteristics what kind of device I require.

So you know you see that this voltage has to block the forward voltage, so we cannot use diode here. So it has to use active devices and since it is a high frequency application I told you, you know that one of the solution is actually the MOSFET gives you the maximum efficiency. So for this reason you will get a MOSFET, generally MOSFET comes with the body diode, anti-parallel diode.

So what happened, so you can see that these characteristics can be achieved by it. Once it is on, it will carry the current of i0. Once it is off, it can block it. Same way for S2, what happened here in S2, S2 will carry the current positive direction unidirectional and it has to block the reverse voltage. So for this is not you know diode in anti-parallel from this point this node point of view this configuration will be more suitable.

Of course, you know we can do something. If current is high and you know that actually this gives you a 0.7 volt drop, so power losses around 1.4 watt. Instead of that why cannot we use devices which will only have Rd on. Rd on is generally MOSFET of very low value. So then it becomes a synchronous buck converter. So accordingly what happened, you can reduce the loss as well as control.

Because you cannot control the diode, diode will conduct the moment it is off but you can control the current of these devices. So for this reason, if it is a synchronous operation and we require to reduce the losses and in a more compact control most of the MOSFET driver will have since these two devices will have complementary logics which does not contend. It is very easier to actually have that kind of logic.

And for this reason, will prefer a synchronous rectification. So this is the one of the example how we will choose a device.

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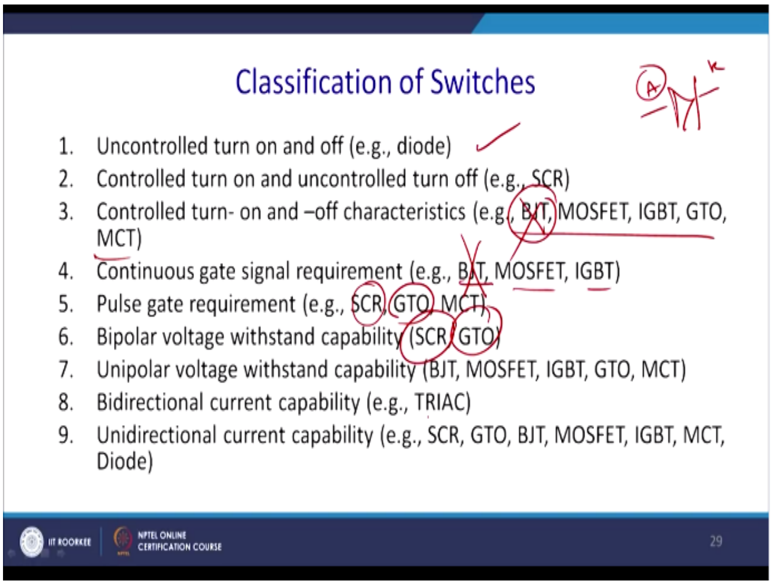

So this is a classification of the devices, uncontrolled turn on and turn off that is diode. If the voltage between actually cathode and anode, anode is more than cathode it will conduct, otherwise it will block. If it is suitable for your application, use diode that is the simplest because it does not require any control. It will be automatically allow which is something like a valve, it will allow the current to pass in one direction and it will block to another direction.

Controlled turn on and uncontrolled turn off, once you want to control and get it open and then putting off it does not require, you may have a natural commutations or natural off, then you use SCR. Once you require both, controlled turn on and controlled turn off then use either of these devices depending on the rating frequencies and the power levels. BJT is nowadays is obsolete because of this actually high power requirement in the best driver or the great driver circuits.

But these entities are pretty frequently used in our power electronics devices. The continuous gate signal is required BJT though it has been disconnected which is now no longer used MOSFET but yes theoretically yes MOSFET and IGBT. Power dissipation of MOSFET is the least because you know it induces a channel and that way actually power flow. So power dissipation across the control devices require a least power in case of the MOSFET thereafter IGBT.

And pulse gate requirement is SCR, GTO and MCT. So you can give me the pulse, it will be turned on but turn off cannot be done in case of the SCR. In GTO, you can actually put it off by negative pulses but it does not require any power in between for this is in power handling capability of this devices is quite high but limitation is that it is high frequency operation. It cannot go for the high frequency.

GTO is a full controlled device but problem lies it has frequency limited to the around 500 Hertz and same way for MCT. Now based on bipolar voltage withstanding capability, so it can withstand the bidirectional voltage and block and allow. So this is SCR and GTO. We will come little later that is actually MOSFETs comes with the body diode so for this reason it does not have a bipolar withstanding capability.

Unipolar voltage withstanding capability is BJT, MOSFET, IGBT, GTO, MCT. So if you require a unipolar voltage blocking, then you can have a plenty of choice and if you want actually bidirectional current capability, so then you have to use a TRIAC or will show at one different configuration on the matrix converter. Then, unidirectional current capability that can be done on SCR, GTO, MOSFET, IGBT MCT as well as diode.

These are the few actually take away today's class about this devices. So we have to choose a device based on this actually the applications. So this is a different way to find it out devices which will be suitable for our applications, one of the classifications based on these classifications. Thank you for your attention. We are looking forward to device applications in next class also. Thank you.