Flexible AC Transmission Systems (FACTS) Devices

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Lecture – 03
Switch Realization

Welcome to the 3rd lectures of FACTS devices. Today, we will discuss the Switch Realization that is most important to realize the facts. Now, we shall start with our simple concept of single pole single throw switch.

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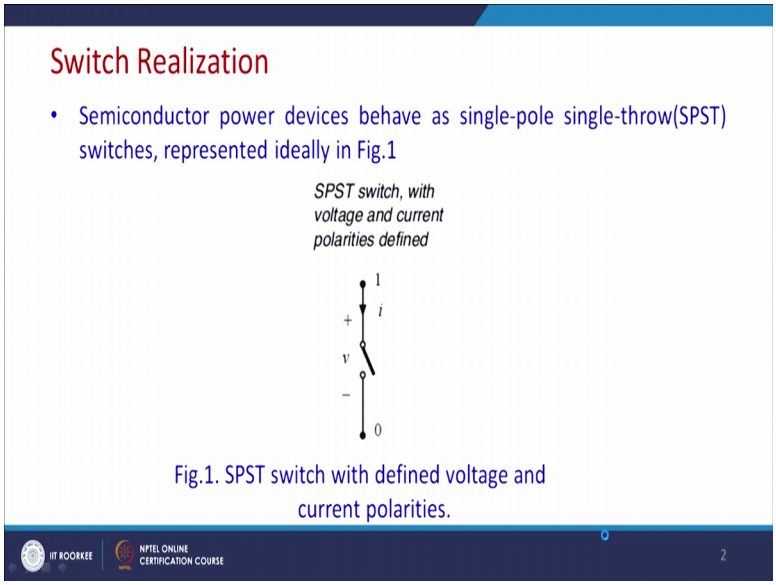

So, where current where it can block and block voltage and current by in when bidirectional and it can flow the current also bidirectional. So, we require to actually realize this mechanical switch by the semiconductor switch. So, we shall see in consecutive slides how it is possible?

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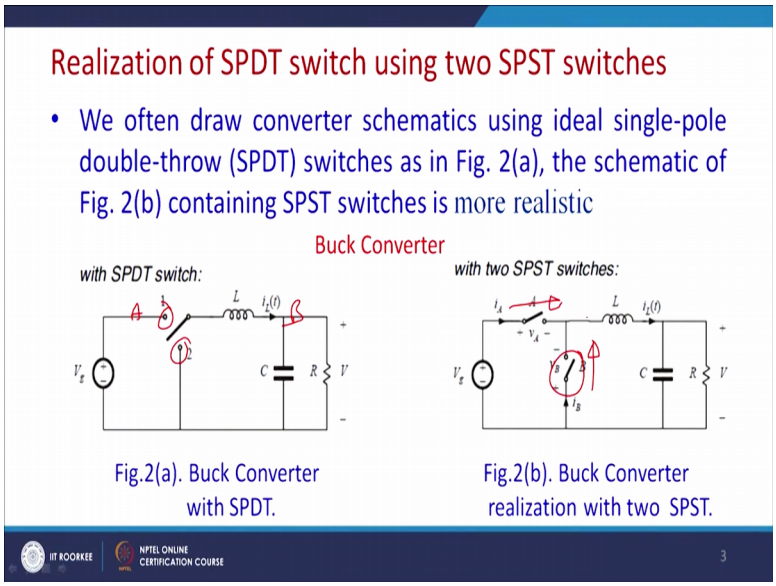

Let us take a single DC to DC converter this figure 2.1 is a buck converter, here this has been realized by single pole double throw switch. So, this switch can be position 1 or 2 depending on the requirement; 1 power flow goes to the point let us say point A to point B, then switch is connected in the position 1 and when we require to actually connect to the position 2 for freewheeling time. So, then it will be in a position 2.

Same thing you know it can be realized by this 2 switches of SPST. So, it is the V A and it will block the voltage V A and current will pass through it and it will blow this switch will block the lower switch will block the voltage V B, and current can current will be passing through it. But generally what happen most of the semiconductor switch you will see that current will allow to flow this direction not in this direction. And, similarly current will be allowed to flow in this direction and this not this direction.

So, based on the quadrant of operation we can put different kind of switch. Simple single pole single throw switch actually it has a on state and off state it has been shown here.

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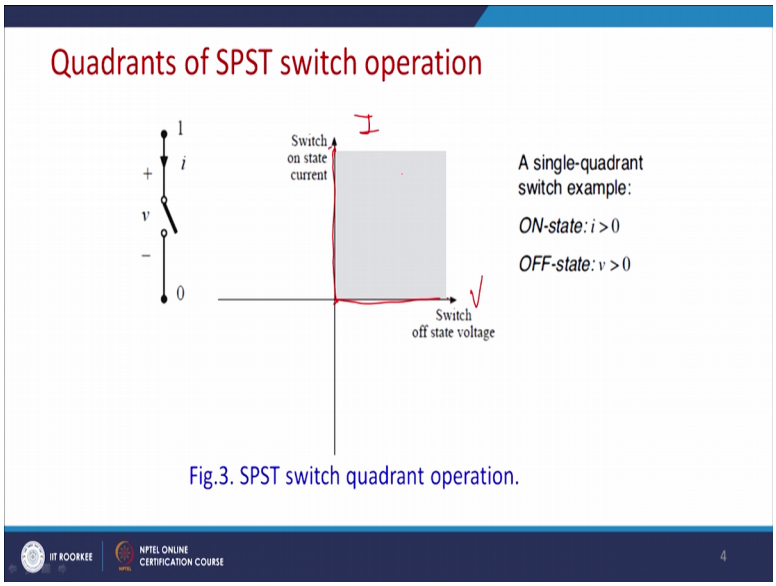

So, this is it this is this is it is a blocking potential, you know this axis stands for the V and this axis stands for I. So, we will have actually it can block this much of potential and it can block it can block this much of actually all state current can flow in this direction. So, in this zone it can conduct and this zone it can block. So, this is called a single quadrant operations of the switches, we shall see that what kind of switch will give this kind of operation.

And next this is a single quadrant switch where it is a switch off state voltage.

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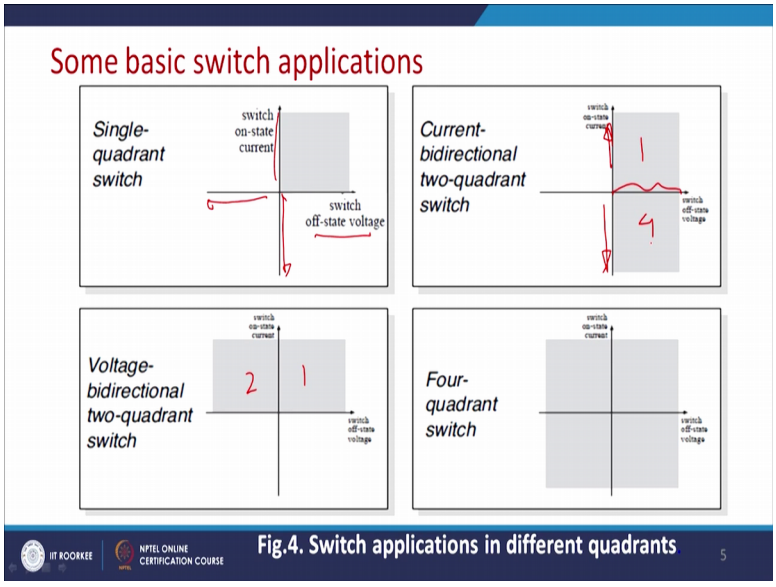

And, here it is switch on state current. So, switch does not have a reverse blocking capability and in this direction, and switch does not have reverse flowing current capability in this direction.

Same way we can we did some FACTS devices may require a bidirectional current flow where current can flow this direction as well as this direction. But it should be able to block the voltage in one direction and it should conduct the voltage in other this is the this it this can it can block the voltage in direction and this will flow the current in reverse direction.

Same way we may require current to be flow in one direction and voltage to be flow either direction. So, then the quadrant of operation is first and second. Here, the quadrant of operation is first and 4 same way we may require a current of switch which can flow in the either direction, and it can block the potential in either direction. So, then if it is possible by a switch then or combination of the switch, we say that this is a fourth quadrant switches because see an application of it.

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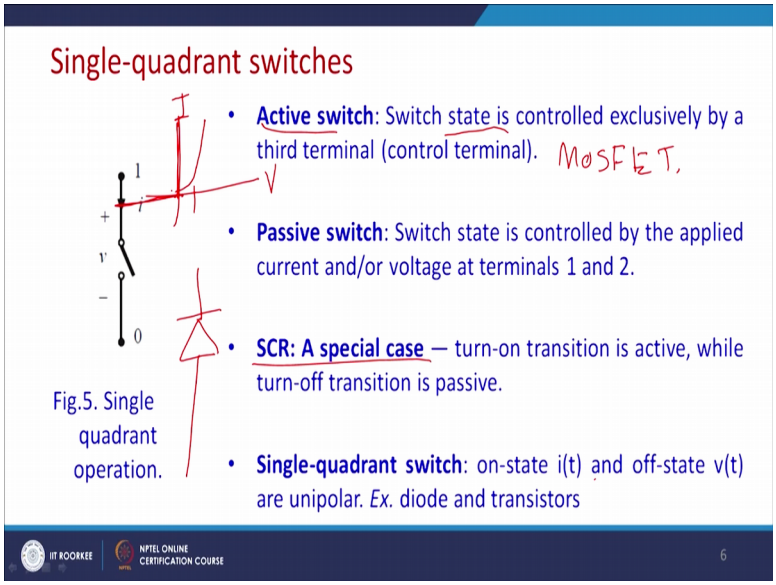

Now, a problem of the mechanical switch is that it will be slope. So, for this as in we require to actually supply semiconductor switches. Since, semiconductor switches has a depletion layer and junctional potential all inherently inherit some amount of the blocking potentials. So, for this reason this switches are basically active devices. And, what is active switch there is a difference between active devices and active switch.

An active switch is one it is controllable. So, and there are devices which is half controllable there are devices which are full controllable. Switch is switches an active switch, it state is actually control exclusively by another terminal then it is called the active switch MOSFET igimity these are basically the active switch, but Thyristors or SCS are the hub control switch, because it turn on is actually controllable, but turn off is not controllable.

So, for this reason these are semi control or semi active switch. Same way passive switch passive switch is basically the mechanical switches though and the current will flow whatever be the direction, we can actually control. So, SCR is a special case is a semi control switch and turn on of the transistor in active device while turn off transition is passive. So, SCR is a special case.

And so, single quadrant switch is on state and off state is unipolar example of the single quadrant switch are the diode since diode if you refer to the v i characteristics of the diode. So, V and I you know actually it will have it will this is a cutting potential and in reverse if you consider the ideal dialer diode. So, this will be the zone of conduction and this will be the zone of locking.

So, for this reason dial is a single quadrant switch same way the dial is a uncontrol switch and same way you have a SCS you have actually the BJT will be the control switch. So, this is a example.

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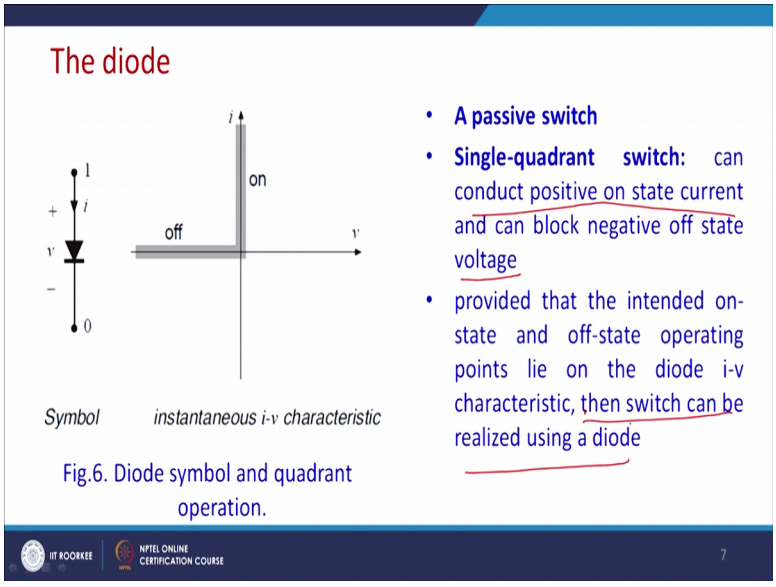

Fig.6. Diode symbol and quadrant operation.

This is a passive switch because it does not require any control and it is a single quadrant operation as will be explained in the previous slide and this is the pictures of it. So, it can conduct it can it can conduct on state current and can block the negative off state voltage. And, it provides the intended on state and off state operation point lie on the i-v characteristics,

So, then the switch can be realizing by a diode. So, so which switch can be realized by diode this switch can be realized by the diode. So, simple SPST, switch is will be realized by the diode.

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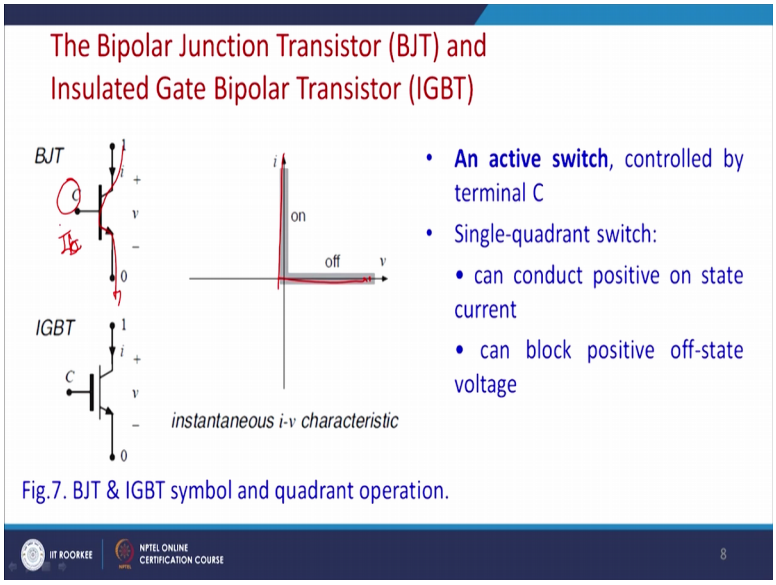

Fig.7. BJT & IGBT symbol and quadrant operation.

Now, same thing with can be realized by IGBT without any anti parallel diode or the BJT. So, you can see that in active switch. So, there is a third terminal available. So, it is it is also single quadrant switch, where current flows this and this and the voltage locking capability is this.

And, it can conduct only possible for this for this NPN transistor this is a direction of the current flow and of course, it can block the voltage in off state for this reason, it can block the positive off state voltage for this and this is also semi also BJT and difference of b BJT and IGBT is just a gate voltage and the gate current.

Here you require I B to make it and then cut off to the transition region here you have to apply voltage. So, that your gate current is actually. So, that actually power consumption

in a gate is much much reduced, but otherwise these two device as per the quadrant of operation they are same code devices. Now, let us see a same buck converter we revisit the circuit using 2 SPST, switch which was been shown in the second slide.

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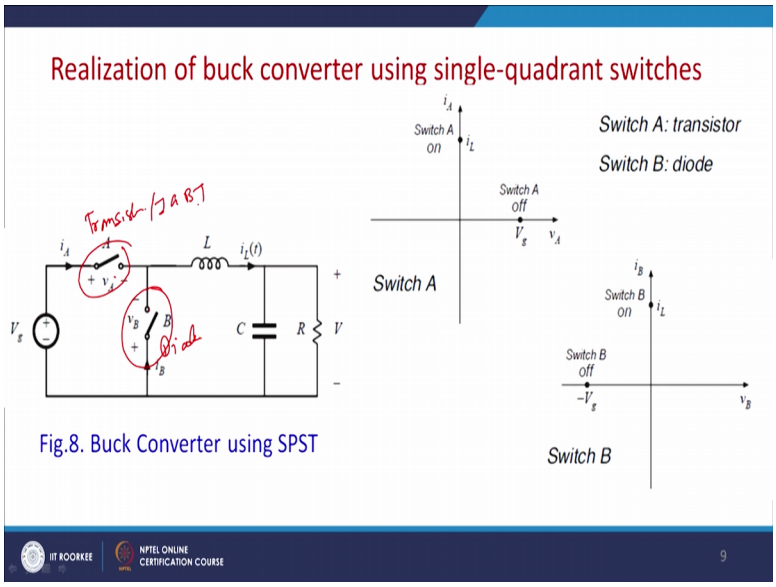

So, this is the mechanical switch SPST and another SPST switch. So, we can use the these two SPST switches to realize it. One can be controllable, another can be uncontrollable. One this generally we put generally we put a BJT or MOSFET or I wall play of MOSFET into MOSFET inheritably comes with the body diode with it will discuss in little bit later. But here we will put a we can put an IGBT best is under rate rating and thereafter this if we require another switch this switch can be IGBT and also diode.

And, since control is not required most of the cases this SPST switch will be diode and this is switch will be a transistor or IGBT.

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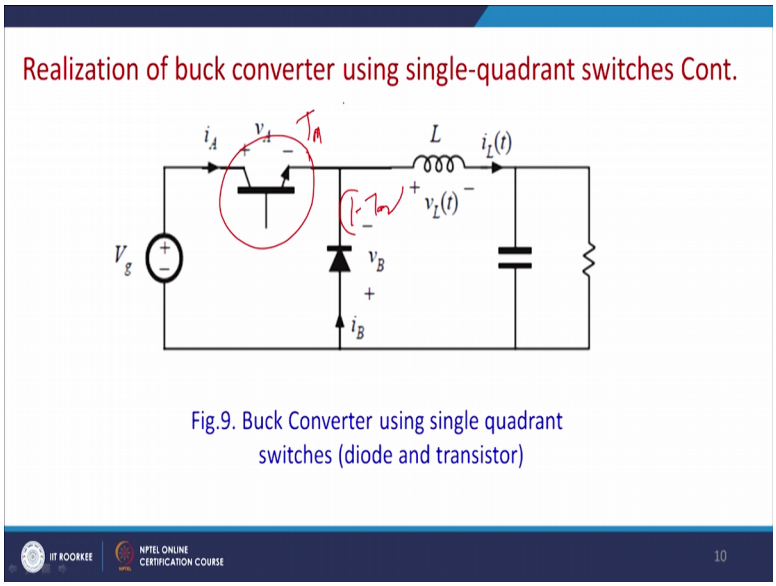

Now, this is the practical realizations of the DC to DC converter.

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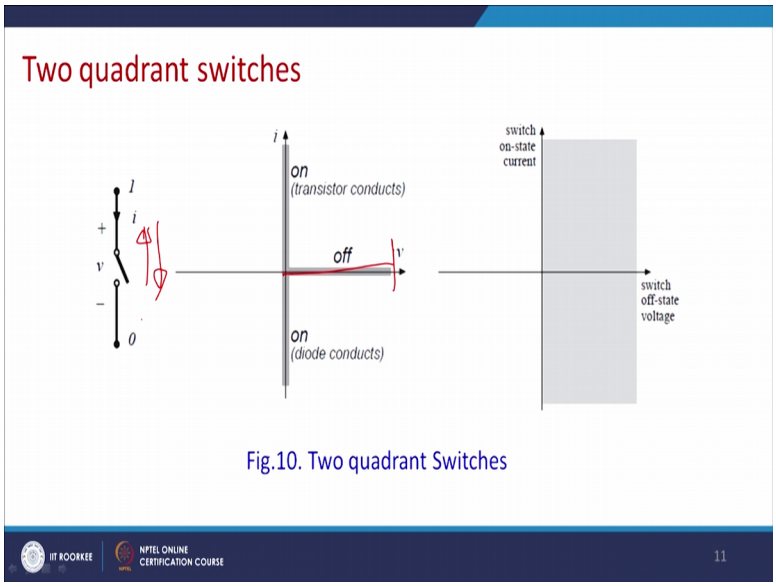

Where this switch this is a controllable switch and it has been realized this SPST switch is realized by a by a IGBT or BJT here in this case we have put BJT, but problem of the BJT is that it is efficiency we require a huge gate current, to get make is operate or this is in most of the cases it will be replaces by IGBT.

And, here since the control operation is not required whenever free wheel action is required for this reason we can since it is T on and this is 1 minus T 1 by controlling T 1

you can automatically control 1 minus T 1. So, thus no control is required in case of the diode. So, diode will conduct rest of the time depending on the mode of conduction whether it is continuous mode or discontinuous mode. So, this can be realized by these two single pole single throw switch.

Now, let us come to the 2 quadrant switch, where the switch can block this voltage this much and the current should be bidirectional current can be this as well as this. So, let us see that which semi-conductor switch can realize this diode.

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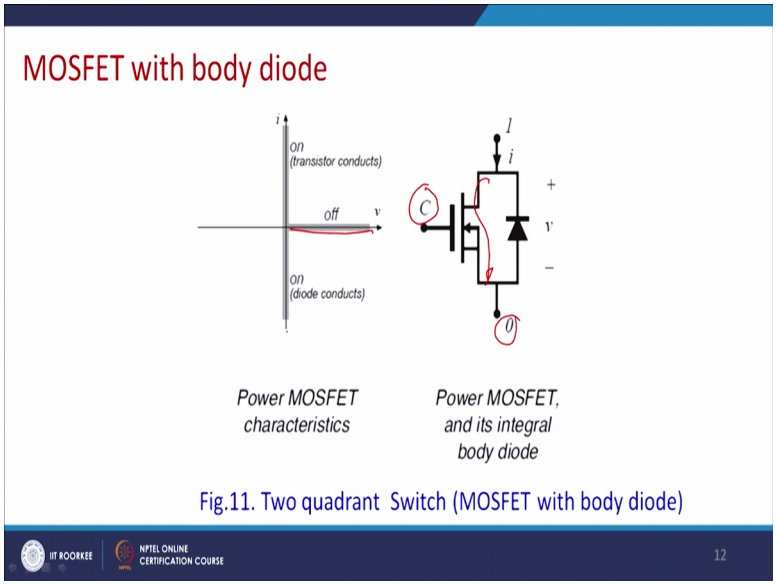

Now, this is actually the MOSFET as we know that this is a n channel MOSFET, it comes with the body diode inherently. Thus you know why let us pa potential 1 and 2, it is controllable. Because, if you be apply a positive gate voltage (Refer Time: 12:40) then current will flow in that in this direction.

But, if the voltage of the potential 0 is more than 1 the current will find it is path to the diode. So, it can block by see it can block this voltage and it can control this voltage and also the control this current, but current can be bidirectional with this switch. So, for this is a this is a 2 quadrant operation and we can say that it is a DPST switch and ca and can be realized by it.

So, this is one example.

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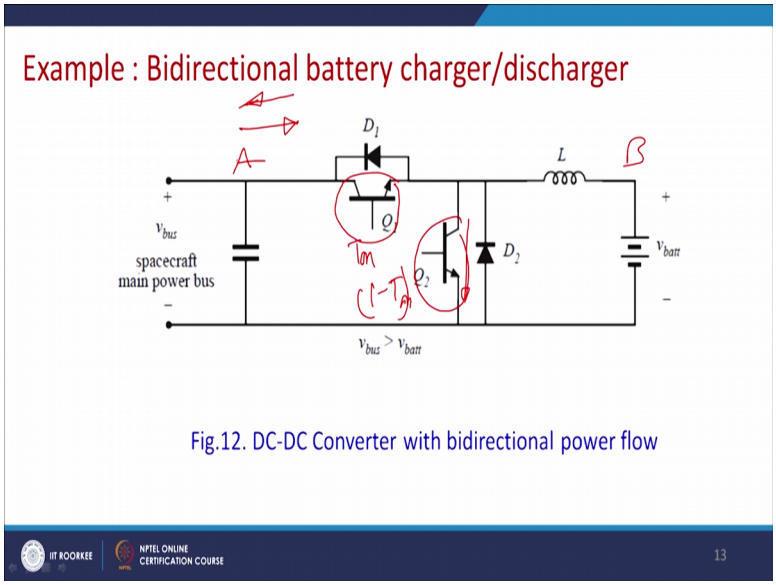

Fig.12. DC-DC Converter with bidirectional power flow

This is an example of the bidirectional battery charger, where there is a little bit change we had in this case buck converter, this was IGBT or BJT and this was diode since actually this was T and automatically it should T on and the automatically this becomes 1 minus T on.

So, in this case the there will be changing thing then power can in a mo normal mode of conduction or the charging of the battery power required to be flown for the point A to point B, but in case of the battery is supplying then power required to flow B to A. So, let us understand what does happens?

Now, most of the cases we require to buck the voltage to charge the battery, battery pass is connected little bit to higher voltage. So, for this reason you know this bucking operation is done by mostly Q 1 and D 2. And we can put same way here a MOSFET so, which can have a body diet. So, ultimately diode will conduct when it is oh when it is actually when free in the free-wheeling region, but when boost mode comes into the picture. There essentially then Q 2 and a D 1 come into the picture.

So, when it will be shorting. So, volt actually there will be huge voltage build up across the volt and ultimately diode will be forward biased than the va, and ultimately power will flow back to the main bus.

So, bidirectional DC to realize bidirectional dc to dc converter this SPST switch will be converted to the SPDT switch. And so, this can be realized. Now, let us talk about bidirectional voltage and 2 quadrant switch.

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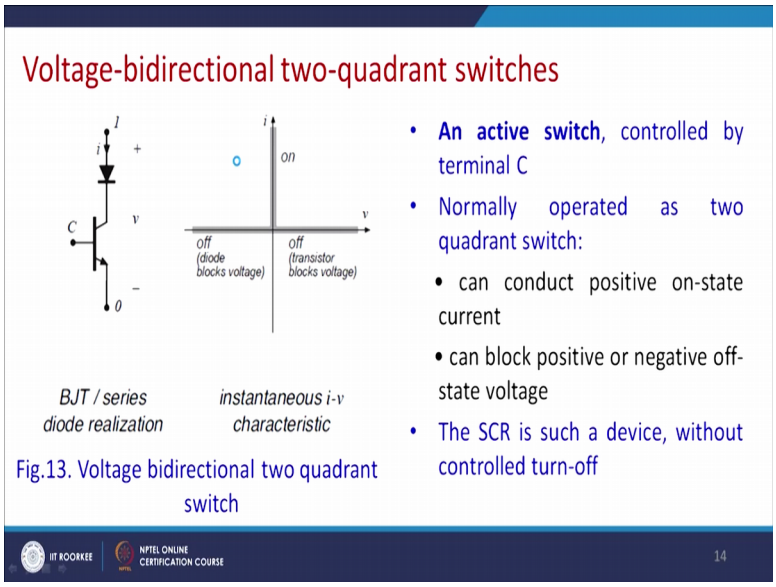

Fig.13. Voltage bidirectional two quadrant switch

Here, voltage can be bidirectional this way as well as this way, but current is unidirectional this is realized by 2 o by 2 1 quadrant switches. Diode will may diode and this configuration make current unidirectional and blocking capability of the current in the forward mode is been actually achieved by the control switch, but reverse direction it is actually this will be blocked by this diode.

So, what is the take away from these switches in active region? So, that the terminal C will control the flow of the current, normally operates in the 2 quadrant and can product positive on state current, can block positive or the negative off state voltage. One of the example will be SCR, but problem of SCR is a it is a semi control switch your control turning on is in your hand, but turning off is not in your hand; Generally, this kind of switches when used in current source inverter the current bidirectional to quadrant switch.

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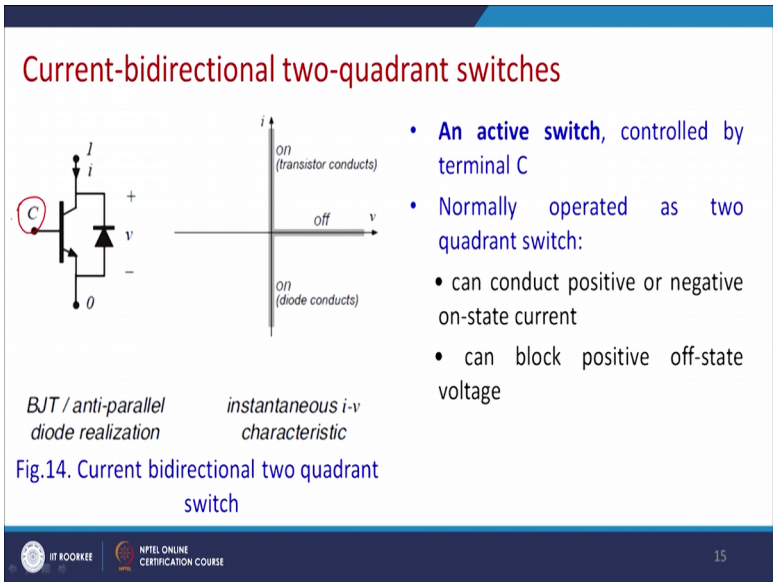

Fig.14. Current bidirectional two quadrant switch

Here you can see that same thing acting switch is controlled by the C, now talk about a 4 quadrant switch.

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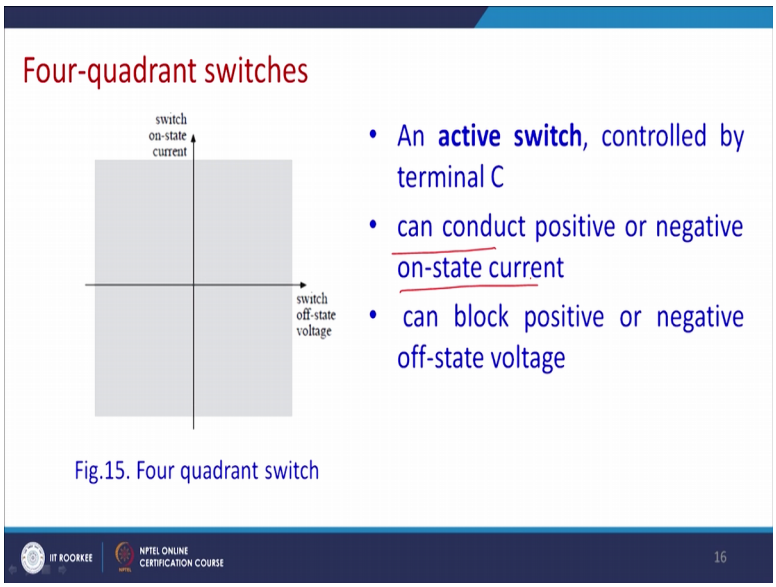

Fig.15. Four quadrant switch

It require to be realized by the active switches only, because it require to block current as well as the flow current, when it is designed since all the quadrant require to be incorporated in this circuit. Thus can conduct positive as well as a negative off state current, can block positive or the negative off state voltage these are the requirement. So, for this reason there are few realizations of this circuit the voltage and current require to

flow between 0.1 and 0. So, this can be realized by the many switches. Normal mechanical switch is automatically of this configuration, let us see that how this can be realized by the semiconductor switches.

So, right more circuit we shall take it first.

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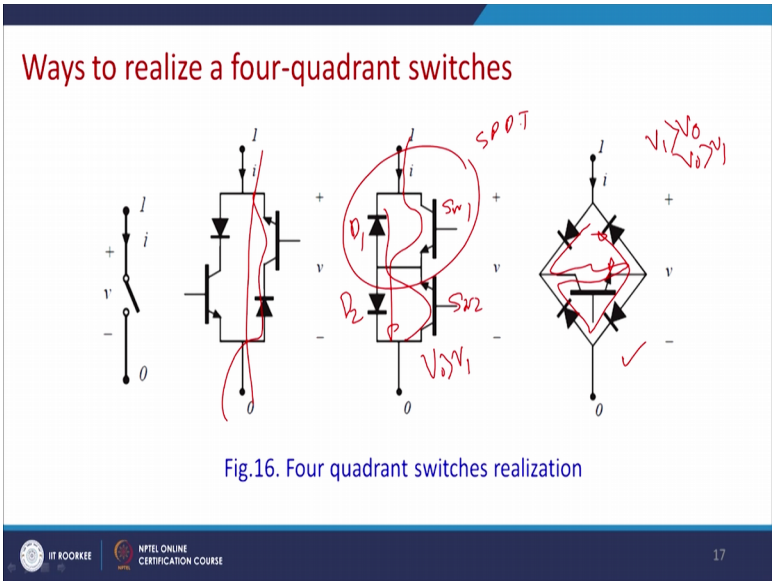

Fig.16. Four quadrant switches realization

So, this circuit you know. So, if the if the v one is greater than V 0, then path of the current will be through this and what happen? So, this and in reverse happens in V 0 is greater than V 1 then definitely current will be flowing by this direction. Then what is the advantage of it this require only one control switch that is the one of the biggest advantage of this. But disadvantage is that it will have a loss it has to incorporate losses of the 3 devices, because all it has just blocking voltages and generally power dats voltage is around more than one volt.

So, we will have almost 3 volt drop across this devices. Now, this is one the realizations with less number of control switch, another realization can be with this anti parallel BJT or the IGBT. So, if same way if this terminal is positive then flow of current through let us say switch 1 and diode 2 and same way. If, if actually V 0 is greater than V 1, then it should flow through switch 2 thereafter with diode 1.

So, in this case this device will actually incorporate losses or will have to face losses of the 2 devices, but in this case we require two control switches. Same thing can be

realized by this by this configuration this is symmetric configuration this is asymmetric configuration otherwise there is not much no difference in this case configuration. So, here it has been made by SPST switch and here it is made by SPDT switch that is the difference. So, these constitute 1 SPST switch and these constitute 1 SPDT switch.

So, as far as principle operation or the number of the component found all are same. So, this is the fourth quadrant operation of the semi-conductor switches, what is the application of it; application of this three phase matrix converter. So, we can we want to have generate AC to AC conversion direct AC to AC conversion this switches can this switches you know can flow current bidirectional as well as block the voltage bidirectional.

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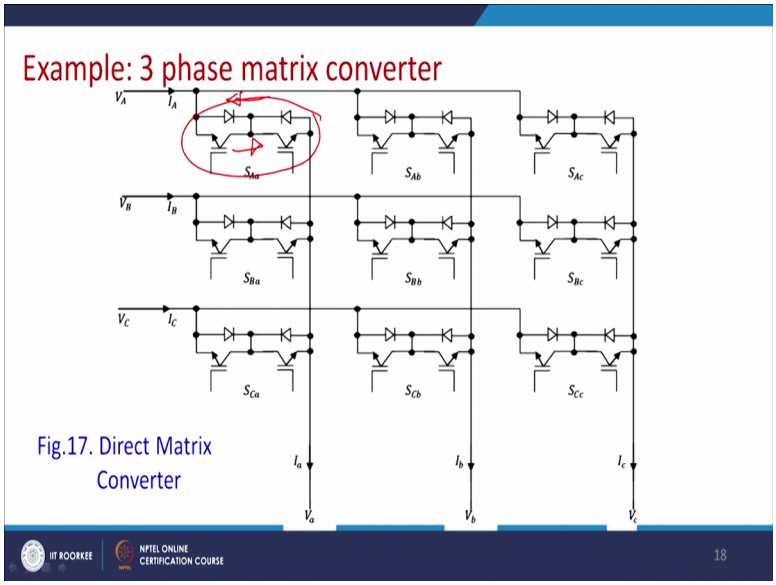

So, this const these 9 switches constitute the matrix converter try this matrix converter has a property to flow and the block that voltage in either direction.

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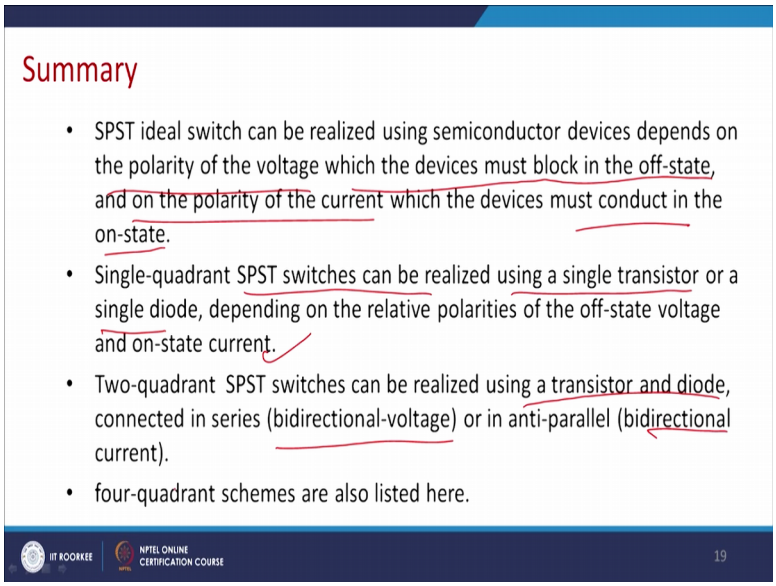

Now, what are the summary of this switches, ideal SPST switch can be realizing by the semi-conductor devices, depending on the polarity of the voltage which device must be blocked in off state. And on the polarity of the current which device must conduct on the on state.

Single quadrant SPST switch can be realized using a single transistor or a single diode depending on the relative polarities of the off state voltage and the on state current. And 2 quadrant switches, 2 quadrant SPST switches, can be realized by a transistor and a diode connected in series and a bidirectional voltage or anti parallel it is a bidirectional current and 4 quadrant switches can be 4 quadrant switches can be realized by 2 SPST or 2 SPDT switches.

Now, let us see how this actually comes into the picture in facts application. So, inverter can be realized by the help of SPDT switches.

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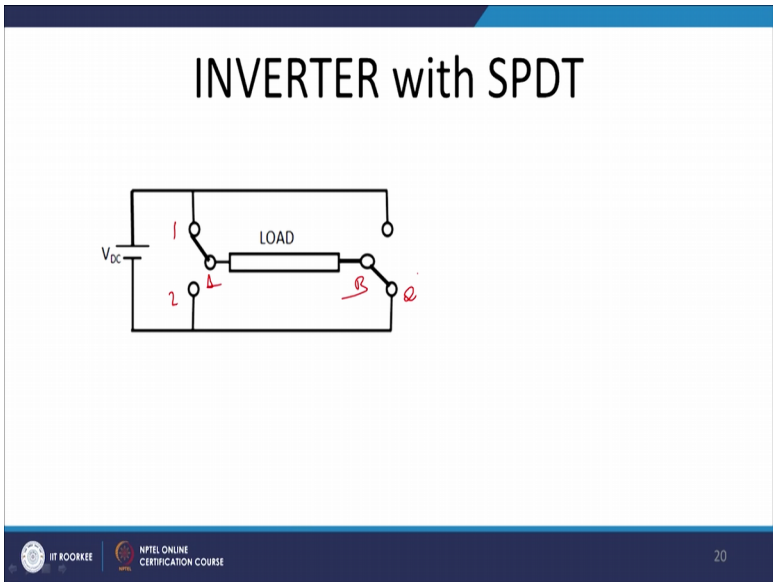

So, this is the pole of the inverter and that this is the 2 terminal one and 2 and this from the point is A and B. So, the voltage A B will be connected to the DC plus voltage positive DC plus voltage, if point A is connected to the 0.1 and similarly point B is connected to the 0.2. So, we can change this point thus we can change the voltage across it.

So, how can we realize this SPST switch we have seen dc to dc converter let us see how we can do it the same thing for the inverter application. So, this is a application.

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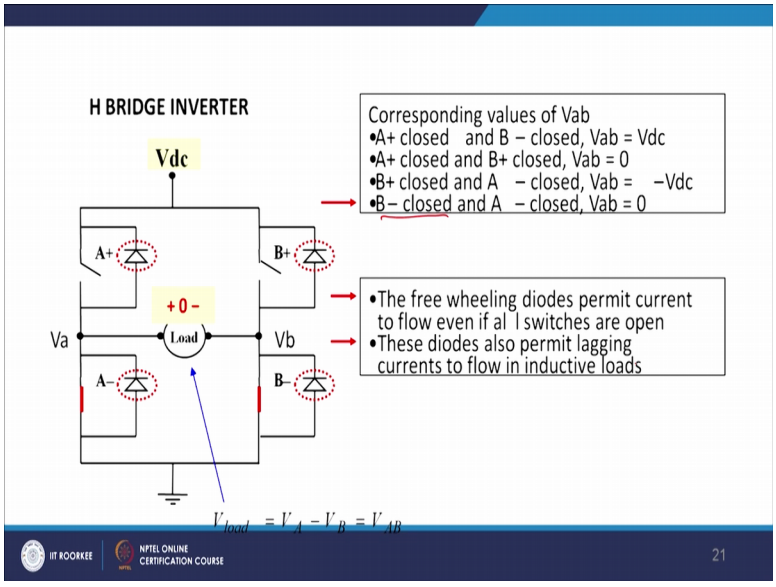

So, this is a node and voltage is 0. So, so this is basically the A and B A the block B block and C closes the voltage across it will be basically 0. So, a lower 2 switches has been closed. So, you are getting A 0 voltage.

Now, free wheel diodes permit the current to flow through the switch 1 and opens thereafter what happens? Then this diode also permit the lagging current to flow through the inductive load, because most of the cases we will find that load is inductive if it is for the drive application, it will be the induction machines. And if it is a FACTS application like the STATCOM and all those things we shall consider the inductive loading.

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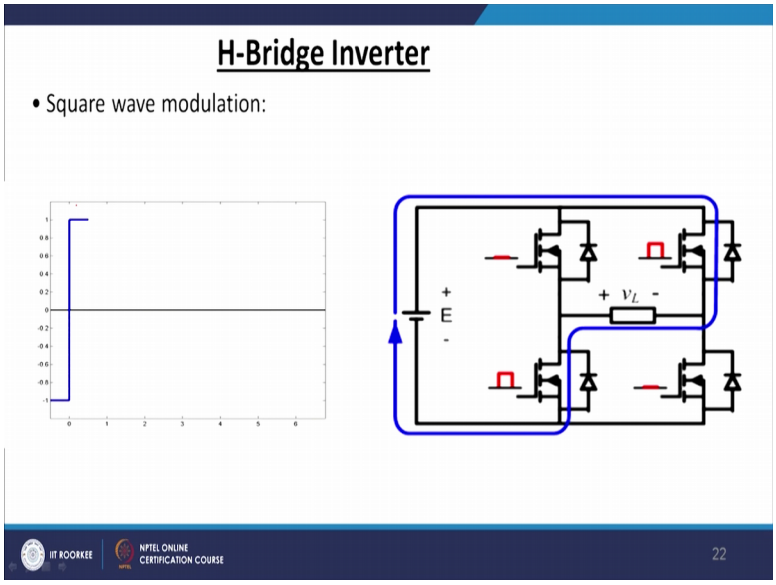

So, for this reason you see that this is the direction of the current flow, if we have applied this kind of voltages. So, ultimately this kind of voltage will come when this is a flow of current and after that this flow of current will change.

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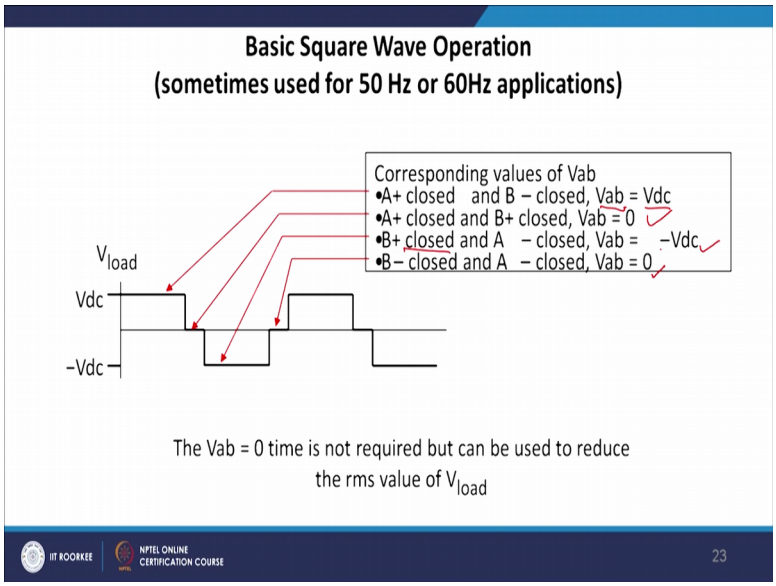

Now, ultimately this is a basic realization of the 50 hertz inverter. See, that first a is closed and B is closed you are getting Vab equal to Vdc, then A is closed and A plus is closed and B plus is closed; that means, both the top terminal are been closed. So, you are getting 0 voltage thereafter B is closed and then minus A is closed thus actually potential reverse.

Again, thereafter all the loads which is closed minus B and minus A is closed so, you are getting a voltage of 0 volt. So, this is the actually the cases. So, what we can say you know why you require a 0 voltage, because to match the volt area criteria. So, this basically used to reduce the RMS value of the applied voltage.

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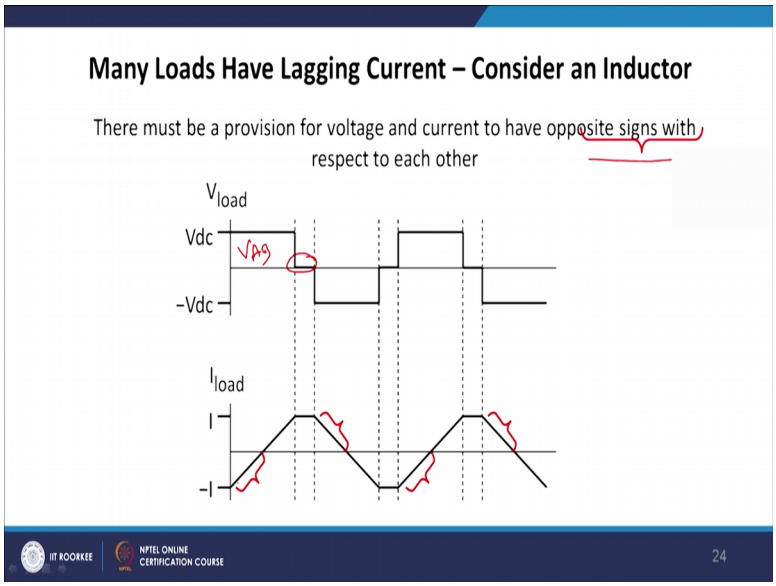

Now, this is the load characteristics. So, we can see that you can consider an applying load and say it is fitting an inductor highly inductive load then in this case current will lag if you apply dc voltage Vdc so, or Vav so, ultimately current will ramp on, thereafter when we apply 0 voltage current will be flattened.

So, current will flow through the diode under region, thereafter once you apply the negative voltage then voltage will again come comes into the place and voltage will drop will have a 0 cross that the same will happen here in the plaque region. So, this will be the. So, what happen by increasing this value you can increase or decrease the value of the RMS voltage this is the sim operation of the simple sing simple square wire inverter.

So, what I want to say that the opposite signs repeats each other. So, in this region voltage and current have the opposite signs with respect to each other. So, again in this region voltage and current are in opposite sign. So, what happen then, when you got a forward voltage and negative current. So, ultimately diode will conduct. So, in what you have a forward voltage and the forward current then control switch will conduct.

So, it can be very well realized by the simply realizing by a SPDT switch. So, this is few application this is the direction of the current flow.

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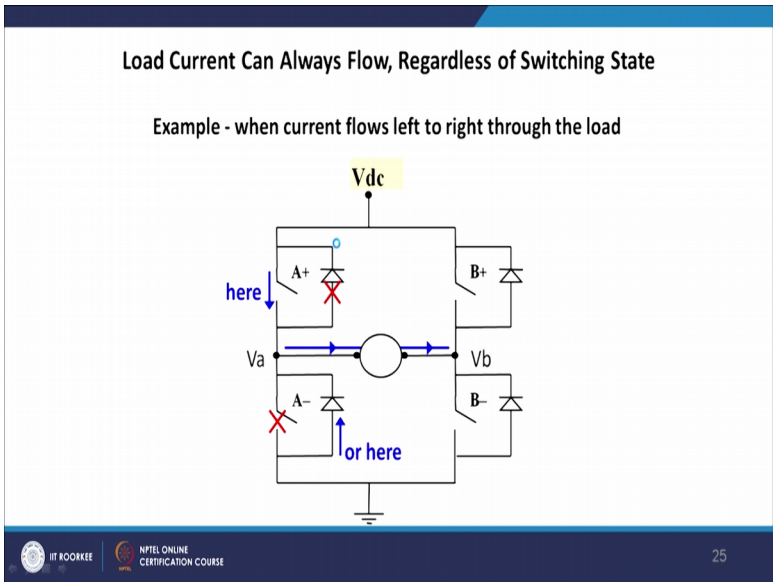

I will show that this is the direction of the current flow. So, it is here or here thereafter what happens?

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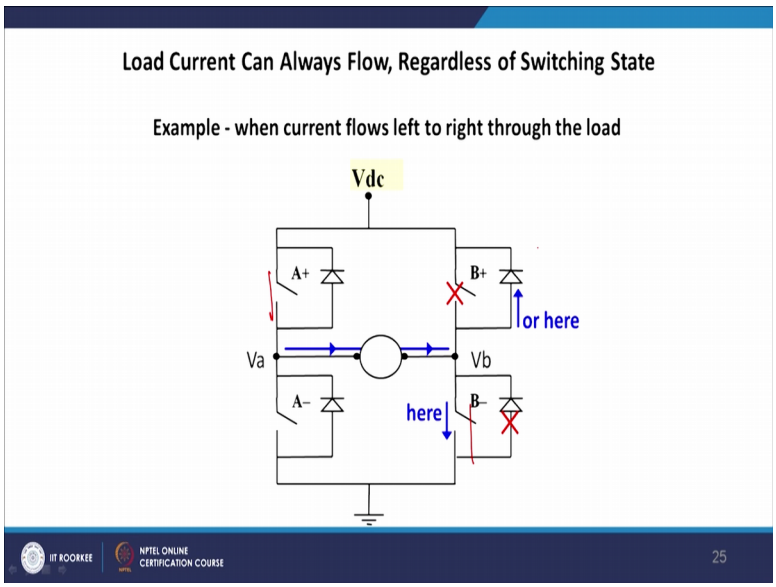

So, if we change it then when current is actually ramping on it is positive of cycle, then current will flow through this switches and this switches and this will be oh will be here. And, thereafter what happen current will flow through this and in thereafter what happen.

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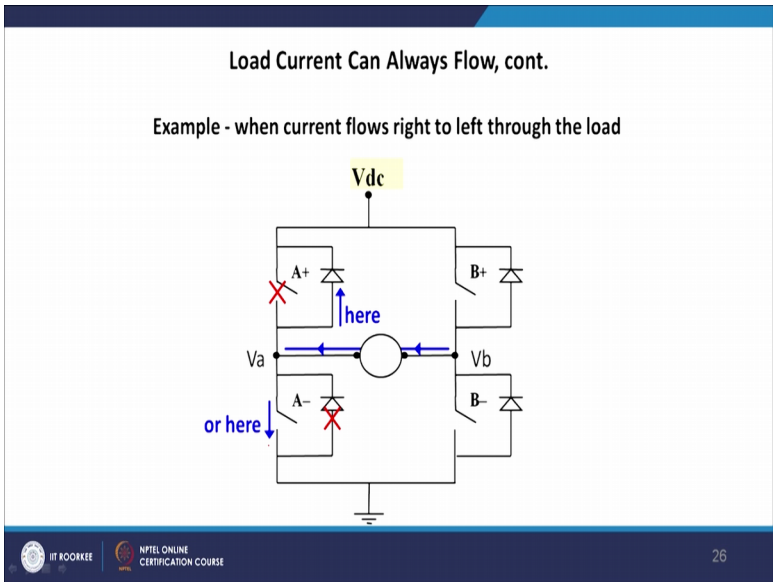

When current direction changes, then this will be the direction of the current initially.

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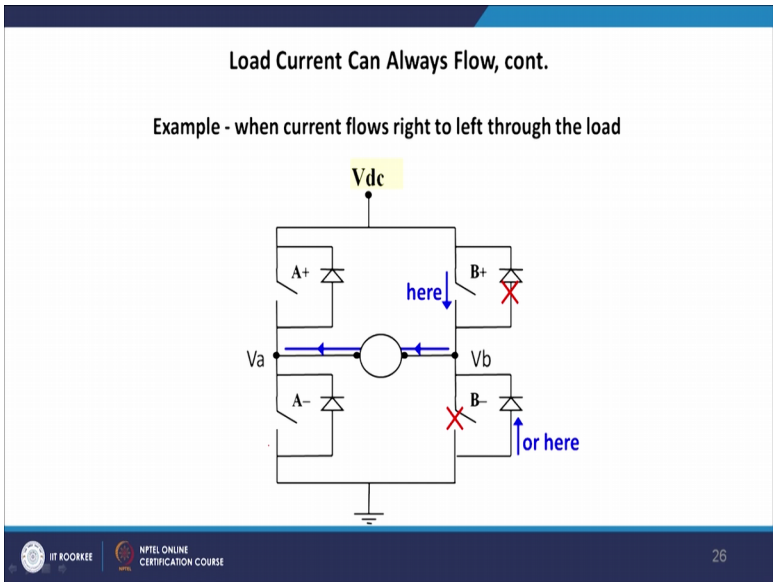

Thereafter, diode will flow into the pictures there this will be radiation of the current and thereafter this is the total circuits.

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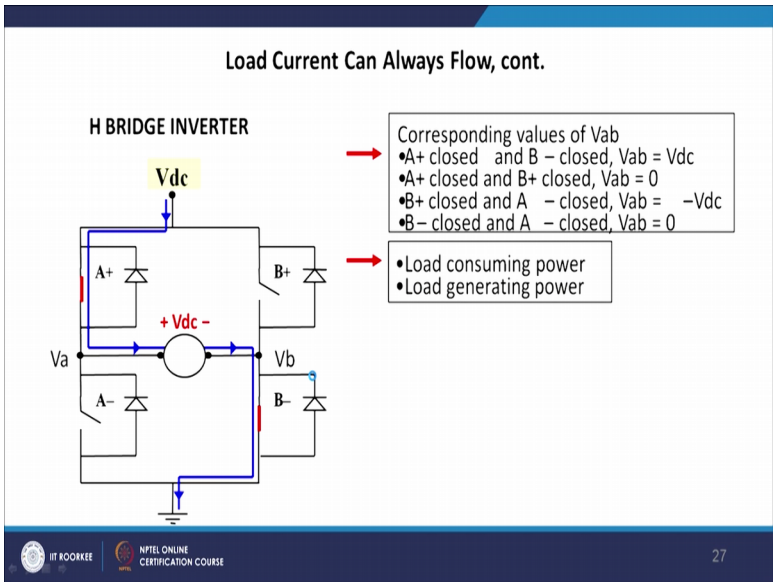

So, when plus A closes and plus B closes you get Vab when plus A closes plus B closes you get 0 when plus B closes plus A closes, you get minus DC when both this things are closes you get also 0.

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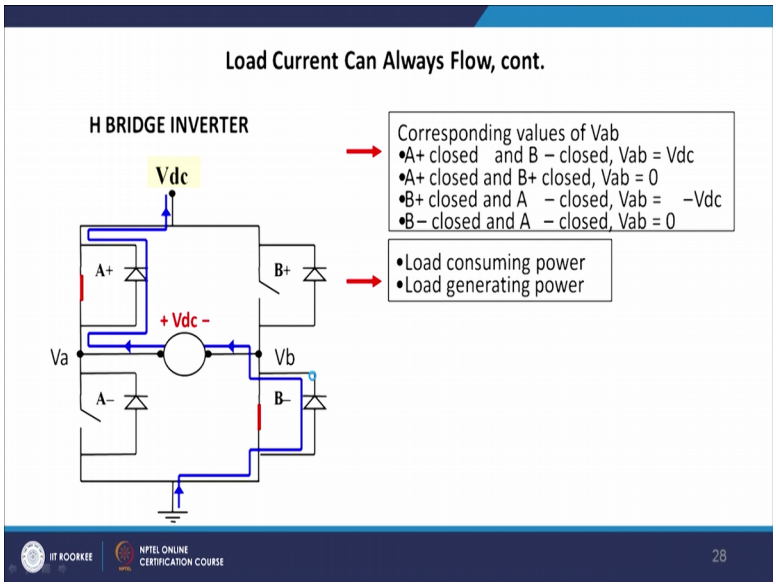

So, this is the operation of it where low t generating power and previously in this configuration that we will assume that load is consuming power, because we have considered an highly inductive load. So, practical la real power loss in the system is negligible.

Now, we have discussed SPST switches realization for two level two level inverter. Now, we shall see that by SPST switch how can we use the current source inverter, both are extensively used in the applications of the facts devices.

So, in next class we shall continue with the switches thereafter we shall discuss about the difference of different kind of PWM techniques suitable for the two level inverter, and thereafter we switch able to the multilevel inverter and followed by it is control technique.

Thank you.