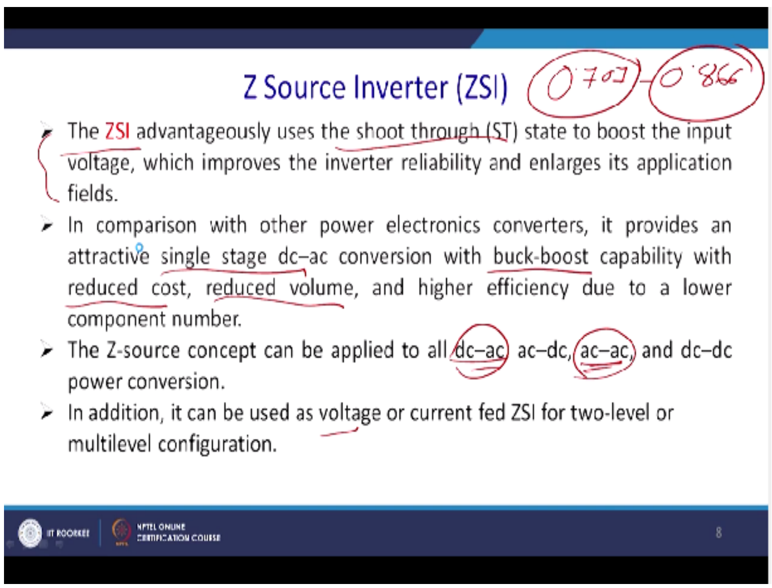
Advance Power Electronics and Control
Prof. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology - Roorkee

Lecture – 30
ZSI - II and Space Vector Modulation (SVM)

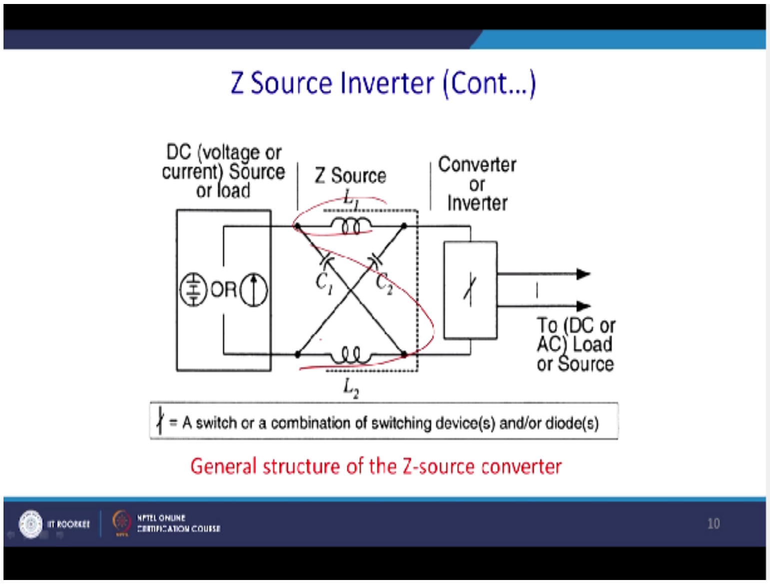
Welcome to our lectures on the advance power electronics and control. We were discussing with Z-source inverter. So we will discuss about the Z-source inverter initially. Thereafter we shall discuss today also the perspective modulation for 2 level as well as the 3 level. So we were here basically.

(Refer Slide Time: 00:47)



So the advantage of the Z-source inverter are as been discussed. Let us go for the detailed discussions of the Z-source inverter now. Now this is the topology of the Z-source.

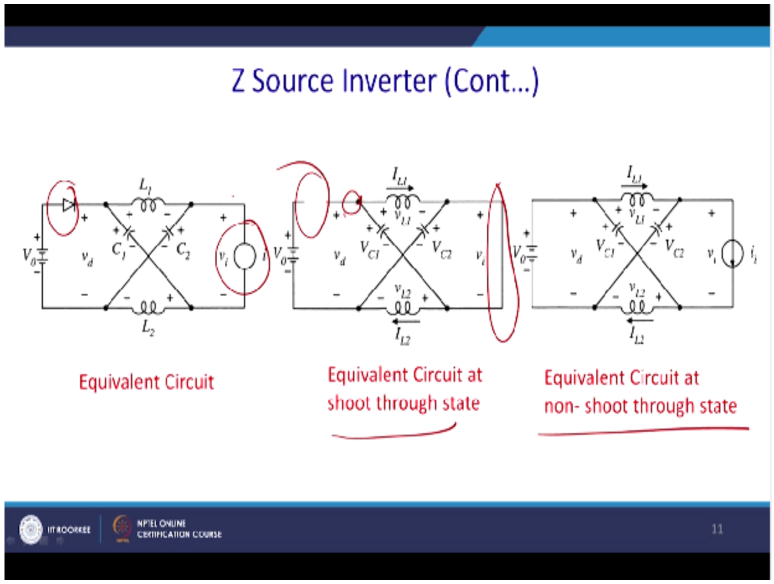
(Refer Slide Time: 01:01)



So you can see that, so this Z topology comes in various way. For this it is called the Z-source inverter. You may have a DC voltage or current source. And thereafter, you have a cross linked capacitor and followed by an inverter or converter depending on a different kind of applications and your load. May be DC, then it is a DC to DC Z-source converter. And if we have a load, may be actually AC and you are using an inverter, then it can be DC to AC operation.

Thus it can be an inverter. So it can be an inverter. And a switch or combination of switch or device is generally used. And generally, actually you are not allowed to come back flow depending on the kind of applications, if your solar application and all and you may have a little modification depending on the different kind of application.

(Refer Slide Time: 02:10)

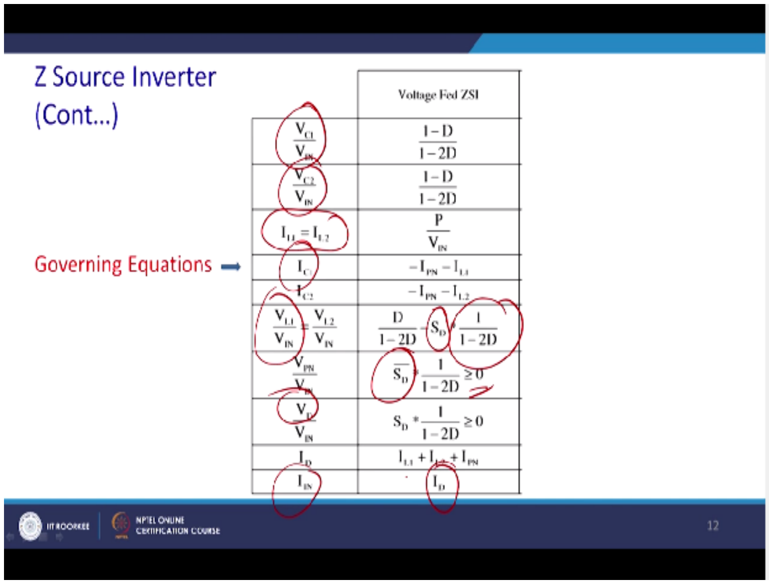


Now this is the equivalent circuit of the Z-source inverter. And if we wish to have a shoot through state, then we require to short 1 line and this is the one of the disadvantage of the normal inverter. Generally normal inverter legs are given a small dead time. So simultaneously shorting of the inverter is not allowed in one of the leg. And for this then actually we require little modifications so that we can give it.

And there is a different kind of technique of this, actually PWM that is called a POD, the phase opposition dispositions. You can refer to few of those my conference papers where this kind of technique has been discussed in detail. We shall keep those things in reference. So you require to short it. Once you short this DC voltage, this voltage becomes 0 and ultimately what happens?

These 2 capacitors comes into the series and ultimately this diode gets reverse bias because this voltage becomes higher potential than the source voltage. So these higher voltage of this VC1 and VC2 will appear. And once you again go to the normal mode of inverter operations, then higher voltage will actually aid and thus you will get a boosted voltage into this line. So this is the principal operation and this is non-shoot through state and this is the shoot through state.

(Refer Slide Time: 04:09)

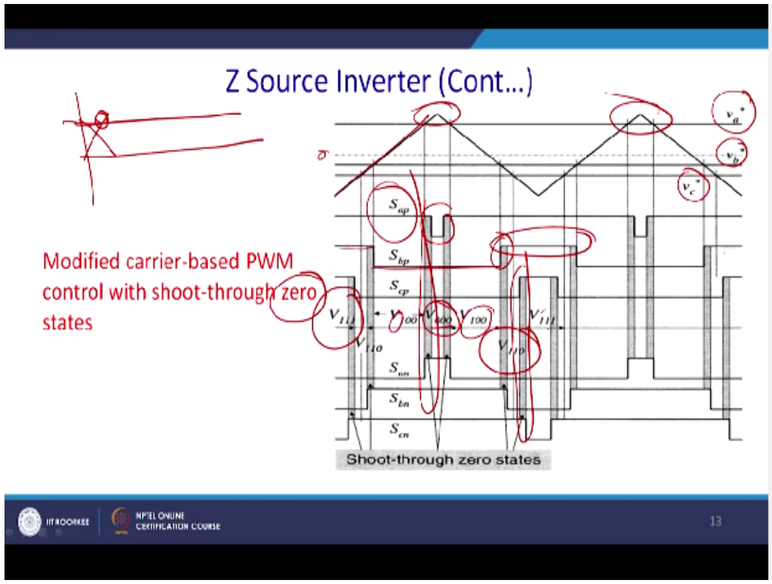


So these are the governing equations of the voltage fed ZSI. You may have a current fed as ZSI also. So you will find that actually if it is shorting for a duration D, so VC1/VIN will be 1-D/1-2D. Similarly, it will be same expressions assume that these 2 capacitors identical in nature. That is 1-D/1-2D and IL1=IL2. If it is so, then current will be P/VIN. Similarly current into the capacitor will be very small and that will be given by IPN-IL1 and IC=-IPN-IL2.

And this inductor voltages, VL1/VIN should be equal to VL2/VIN and that gives you the voltages basically D/1-2D-the amount of the shoot through. Generally shoot through is generally very less. It is basically only 0.05 to 0.2 of the total time of this duration. So it is 5% to 20% maximum. Otherwise, we will have a stability issues. We have to stabilize the circuit. So this is the applications, 1/1-2D.

Similarly VPN, the pole voltage, /VIN=SD bar, that means if it is 0.2, it will be 0.8, 1/1-2D and that should be equal to 0. Similarly VD/VIN should be SD*1-2D greater than 0 and current through the diode will be actually the voltage across the diode it is blocking is this much. And current through the diode will be IL1+IL2+IPN and IN is the input current and that should be equal to the diode current because when it is a normal inverter mode, then only current flows. So let us see the operation. Let us see that at the instant you have 3 phase voltages.

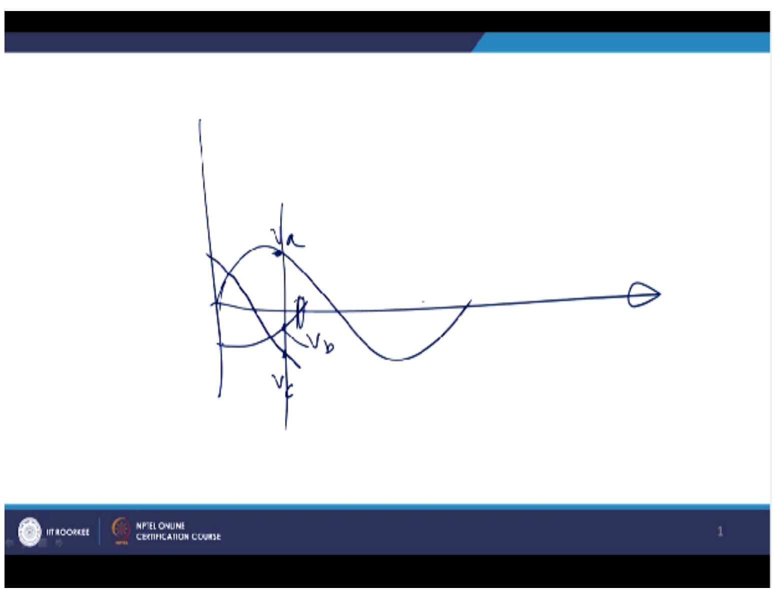
(Refer Slide Time: 07:00)



At the instant, you have a 3-phase voltages where A and C cuts and thus you can see that A voltage is more, that means you are somewhere here. And B is actually lower. So it is more than 90 degree. And C is basically further lower. So this voltage is A and this voltage is B and this voltage is C.

So this is actually the point may be we are discussing. And since it is the 50S supply and this is around 10 KHz with respect to the snapshot in a switching logic which is actually 100 microseconds. You can take this sine wave as a state curve, okay. Because we have to switch over to better understanding over it.

(Refer Slide Time: 07:58)



So let us take this is the sine wave of single phase and C phase will actually intersect at omega t=30 degree and you carry on like this. And B phase will intersect at this point. And you may be actually talking about actually this point where you have actually this value is a, this value is Va and this value is Vb and this value is Vc. So it is somewhere here. So after 90, before may be 120.

So let us constrict our discussion at this point, what will happen depending on the different voltage level as has been shown here. So this constitute your Va, Vb, Vc and that is drawn as a straight line because basically switching frequency is around 1000 times higher or at least 500 times higher. So now see that the modified carrier based PWM, how it gives to the shoot through.

So you will give a shoot through for very small interval of the time. So this is the switching of the SA and here actually in this peak, in this peak, you give a shoot through. So what will happen? Here it will be low and for this duration basically you can find it out the triangular wave is more than the sine wave. Or since till that time, since till this time, triangular wave is more than, sorry, triangular wave is less than this Va, so Sap will be on.

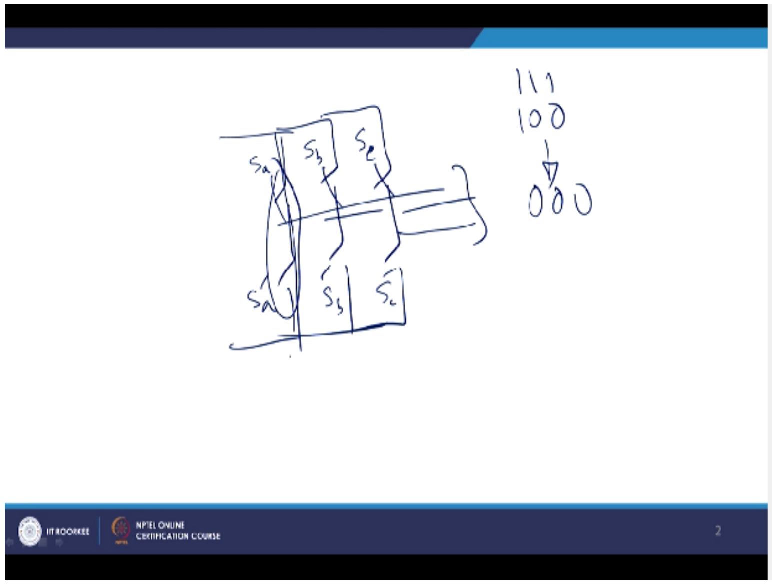
And for this duration, this will be off. Similarly for Sb, this one, so it will cut this point and till this time, this will be off and this time, Sb will be on. And similarly you will have this logic. And what you will do here, you see that. And thus you make transitions, switching transitions. You start from the, just after this class or may be actually just after or may be in the same class, we shall discuss with different state of actually space vector modulations.

Then it will be more clear, so you require to rewind this lectures again. 111 are actually the rotations of the space vector. It means that for the 2 level inverter, all the upper switch is closed. And thus you get a 0 voltage and the inverter. And thereafter initially when it begins, phase a is greater than the triangular wave, thus you get 1 and other phases are less than this triangular wave.

For this, this will be 0. And here, you will have transitions again. All the switches, actually all these actually phases are less than the triangular wave. Thus you will make actually 000.

Thereafter again it will transition to 100 and 111. Now what will happen? In between this 100 to 000, you will give a small shoot through.

(Refer Slide Time: 12:25)



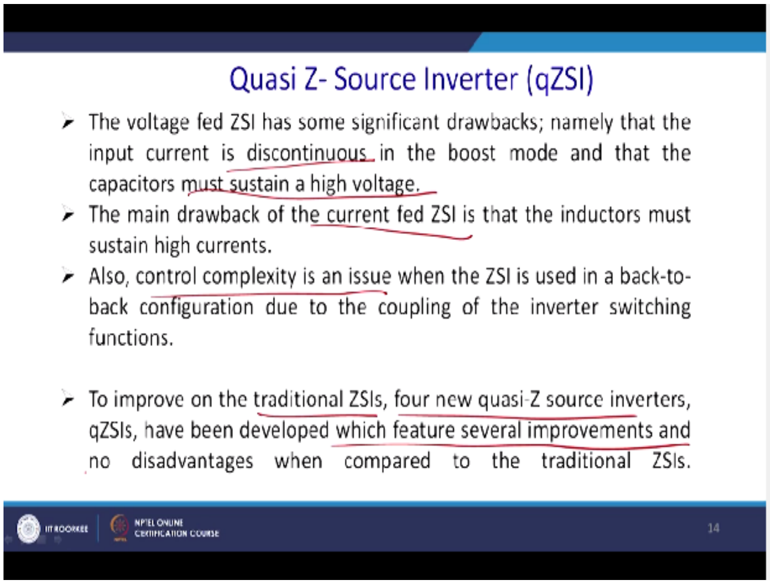
You short 1 of the leg. So to better understand it, so you have different switches and once actually, this is Sa, Sb, Sc and these are all prime. Once all the upper switches are closed, you get a 0 voltage that is 111. Thereafter, since a phase is positive, so it will be actually meant and other 2 phases are 0, so you will get 000. But again you will make it as transition to the null vector to 000.

While doing that, basically 0 means lower switch is closed. And 1 means upper switch is closed. So for small interval, you will close this leg and thus you will achieve the shoot through. Let us switch over to our slide again. Same thing happens here, according to the switching logic in the negative part of this actually triangular wave, this actually dotted line is a 0 point. Then what will happen?

The sequence of the switching will be 110. And then it will be switch over to 111. In between that transition, 110 to 111, we will give the shoot through of phase. You will get from 100 to 110, sorry, pardon me, 110 to 110, you will give a shoot through at phase. Similarly once it makes transitions, 110 to 111, give a shoot through to basically in phase c.

So this is the way introduce the equal shoot through in all the phases in a cycle and you get a constant voltage. And this is the way actually shoot through has been incorporated in the Z-source inverter. Now we have another topology of this Z-source inverter. These are the modified Z-source inverter that is called quasi Z-source inverter.

(Refer Slide Time: 15:26)



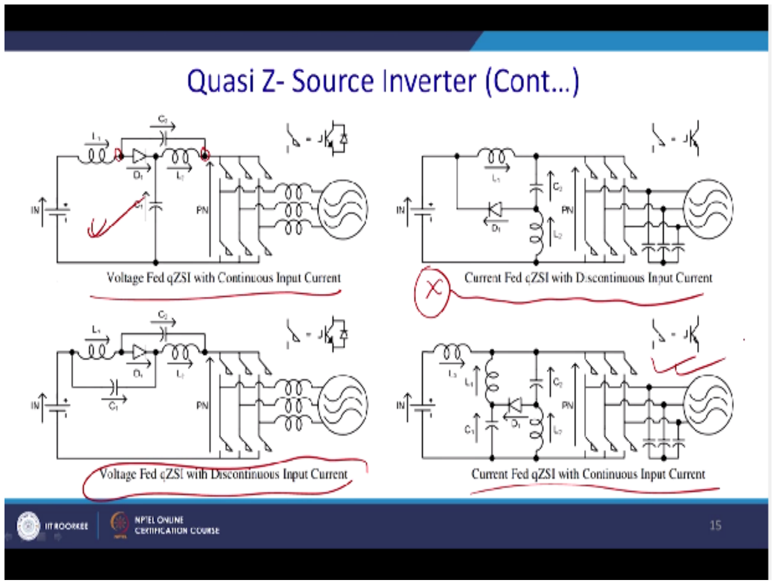
The Z-source fed ZSI has some significant drawback. We shall criticize the Z-source inverter. Namely the input current is discontinuous and you are blocking, please go back, you can see that you are blocking it. And if you are using a solar inverter, if you are blocking it, you are shifted to MPPT points.

And if it is a CSI, you cannot do that. So namely the input current is discontinuous in the boost mode and that the capacitor must sustain a high voltage. The main drawback of this, that is why we are saying the current fed ZSI is that the inductor must sustain the high current. So that is one of the challenge and thus site of the inductor got to be very high to maintain the constant current.

Also control complexity is an issue when ZSI is used back to back configuration due to the coupling of the inverter switching functions. There is a controlled technique and switching logics will come and that has to be incorporated with the Z-source. So all those complexities will pop in and ultimately that gives you a problem related to the controllability and observability.

So control becomes complex. And thus to improve on the traditional Z-source inverter, 4 quadrant quasi-Z-source inverters, aZSI have been developed which features several improvements and no disadvantage over, as stated above has been removed when compared to the traditional ZSI. So see that what is the difference between it. Please recall you have basically a T junction. And capacitor has been connected between these 2 points.

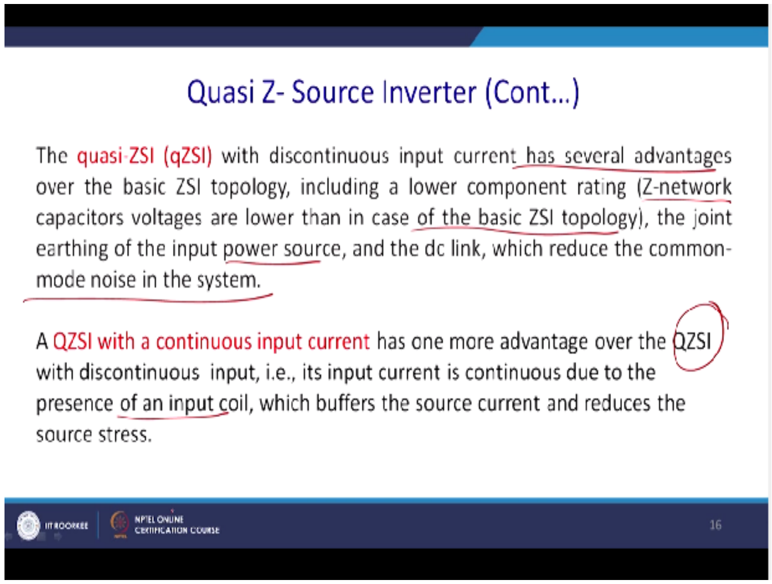
(Refer Slide Time: 17:49)



And analysis becomes quite easier and you close this switch. So this is the voltage fed quasi Z-source for the continuous input current. And once actually if it is little complex in operations. Current fed quasi Z-source with a discontinuous input current. Voltage fed qZSI with the discontinuous input current. And this is the current fed qZSI with the continuous input current. All those actually, combinations are possible with the quasi-Z-source multilevel inverter. And accordingly this circuit will change.

This is the most common circuit users that is basically voltage fed quasi Z-source inverter with continuous input current. So that is quite trivial if it is discontinuous, that means loading is less. And if it is discontinuous, then this actually this capacitor automatically once current does not flow through the circuit, automatically comes at this point. And this is generally hardly used in practicability, current Z-source, ZSI with discontinuous input current. But it is highly efficient and it is quite used in many combinations of the circuits.

(Refer Slide Time: 19:29)

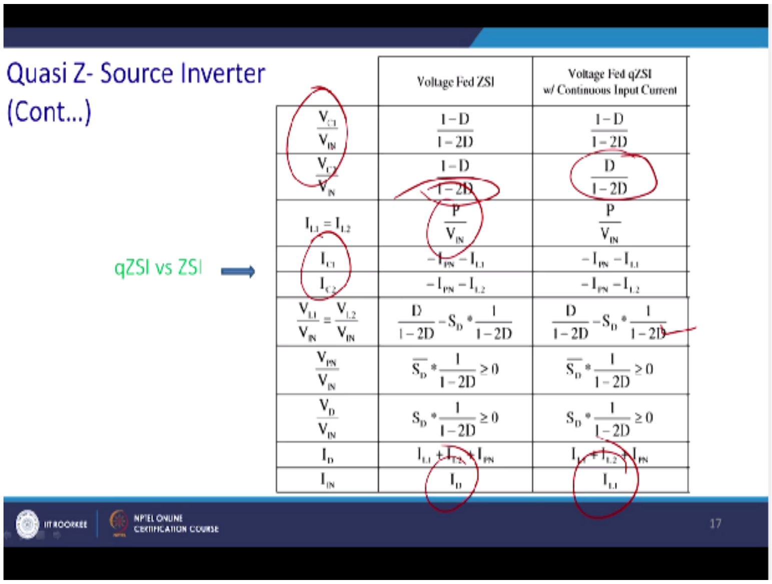


Now same kind of analysis can be done with the quasi-Z-source inverter but because of the shortage of time, we have to actually brief it. And it is the modern research topic and many researchers are working on it. The quasi-Z-source with the discontinuous input current has several advantages over the basic ZSI topology including a lower component rating because high stress comes into the picture and the ratings of this diodes will be very high in case of the Z-source inverter, component rating.

Z-network capacitors voltage are lower than in case of both basic ZSI topology. The joint earthing of the input source and the DC link, which reduce the common mode noise of the system. A QZSI whit the continuous input current has one more advantage over this QZSI of discontinuous input, that means the input current if it is continuous due to the presence of the input current or the inductor, which buffers the source current and reduces the stress across the sources.

So operating actually those, any converter, please remember in a continuous conduction mode, it is easier. And apart from that, in case of the ZSI, actually is stress across the switches as well as the source will be less if it is operated in the continuous conduction mode. Now same analysis what we have done in case of the Z-source inverter, we can do it here. And it has been actually compared in the same segment.

(Refer Slide Time: 21:33)



So VC1/VIN, it is same but in case of the VC2/Vin, you can see that this value is actually D/1-2D. So it is just reciprocal and mostly this value is less than 0.5 because there is a stability issues at 0.5. but most of the cases, if these value should be less than 0.3 because if you put 0.5, then you can understand that system is unstable. So here you can see that gain here is restricted. So 1-D, here gain is just reversed.

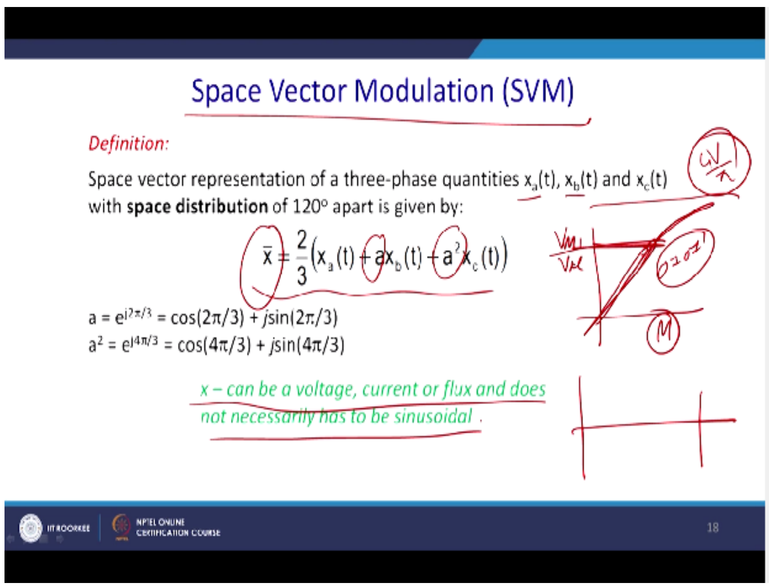
Similarly, power. Power will be the same in both the cases and same way this capacitor current, these will be the same but this gain, VL1/VIN, there will be some changes here. It is actually D/1-2D-SD/1-2D and this is the case. And this also will be the same. VPN/VIN and these value will be the same. VD/VIN, this value also will be same. Here, input will be the diode current and here input will be the inductor current.

So this is the one comparisons with the Z-source inverter with the quasi-Z-source inverter. Since thus actually you can see that there is a specific advantage of this rating. See that since the gain is lower with respect to input, so what you require to have, less stress on this capacitor and capacitor rating can be lowered in this configuration. Same way we can find it out the value of the inductor which has not been discussed.

Because we can discuss basically the voltage fed inverter because if you have discussed actually current source inverter, we will see that the current, the size of the inductor will be lower in case of the quasi-Z-source inverter for continuous input current. So now let us begin with our new topic that is the space vector modulations which I was actually referring little bit ago for discussions.

And the space vector modulations is essentially are a way of representing. We have already discussed sine triangle PWM. In sine triangle PWM actually, there is a problem of utilizations of the DC bus voltage. Because utilization of the DC bus voltage is a challenge here generally actually if you consider that actually the M, modulation index of the PWM and the voltage gain that is actually fundamental by VDC, up to some level, it is linear.

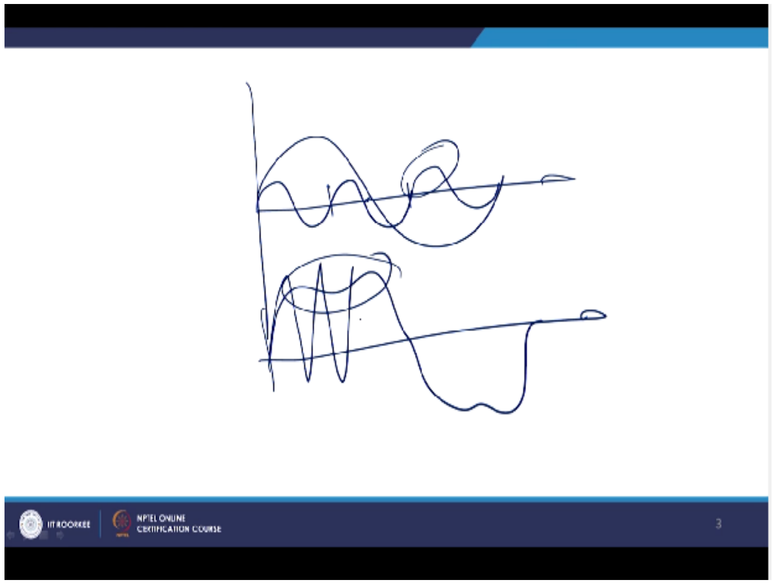
(Refer Slide Time: 24:40)



And after that the hysteresis come or the doping characteristic starts and this value goes to actually 4VM/pi for over modulations. But it will be contaminated with the harmonic that we have already discussed in our different discussions on this converter. So you have to be restricted around this and one of the advantage of the PWM is that it shifts, this actually spectrum to this higher frequency and thus you can basically, you can filter out with the smaller filters.

But this linear region is mostly restricted to 0.707. Now there is a way of actually increasing the linear region by little bit of harmonic contamination. You can inject essentially a third harmonic with some portion of it. So you can draw the third harmonic here. Or let us switch and draw it and let us try to understand what actually I try to say.

(Refer Slide Time: 25:57)

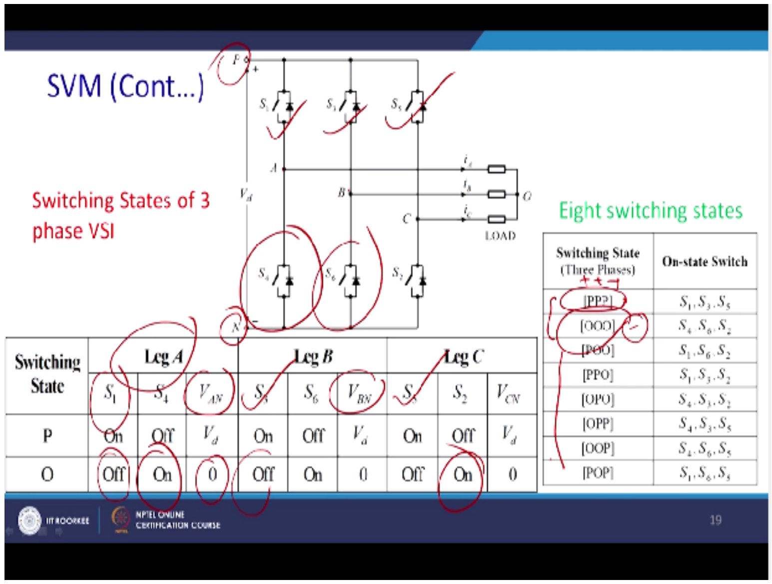


So you have a normal fundamental sine wave. With that you have a third harmonic. Sorry it should be coursed as a. Now you can see that if you inject these 2 harmonics, so what will be the resultant waveform? Resultant waveform will be this depending on the percentage of the third harmonic. There is a calculations of what is the. So what happen? Actually if you have a sine triangle comparison, so here effectively if you analysis, you get around 16% more voltage than the actual PWM voltage.

And thus we get a greater voltage and greater utilization of receiver's voltage. But there are limitations because if you use the third harmonic injections, then it will appear in the phase voltages down 9 voltages if it is actually the delta connected load. But same technique, it can be incorporated in a different way. Main challenge we increase the utilization of the DC bus voltage and one of the solution has been provided by the space vector modulations with loads stress across the switches and high utilization of the DC bus voltage.

It is same as equal injecting the third harmonic but advantage is that stress across the switches will be lower. Let us see that how it can be incorporated. Space vector representations of the 3 phase quantities, that is or the voltage current or whatever, it is xa, xb and xc because space distribution of 120 degree apart. It can be represented as actually the a gives you the 120 degree phase shift, a is e to the power j2pi/3 and thus x can be voltage, current, flux and does not necessarily to be a sinusoidal quantity also. So this can be represented like that.

(Refer Slide Time: 28:27)



Now let us see that we will have a 2 level inverter and we have a leg A and this is the phase voltage with respect to the mid-point of the capacitor. And this is the point N and this is basically voltage BN, this is voltage CN and we will see that what will happen? When actually S1, S4 is basically constituting the leg 1. Similarly, S3, S6 constituting to leg 6 and (()) (29:32) phase C.

So once S1 is on and you have a matrices of different combinations and S3 is on that means this switch is on, this switch is on and this switch is on, all the upper legs are, switches are on and then what happens? You get the voltage VAN, you get the voltage VBN, you get the voltage VCN and ultimately since all this point is coupled to the point P, this point is attached to the point P, this point is also attached to the point C.

So voltage across it, across the load will be 0. So for this reason, we shall see, we shall write the convention here we are following actually the convention followed by (()) (30:37) you can refer to the other book also. They are using a different kind of convention. So they are using the +++ or 111, whatever may be. Here we are using PPP. So this point is P. For this we are writing PPP.

So it is S1, S3, S5. Similarly, once all the lower switches are closed, so S1 is off, thus S4 is on. This actually complementary logics. Similarly, you get a voltage 0. Similarly, S3 is off, S6 is on and similarly S2 is on. You are here that is S4, S6, S2 and you get a 0 voltage. So irrespective of this level that gives a 0 voltage to the load and for this reason, these are 2 represented are called a null vector.

And we shall continue to the another vectors since this are combinations of the 3 bead you can consider now. And thus you have actually 8 states. And we shall discuss all the 6 active states in our next class. Thank you for your attention. We shall go into the deep discussions of the SPWM in our next class. Thank you.