**High Power Multilevel Converters - Analysis, Design and Operational Issues**
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**Lecture – 34**
**Other Topologies of NPC Converters – Higher Level NPC, TNPC and Active NPC**

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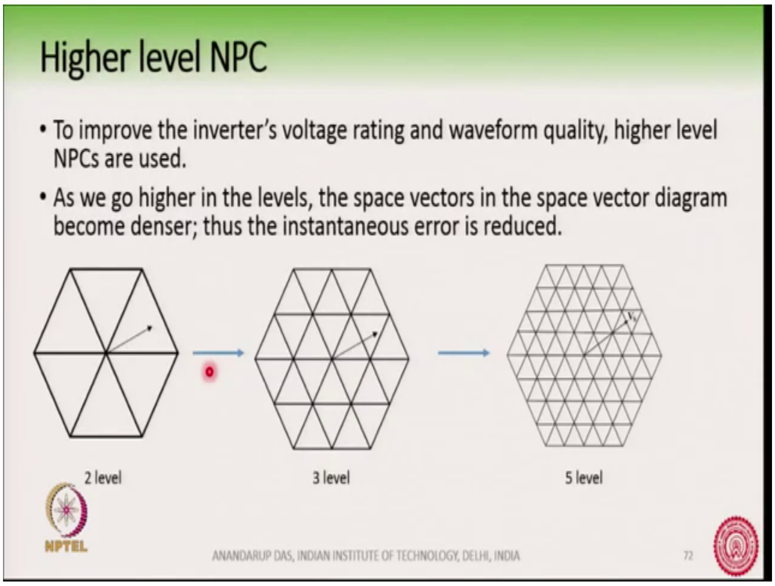


We now, see the possibility of having higher level NPC based converters ok. Now often and it has been proposed in the research community that, we can go from a 2 level to a which in a conventional NPC we have gone to 3 level NPC. Why do not we go for a higher level NPC ok? Now why do we want to go for a higher level NPC? Because, it will improve the waveform quality and of course, it will improve the inverters voltage rating or the converters voltage rating.

Now, if you go with a 5 level NPC, if you see the space vector diagram; then you can immediately see what is the advantage of having 5 level space vector diagram or a 5 level NPC. You can see here in the diagram, so, you have a space vector diagram for a 2 level converter for a 3 level converter and for a 5 level converter. And you can see that in a 5 level converter the space vector diagram, the space vectors in the space vector diagram, they are getting closer and closer to each other; they are becoming more dense.

So, that the instantaneous error between the reference vector and the actual vectors which we are switching that instantaneous error is reducing. And if the instantaneous error reduces, we are approaching closer and closer to the sine wave desirable sine wave. So, that is why a 5 level space vector diagram or a 5 level NPC will be better in terms of waveform quality than a 3 level NPC ok.

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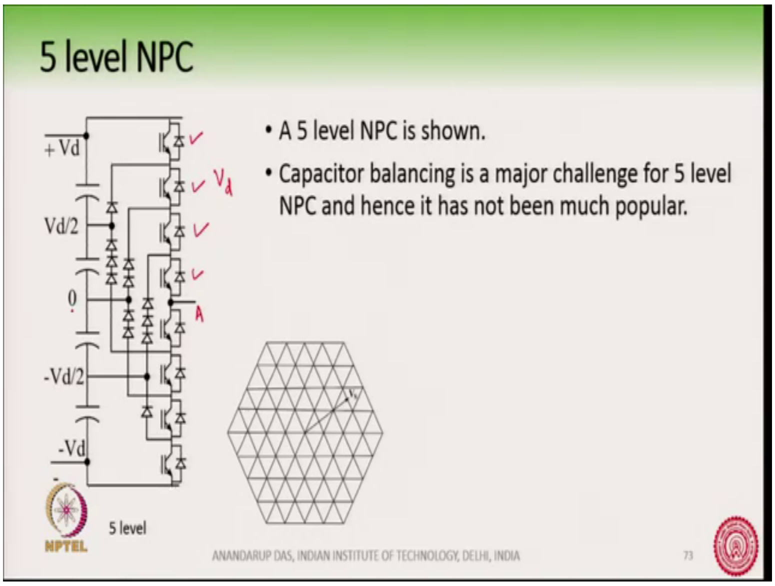

So, how does a 5 level NPC look like? So, it is you can see, it here in this circuit 1 phase is shown. So, you can see that you have like 8 switches here for the 5 levels and there are also clamping diodes, but these are clamping diode there are several camping diodes here. So, let us see a little bit about this one the circuit. So, you have this Vd voltage here and the minus Vd voltage and the 0 point here like a conventional three level NPC.

But now, you have also like 4 capacitors here and the voltages at this points are all the capacitors have equal voltages so, that this is 0 this is Vd by 2; this is Vd and then minus Vd by 2 and minus Vd. So, the whole DC bus voltage is split into four equal parts across all the capacitors ok. So, in this converter, suppose we want to get the Vd voltage that is the voltage of the pole voltage with respect to this 0 point. If I want to get Vd, then I will turn on 1, 2, 3, 4 all the 4 switches here.

On the other hand, if I want to get Vd by 2 voltage plus Vd by 2 voltage, you can what we can do is, we can turn off this one; turn off this switch and turn on this switch right. We will turn off this switch and turn on this switch. So, if we do that then what happens? The current will flow from this way. So, let me so, for Vd voltage, we will turn on these 4 switches for Vd voltage ok. That means, point of the voltage of a with respect to o then we will turn on these 4 switches ok.

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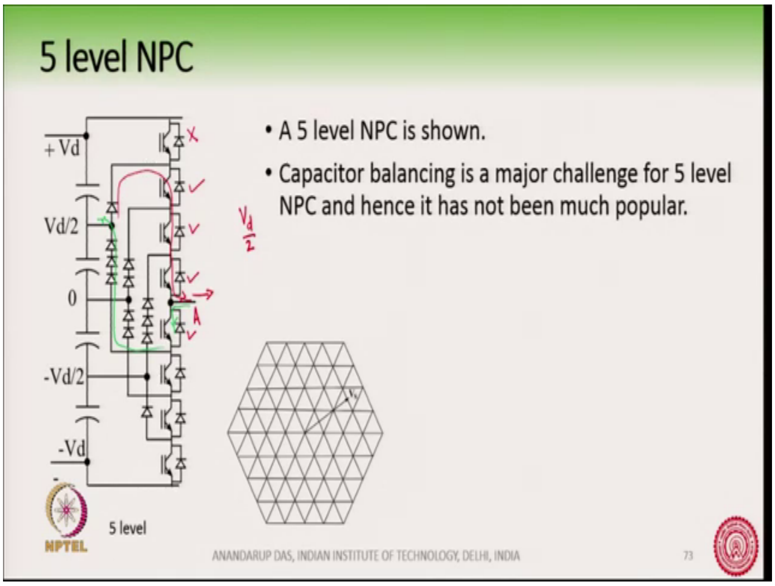


And then, we will in order to get Vd by 2 voltage, what we will do? In order to get Vd by 2 this switch is turned off and this switch is turned on.

So, now, we have these 4 switches conducting. So, if the current direction is positive in this way, if the current direction is positive then the current will flow like this here right; the current will flow like this. On the other hand, if the current direction is negative, then the current will flow like this like this. So, this is how, we buy these 4 switches; we will be able to get a Vd by 2 voltage right.

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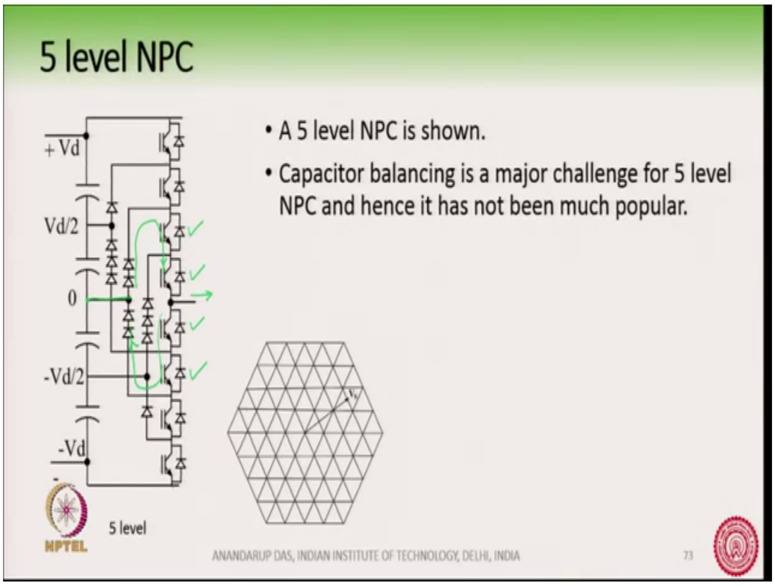


In a similar way, if we want to get the Vd voltage then what can we do? If you want to get sorry, if we want to get a 0 voltage what can we do? We can turn on this 4 switches here ok. So, and so, this point will be access via this so, either the current will flow like this or the current will flow like this ok. So, if you go on analysing this way, you will see that this in this particular NPC or the 5 level NPC how we can get the 5 levels of voltage that is Vd, Vd by 2 0 minus Vd by 2 and minus Vd in the pole voltage ok.

This particular converter although is attractive, but there is a one drawback and the capacitor balancing because now, we have 4 capacitors here and balancing these 4 capacitors is a major challenge for this type of a converter. And so, it has not been much popular. So, 3 level NPC is very popular; however, 5 level or higher level of NPCs are not so popular ok. The capacitor voltage balancing is a major issue.

But if somebody some of you are interested in exploring furthers, we will add references where you can study this material ok.

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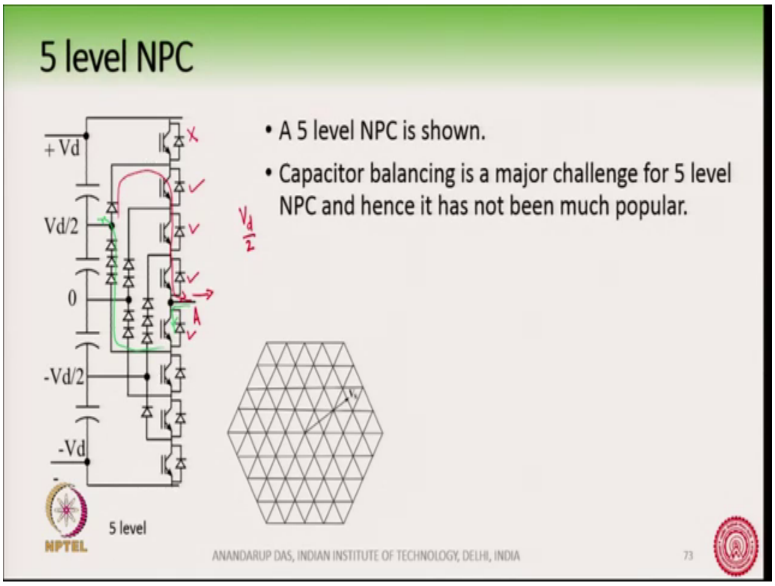


Then, we will talk about something like a TNPC ok. So, this is another so, this this is another type of NPC where this has been proposed more recently ok. So, here what happens is circuit is like what I have shown on this circuit diagram here.

Now, if you see here the in TNPC, we have 1 upper switch, 1 lower switch and 2 switches to access the 0 point here ok. So, this point is like doted here ok. So, this is what we have. Now in this case the difference of this is the difference of this TNPC from the conventional NPC is that, we have only 1 switch here and there are no clamping diodes. Instead of the clamping diodes ok; here there are no clamping diodes instead of the clamping diode, we have this 2 switches ok.

Now remember that so, what are the so, remember that that what are the ratings of this switches here? So, this switch the upper switch is rated for the full DC bus voltage. And the same is applied for the low lower switch also because, if this switch is off and this switch is turned on, then the whole voltage will come here. So, this switch has to block the full DC bus ok.

So, the voltage rating of this switch as well as this switch is Vd or the total DC bus. Whereas, the voltage rating of this switch here is half the DC link voltage ok. Now this switch is a 4 quadrant switch. So, which means, that this switch has to block both plus and minus, I mean positive and negative voltage right and the current through this switch here should be bi directional.

Using, you can see that if S 3 and D 4 are conducting the current will flow like this here. If S 4 and D 3 are conducting current will flow like here. So, this switch is a bi directional current switch ah. It can also block bi directional voltage. So, if I turn on S 1, the plus voltage will come here, the plus voltage will come here and if I turn off S 3 then this device will not conduct ok.

On the other hand, if i turn on S 2, then the minus voltage will come here. So, therefore, we can say that this switch is a four quadrant switch ok. Rated for half the DC link voltage, but switches S 1 and S 2 are rated for the full DC link voltage.

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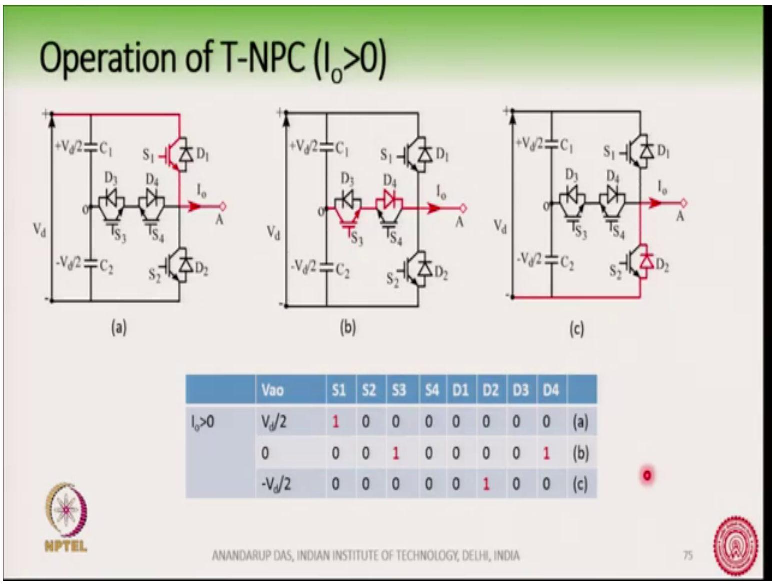


Now, let us see, how does this circuit operate? So, if I want to get the positive voltage and suppose the current which is going out is greater than 0, then I have this this is the switch S 1 is the switch which is conducting.

If I want to get the 0 voltage, then the red path here is how the switches will be conducting and on the other hand if I want to get the minus Vd by 2 this diode D 2 will be conducting that is what it is shown here ok. So, this is for the condition when the pole current is greater than 0. What will happen if I 0 is less than 0?

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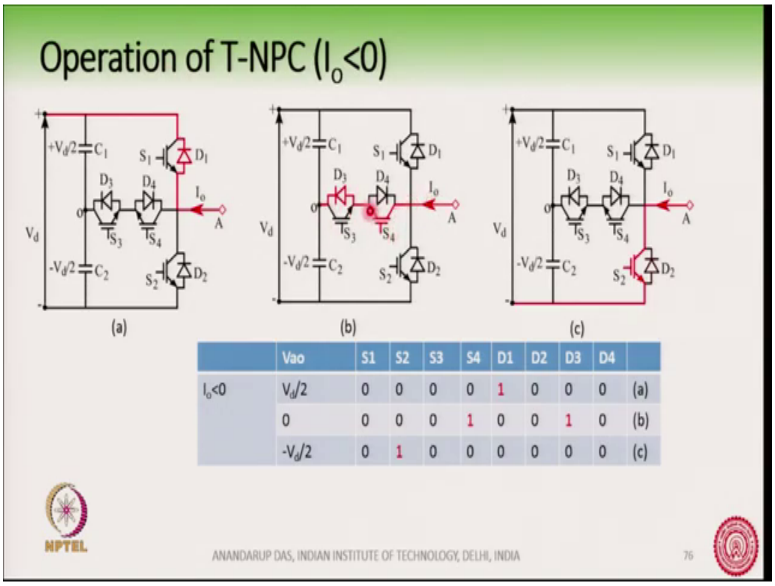


In that case for Vd by 2 voltage the diode D one will be conducting and for the 0 voltage, these S 4 and D 3 will be conducting and for the negative voltage S 2 will be conducting ok. So, these are the different switching states of different configurations of the switch for these 3 states ok.

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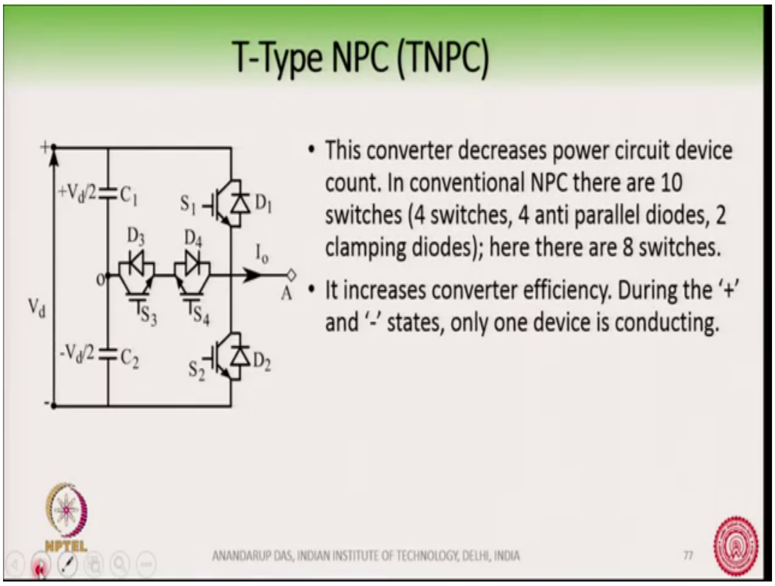


So, therefore, comparing this T type NPC or TNPC, we see that compared to a conventional three level NPC we have less number of switches here. Why? Because in conventional NPC there are 10 switches; there are 4 transistors, 4 anti parallel diodes and 2 clamping diodes right. But in this topology in this TNPC topology, there are 8 switches ok.

Of course, these 8 switches have different voltage ratings, but overall it has been reported that this operation it increases the converter efficiency ok. You can easily understand that, when you have the plus and the minus states, then only one device is conducting in this topology. Whereas, in a 3 level NPC during the plus and minus states 2 switches are conducting. So, therefore, it has been reported that T NPC actually increases the converter efficiency.

We will again not go much in details about the operation of TNPC and interested viewers are requested to see additional reference material.

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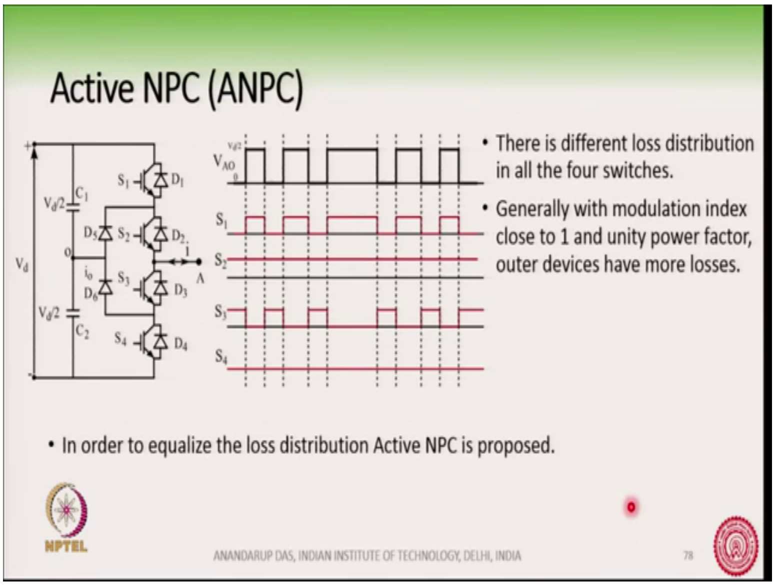


The other NPC which is also somewhat popular is the active NPC. So, active NPC was also proposed in the around 2000 or 2001 may be. So, in active NPC, what happens is we know from our operation of conventional 3 level NPC that there are there is an uneven loss distribution in all these 4 switches.

So, among all these 4 switches there is an uneven loss distribution. The suppose, we are working with modulation index close to one and unity power factor, then we have seen that the outer devices will have more losses ah. Why? Suppose, you can see suppose the VAO voltage is like this and S 1 will be therefore switching like this and S 2 will be fully clamped right. And so, if it is like unity power factor, the current waveform is also very closely following the fundamental of the pole voltage waveform. And so, we see that S 1 has both conduction as well as switching losses, whereas, S 2 have only conduction loss.

So, with a reasonably good switching frequency, S 1 will have more losses. Similarly, S 4 will have more losses. So, in order to so, then what happens is over time the temperature of S 1 and S 4 becomes more than the temperature of S 2 and S 3. So, active NPC was proposed in order to equalize the loss distribution ok.

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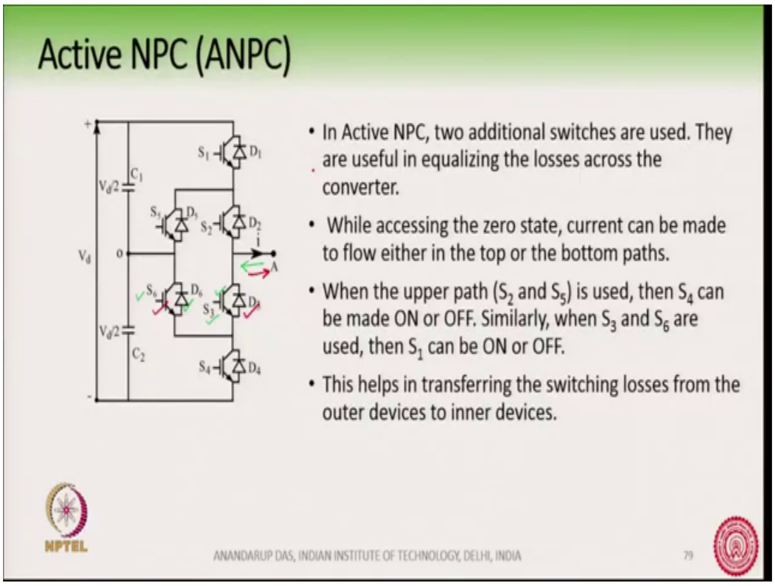


So, what happens in an active NPC? The circuit topology is this side remains the same whereas, here we have 2 switches. Here we have 2 additional switches and these 2 switches are used in equalizing the losses ok. Now again so, here one we thing we observe that, the 0 state the 0 state can be like this combination ah. So, the current can flow through the upper path or current can flow through the lower path for the 0 state ok.

How for example, I want to access the 0 state, I will turn on if I turn on S 2 and S 5 for the 0 state, then if the current is if the current is going out so, the current can flow either through D 5 and S 2 if the current is like this way ok. And if the current is the other way, if the current is the other way that is coming in then D 2 and S 5 it can be conducting ok.

So, if I turn on S 5 and S 2 simultaneously then, I can fully allow the current to flow through the upper path; both positive and negative direction of current can be allowed to flow through the upper path. So, therefore, the entire loss can take place through to the in the upper 2 switches ok. On the other hand, if I turn on S 3 and S 4; S 3 and S 6 for example.

So, let me again rub this off. So, if I if I want the current to flow through the lower path only for the 0 state, then I will turn on S 3 and S 6 ok. So, now, if the current is like this in this way, then S 3 and D 6 will conduct like here. On the other hand, if the current is like this way then S 6 and D 3 will conduct. So, whether the current is positive or negative, I can force the current to flow through this lower path only ok. And I can fully cut off the upper path. So, this is the one of the main differences of NPC and active NPC ok.

I can force the current to go through the upper path or the lower path ok. Now another thing that is done here is that, when the upper path is being used this lower switch S 4 can be made on or off. Similarly, when these 2 switches are turned on, this S 1 can be made on or off.

Why do we do that? Because next time after the 0 state, if I want to switch on the plus state or the minus state then the switching losses can be minimized or I can say the switching losses can be transferred from the upper outer device to the inner devices ok. Now the full analysis and explanation of this again I will not cover in this course and we will put a reference for this one because we do not means the full analysis will take a substantial time.

So, the full analysis of this can be seen in the references the main advantage of using an active NPC is that it is useful in equalizing the losses across the convertor. So, the temperature rise distribution is more uniform across all the switches in active NPC. So, with this, we conclude the discussion on neutral point clamp converter. So, we started with the basic topology of

NPC then we talked about the space vector diagram and then we also talked about carrier based PWM implementation. We also talked about capacitor balancing and we briefly touched upon some other topologies of NPC which you can explore further.