High Power Multilevel Converters - Analysis, Design and Operational Issues
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Lecture - 31
Neutral Point Clamped Converter - Mid-point Voltage Fluctuations

So, we start with another topic on the Neutral Point Clamped Converter which is called the Mid-point balancing or the capacitor voltage balancing of the three level neutral point clamp converter.

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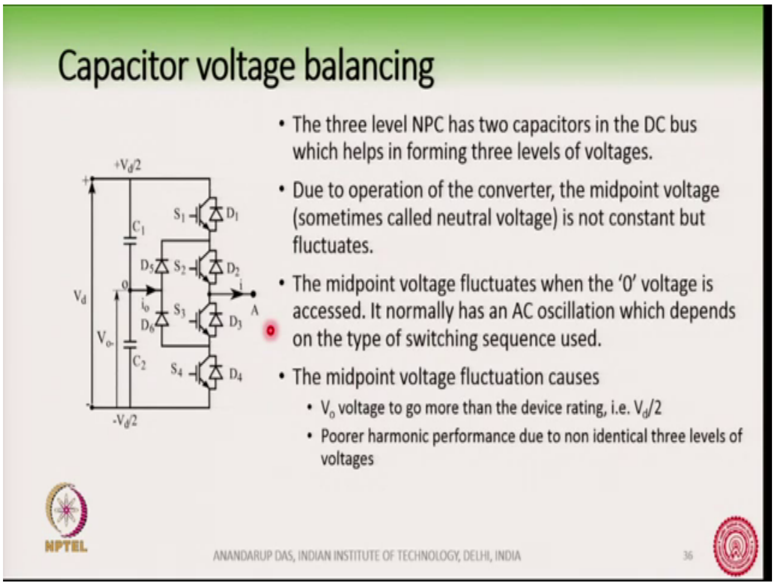

So, this is a topic. So, first we will understand why the midpoint voltage of the NPC fluctuates during the operation of the converter. First we will understand and subsequently we will see two techniques of mitigating this issue. So, the first technique will be kind of, the second technique is a superior technique to the first one and we will see how this works these two techniques work.

Now, this is a subject which has there has been a lot of research on this subject. And you can also find a lot of literature and also it is discussed in several books. So, there are lot of material available. So, let us start what it is. So, if you see here the topology of the three level NPC we find that there are two capacitors which are represent in the DC bus. And the midpoint of this DC midpoint of the two capacitors that is this point o is utilized in this converter.

The midpoint is needed because we would like to have three levels of voltage VAO, should have three levels of voltage V d by 2 this one 0 and minus V d by 2 ok. So, that is why we need this midpoint; however, during the operation of the converter the midpoint voltage the midpoint voltage is also sometimes called the neutral voltage. The neutral voltage or the midpoint voltage is fluctuating it is not constant value we expect the neutral voltage or the midpoint voltage to be perfectly constant, but it will fluctuate due to the operation of the converter and why will it fluctuate?

It will fluctuate you can readily understand from here that, whenever we access the 0 voltage from the converter; that means, whenever we are impressing the 0 voltage at point A with respect to point o. Then we are accessing this midpoint when the when the VAO voltage is V d by 2 then we are kind of like accessing the positive DC bus. When VAO is negative we are accessing the negative of the DC bus.

Whereas, when we are; when we are putting a level of 0 then we are accessing the midpoint ok. And during this condition the current is drawn or current is injected into this midpoint. And that is why there will be a net charge flowing out or in to this midpoint which is the reason why the midpoint voltage will fluctuate. So, normally the we will see over time that there is an AC oscillation on the midpoint voltage ok, which it depends on which type of switching frequency and what is the switching frequency at which we are operating the magnitude of the AC oscillation will vary.

So, if it varies then if the variation is substantial normally the if the variation is very small then we can still go on with the operation of the converter; however, if the midpoint fluctuation is very large or if there is some fault has happened or if there is an unbalanced operation of the converter then this midpoint voltage can substantially deviate from 0 ok. So, far throughout the analysis of the converter so far we had said that the 0 point, the this o point is always at 0 potential, but actually it is not. So, there is a fluctuation.

So, if this fluctuation is very high then what can happen that the it can go more than the device rating. So, see in this converter all the devices are rated for V d by 2 ok; however, if this points voltage. So, the total DC bus voltage is V d. So, this capacitor is V d by 2, this capacitor has a voltage across it V d by 2 and that this capacitor also V d by 2 ok. And under ideal condition when there is no fluctuation in the midpoint voltage; however, if one of the capacitors is charging up; that means, the other capacitor is the voltage across the other capacitor is falling ok. If voltage across one is going up the voltage across the other is falling down given that the total DC bus voltage V d is constant.

So, if that happens whenever we do the switching, the voltage stress on the switches which are off can be more than V d by 2 ok. And if that happens then basically we are crossing the voltage limit or we are crossing the device rating voltage rating of the device right. So, it can be more than V d by 2. We have started our design assuming that all devices these capacity voltages are exactly at V d by 2. And accordingly we will choose our devices of having a voltage rating of V d by 2.

But if this midpoint voltage o fluctuates or goes up or down then the device rating. So, this voltage across the device can be more than the voltage rating of the device. So, that is not a good practice and also if the 0 point of this midpoint voltage is fluctuating. Then the harmonic performance gets degraded because we expect three levels of voltage and these three levels should be distinct and equal plus V d by 2 minus V d by 2. And 0 and those voltage levels V d by 2 should be equal in magnitude then only we get all the symmetries of the waveforms and we get a very good harmonic performance.

However, if the DC bus voltages are unequal then we get poorer harmonic performance, specially lower order harmonics can come into the voltage which is not desirable ok. So, therefore, the midpoint voltage must be kept within a certain limit ok.

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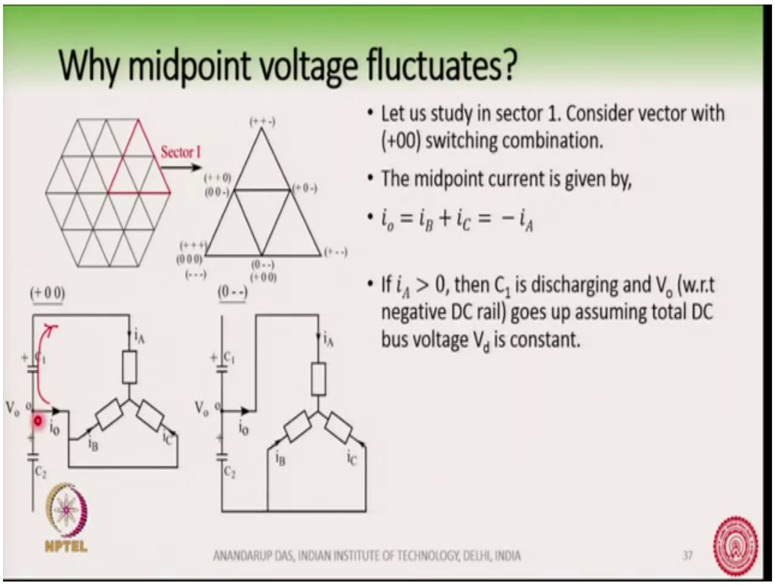

The midpoint voltage fluctuation should be kept with a within a certain limit. So, first we will see why the midpoint voltage fluctuates. In order to understand why the midpoint voltage fluctuates we will analyze sector 1. And in this sector one we will see these switching states and will see what is the effect of these switching states on the current which is drawn from the midpoint. So, let us study the sector 1 and let us first see this vector plus 00 ok. So, sorry this switching combination plus 00 of a one small vector.

So when the switching combination plus 00 is used, this means that the A phase is connected to the positive DC bus. And B and C phases are connected to the midpoint or the zero voltage potential here to the point o here. So, this is the circuit. So, these are the three loads i and where the three currents i A i B i B are flowing and when we are applying plus 00 from the converter. Then this is how the converter circuit looks like assuming all the transistors and the diodes are ideal ok.

So, you see here that the midpoint current i 0. So, this is equal to i B plus i C ok. So, you have plus here coming plus here and 0 and 0. So, this is the switching state. So, the i 0 current is i B plus i C. So, the midpoint current is i B plus i C and if i A plus i B plus and so, it since in this case the load is isolated. So, that i A plus i B plus i C is 0. So, therefore, i 0 is equal to minus i A right.

So, now if i A is greater than 0 for example, at any instant of time where we are applying this plus 00 switching combination for the small vector, at that instant of time if i A is greater than 0. Then what happens then it means that this current i 0 is basically the current is entering into the midpoint because i 0 is equal to minus i A and if i A is greater than 0 it means the current is entering into the midpoint. So, the current is flowing like this here ok.

So, the current is flowing like this the current is flowing like this in the midpoint through the midpoint. So, which means that the capacitor C 1 is discharging, and this points potential the midpoint potential V 0 this points potential with respect to the negative DC bus will go up because the total dc bus V d is assumed to be constant.

So, if C 1 is discharging; that means, the voltage at the point o will go up ok. So, it will go on increasing right.

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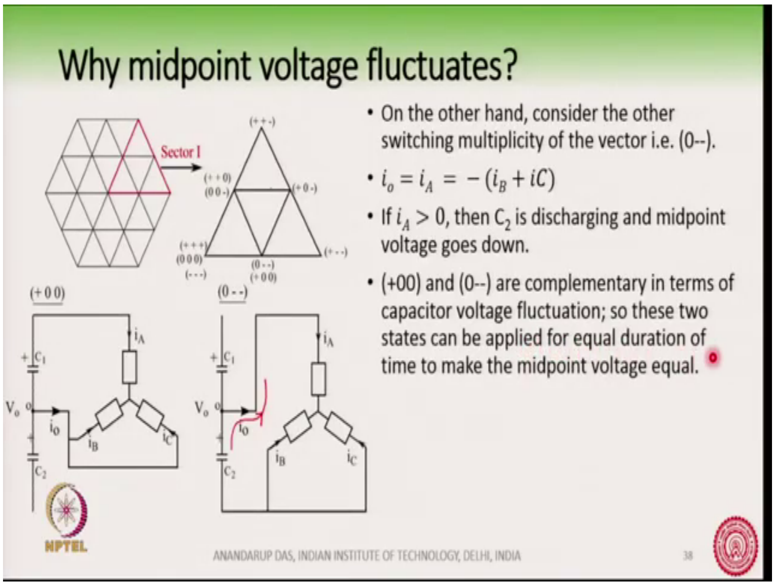

Now, take the other case take the other switching multiplicity. So, you take this 0 minus minus ok. So, we have seen what happens with plus 00 multiplicity. Now, let us see what happens with 0 minus minus. So, 0 minus minus multiplicity or switching means A phase is connected to the midpoint while B and C phases are connected to the negative of the DC bus right.

So in this case i 0 you see i 0 is equal to i A and is equal to minus of i B plus i V like this. Now, if i A is greater than 0 same case as before if i A at that point of time. If i A is greater than 0 then what is happening C 2 is discharging ok. So, if i A is greater than 0 the current is flowing like this the current is flowing like this and hence C 2 is discharging right. And therefore, midpoint voltage will go down assuming the total DC bus voltage is constant right.

So, therefore, we see that for the same value of i A for the same value of i A these plus 0 0 and 0 minus minus that is these two switching multiplicities of the small vector are producing a complimentary effect on the midpoint voltage or on the capacitor voltage. So, in one case the midpoint voltage goes up that is here. So, the midpoint voltage is going up and in the other case the midpoint voltage is going down ok.

So, if we apply these two small vectors in such a way in a switching cycle. So, that they are of equal duration. So, then we can ensure that due to this vector with two multiplicities the midpoint voltage can be made almost the midpoint voltage fluctuation can be made almost equal to 0 ok. These two states can be applied for equal duration of time to make the midpoint voltage equal or midpoint voltage fluctuations to be 0 ok.

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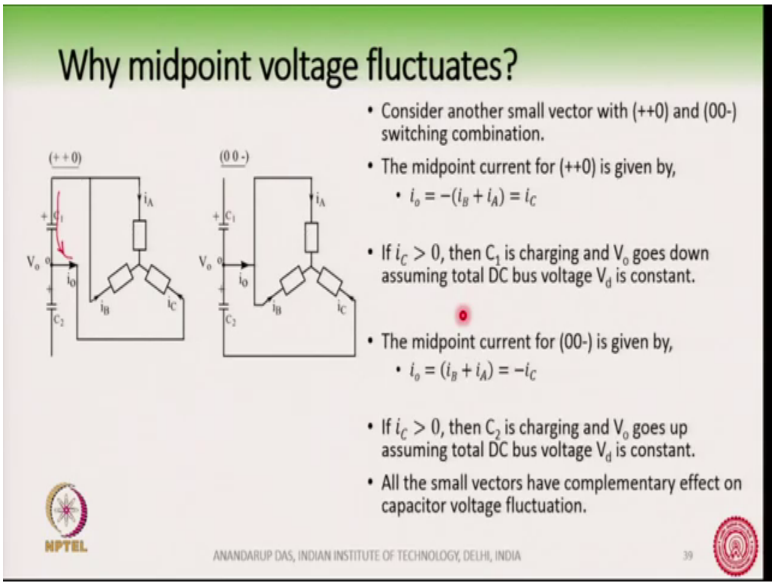

So, this will happen for this small vector here, let us consider another small vector with plus plus 0 and 0 0 minus combination, I mean that this vector here plus plus 0 and 0 0 minus this vector. So, let us see what it is what is the effect of this vector with these two switching multiplicities on the midpoint voltage?

So, for plus plus 0 combination how is the circuit looking like? So, which means plus plus 0 means A and B both are connected to the positive DC bus whereas, 0 means the C phase is connected to the midpoint ok. So, this is the circuit here right. And the i naught current the i naught current is equal to i C, which will be equal to minus of i B plus i A right.

So, therefore, during if I apply this vector here if I apply this switching state and if i C is greater than 0. Then the we see that the current will flow like this here which will cause C 1 to charge up enhance if the total DC bus voltage is constant then the midpoint voltage will go down right.

On the other hand let us take the other multiplicity 0 0 minus that state, in 0 0 minus A and B phases are connected to the 0 point, while C is connected to the minus point. So, if again we assume that we have the same value of i C. So, then the midpoint current for 0 0 minus is minus i C you can see here i 0 is i A plus i B and is equal to minus of i C right.

So, if this happens then V 0 or the midpoint voltage is going to go up. So, here also for this small vector also we see that these two switching multiplicities have complimentary effect on the fluctuation of the midpoint voltage ok. So, in general we can say that all small vectors which have two multiplicities they have a complimentary effect on the midpoint voltage.

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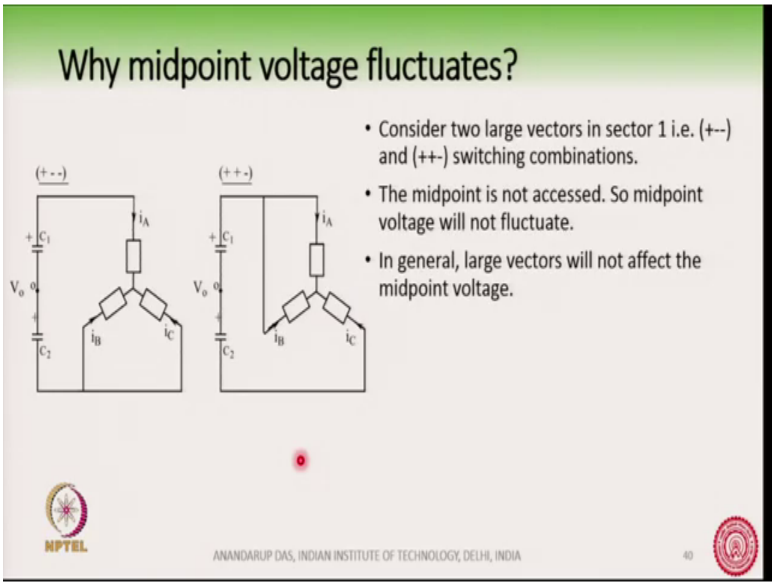

Now, let us see the large vectors ok. So, there are in that sector there are two large vectors plus minus minus and plus plus minus ok. When you apply any large vector then the midpoint is not accessed, see you can take the example of this plus minus minus for example. So, then you have plus minus minus means A phase is connected to the positive of the dc bus while B and C phases are connected to the negative of the DC bus right. So, you see here in this switching combination the midpoint is not accessed. So, there will be no fluctuation of the midpoint voltage wherever it was there wherever it was the wherever the voltage level was it will remain there only.

So, this is the plus minus minus a circuit. Similarly, if you take this plus plus minus circuit you will see that the midpoint voltage is again not accessed. So, we say that in general large vectors will not affect the midpoint voltage.

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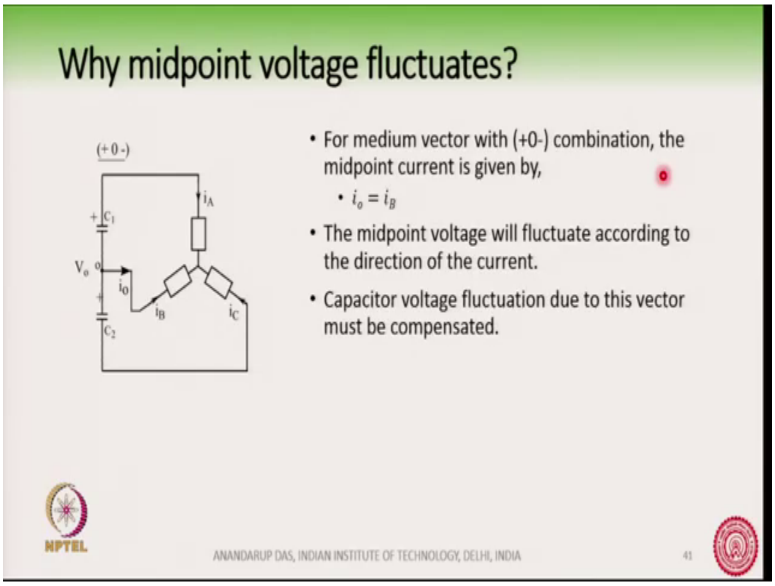

What will happen with the medium vectors ok. So, let us take this plus 0 minus combination the medium vector which is this one on the space vector diagram this one this is the medium vector so, plus 0 minus. So, what is its effect on the midpoint voltage.

So, with plus 0 minus we see that there is a 0 accessed here. So, of course, this means that there will be a fluctuation and the circuit here plus 0 minus means the plus means A phase is connected here, B is connected to 0 and C phase is connected to minus and so, the midpoint current is given by the phase current B and so, whatever is the magnitude and direction of the B phase current the midpoint voltage will fluctuate accordingly ok.

Now, the middle vector or the medium vector you see here there is no multiplicity on the medium vector and so, if this medium vector is used ok. So, it will cause some fluctuation in the midpoint voltage or the capacitor voltage; however, it cannot. So, it must be compensated, but there is no multiplicity on this vector unlike the small vectors.

So, this midpoint. So, this medium vector is something which must be taken care of because it will cause a voltage to fluctuate, but in that sector suppose in sector one there is no one to compensate that ok. So, there is no there is no switching state which can compensate the effect of the middle vector or the medium vector. So, it must be done some done through some other technique which we will see.

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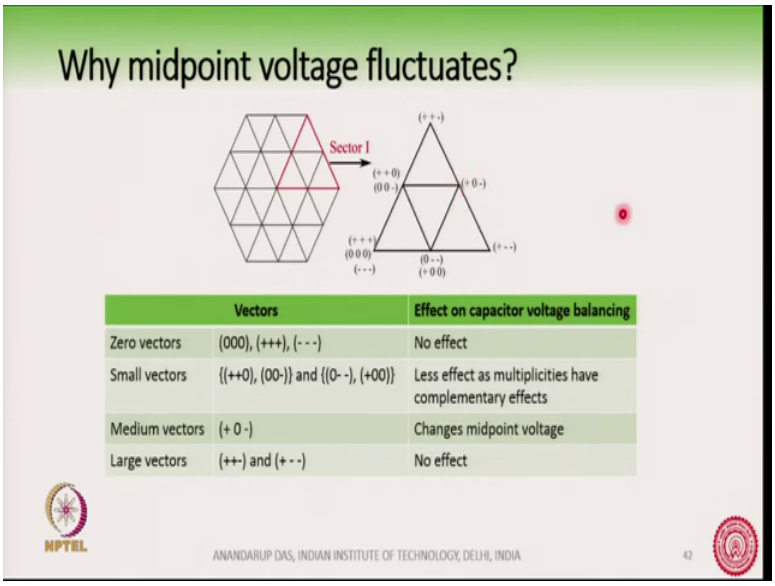

So, summarizing this whole thing what happens in sector 1, we see that the zero vectors of course, the zero vectors will have no effect on the midpoint voltage ok. The small vectors will have some effect, but the good thing is this small vectors have multiplicities which if we can; if we can cleverly use these multiplicities for equal duration then it is possible to compensate the fluctuation in the midpoint voltage.

The problematic one is the medium vector because it changes the midpoint voltage, but there is no vector because it has no multiplicity. So, it must be compensated. So, the midpoint voltage must be compensated by some other means which we will see and large vectors have no effect on the midpoint voltage.

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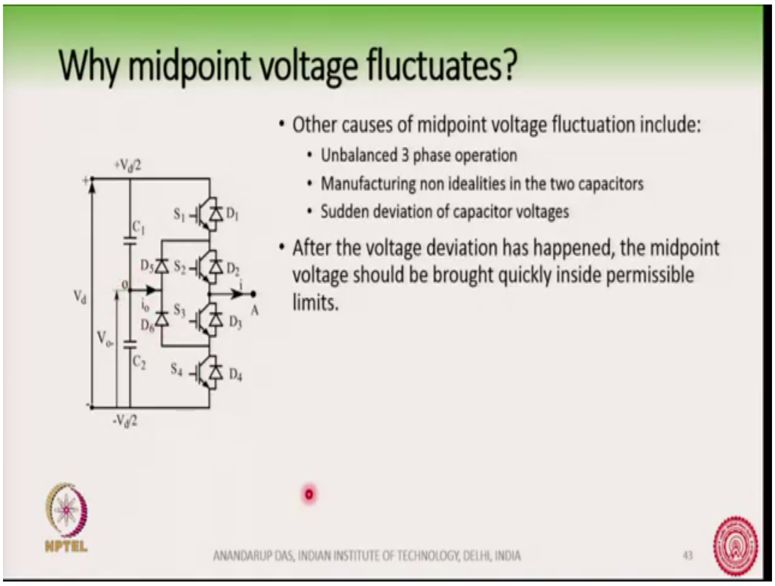

So, now so, apart from that. So, we have to develop some switching strategies to compensate the midpoint voltage fluctuation. So, there are many reasons of a midpoint voltage fluctuation one I we saw that if we choose the switching states then with the multiplicities. Then it causes the midpoint voltage to fluctuate as we had just explained, but unbalanced operation unbalanced 3 phase operation can also cause. And there maybe also capacitor manufacturing tolerances non ideal it is in the capacitor or there may be also certain sudden deviation of capacitor voltage due to some unforeseen circumstances.

So, if those things happen then the midpoint voltage will suddenly it may go away from the 0 potential which we had throughout assumed ok. If that voltage deviation happens then the midpoint voltage should be brought quickly inside a permissible limit or near to the 0 level again it there may be a small fluctuation say 2 to 5 percent is ok, but there should not be a large deviation of point of this voltage at this point away from what we have assumed to be 0 potential. So, we will now see some of the techniques to balance the midpoint voltage.