High Power Multilevel Converters - Analysis, Design and Operational Issues
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Lecture - 32
Neutral Point Clamped Converter - Capacitor Voltage Balancing

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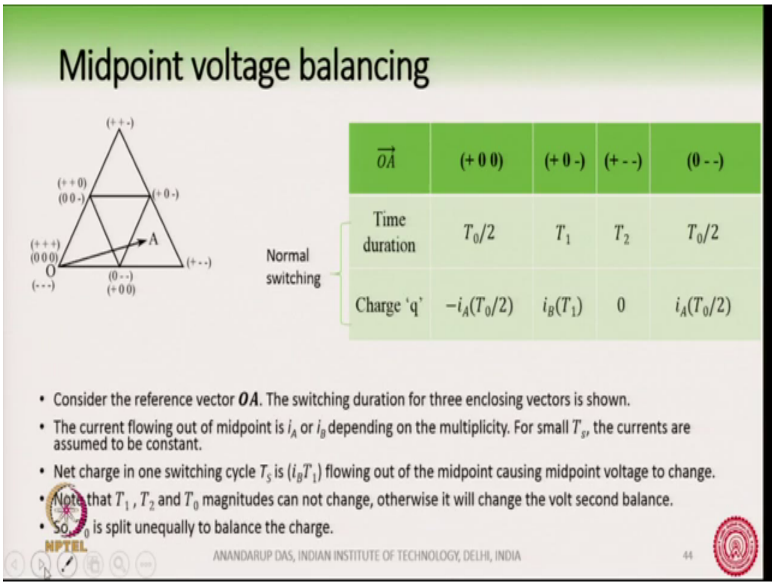

So, now we will see at one technique of midpoint voltage balancing ok. Now one thing that I will have to say here is why are we so much concerned, why there is has been so much research on this midpoint voltage fluctuation. If we can get a very good PWM strategy or the switching strategy by which we can make the midpoint voltage fluctuations very small, then automatically it means that the capacitor size will go on reducing right.

So, because you can see here that we are when the midpoint is accessed, then a certain charge is being either taken out or inserted into the midpoint. Because the i 0 current is flowing, if you apply for a certain duration of time the 0 vector; the 0 this whenever the i 0 is applied. Then that amount of charge is either taken from the midpoint or inserted into the midpoint.

So, there it will cause a fluctuation. So, the certain charge is taken. So, therefore, if you increase the size of the capacitor, the fluctuation in the voltage can be minimized. So, but on the other hand; if you can make sure by PWM that net charge over one switching cycle is made 0 in a very small duration of time, then the size of the capacitors on the DC bus can go smaller and smaller which is very much advantageous because capacitors are bulky in size. So, therefore, a clever technique of balancing the midpoint voltage not only improves the harmonics and not only makes that no devices are subjected to a voltage of vd by more than vd by 2, but it also ensures that the size of capacitors are small.

Remember that in MMC, which we had a studied earlier. The in MMC; the size of the capacitor is much more than that of an N P C. Maybe 3 4 or maybe 6 7 times ok. The reason why N P C has lesser capacitance is because, we have multiplicities in the switching states ok. This ensures that the net charge which is flowing in or out of the capacitor. First of all the net the N P C has a single dc link for the three phases ok. That is one reason which the MMC does not have ok. The MMC cells have capacitors which are like a single phase supplying.

So, the MMC has a current which can help in getting the capacitors back its charge only after half a cycle has crossed. But this is not the case with NPC. In NPC, we have different switching multiplicities which can ensure that the voltage which can ensure that the charge taken out of the midpoint is quickly restored or the fluctuations can be minimized.

So, this is the difference between MMC and NPC where NPC has a much smaller capacitor as compared to MMC. MMC does not have this option, MMC has to kind of like design the capacitors in such a way, it is a big capacitor because you take the charge from the capacitor in one half cycle and you can give it back only in the next half cycle.

So, it has to hold the voltage for half is fundamental cycle. In fact, for that reason; if the fundamental cycle is very big, if the time period is very big for example, in motor drive application going to lower speed 0 means; 5 hertz 0 hertz close to that speed then this half cycle is very big in time. So, the capacitors have to hold the voltage which is not the case with n NPC because we have multiplicities.

And also NPC has a single DC link for the 3 phases which the MMC does not have. So, let us now come back to what we were discussing and we will now see how we can make the midpoint voltage fluctuation minimum using some clever PWM techniques.

So, consider this reference vector O A. So, for this reference vector O A, the switching; so, these are the three enclosing vectors. So, their timings which I have written here in this table so, plus 0 0, plus 0 minus and plus minus and 0 0 minus; these four will be used right. And their timing duration for example is like this, T 0 by 2, T 1, T 2 and T 0 by 2 ok.

Now suppose, the total sampling time or the total switching cycle Ts is which is equal to T 0 by 2, plus T 1 plus T 2 plus T 0 by 2 that is sufficiently small ok. So, we have quite a high switching frequency. So, that the T s period is so small that the magnitudes of these currents do not change in that switching cycle.

Now net charge in the one switching cycle T s is i B into T 1, why? Because when we apply this plus 0 0, the timing duration is T 0 by 2 and we have just seen that the current which is flowing out of the midpoint is minus i A. So, the next charge which is going out of the midpoint is minus i A into T 0 by 2. Similarly for T 1 duration; we access the medium vector plus 0 minus and the midpoint current is i B.

So, i B into T 1 is the net charge which is taken out of the midpoint. When we access the large vector, the midpoint is not accessed. So, we do not so that so, this is 0 and then when we have the complementary state 0 minus minus, we have i A into T 0 by 2 as the net charge which is flowing out of the midpoint.

So, if you add all this in one switching cycle T s this and this will cancel, this this term and this term will cancel, so that the net charge which is flowing out of the midpoint will be equal to i B times T 1 right. This is what is going to cause the fluctuation in the midpoint voltage. Now we would like to make this equal to 0 ok. We do not want the midpoint voltage. So, we want the midpoint voltage to be the fluctuation to be equal to 0 in one switching cycle T s ok. So, we want to do that. So, how can we do that? Note that we the 1 which the technique that we will use is this T 0 by 2 right.

So, we have two vectors of equal of equal magnitude this plus 0 0 and 0 minus minus, they are producing the same vector ok. And their timing durations are T 0 by 2 and T 0 by 2. If we change these timing durations to a value which is not equal to T 0 by 2; for example, we this is 0.5 T 0, suppose we make this as 0.4 T 0 and we make this as 0.6 T 0. So, that the sum of these two is equal to T 0 ok, but we change this to 0.4 T 0 and this to 0.6 T 0.

If we do that, then the impact of this 2 currents will be such that there will be a net contribution from this term and this term here which we will make sure that will nullify the effect from this i B into T 1 ok. If we can do that, then the midpoint voltage fluctuation over this T s time period will be equal to 0 ok.

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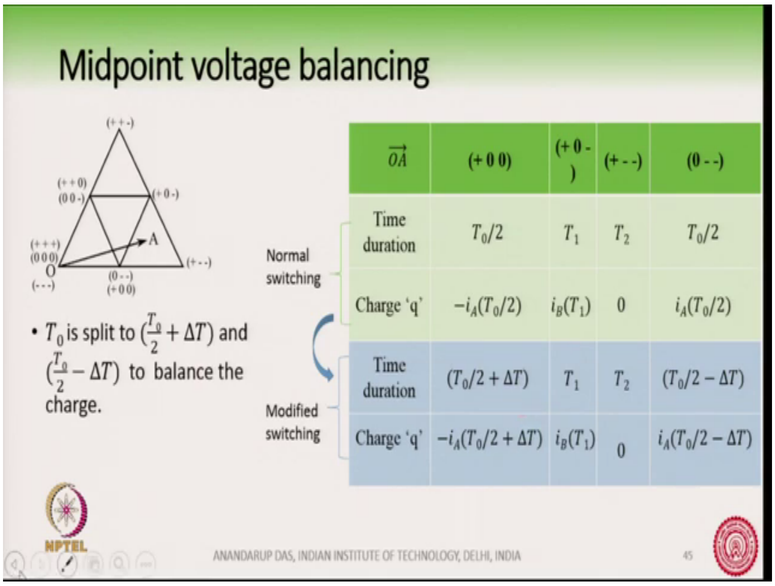

So, this is shown in the next cycle next table here ok, but first we I would like to say that. So, this means that what we are doing here is T 0 by 2 and T 0 by 2 instead of having equal T 0 by 2, we will make these two these two multiplicities or these two switching multiplicities to be not equal to T 0 by 2, something other than T 0 by 2. So, that the effect from i B into T 1, the net charge which we can make it we will try to cancel the effect of i B into T 1.

But you should remember that this is possible because T 0 by 2, tweaking this T 0 by 2 is possible because these two vectors are identical vectors ok. Remember, we cannot violate the volt second balance ok. This is very important because otherwise see we are trying to, we are trying to generate the reference vector O A.

Suppose, I change this vector or this vector here ok. This vector can be changed anyway. If I change this vector, then I am going to change the volt second balance; at all points of time, I have to ensure that the volt second balance must be maintained. So that, that means; volt second balance means the weightages of these three, the weightages of these three must be properly assigned. So, that we come up to this point A. That is the primary objective and it can never be violated.

But here the, what is the degree of freedom we have? 1 degree of freedom that we have is. We are using this vector 2 times and now we are saying that ok. We will use these vector 2 times, but of unequal duration, that is the T 0 by 2 and not T 0 by 2 something other than T 0 by 2 for this 2 times here.

If you do that then we will not violate and some of this T 0. So, if this is 0.4 T 0 and this is 0.6 T 0, you see I have not violated the total T 0 time. So0 that means; I have not violated the volt second balance ok. So, this must be kept in mind.

So, how do we do this is shown in this one. So, here we see that T 0 is split into T 0 by 2 plus delta and T 0 by 2 minus delta to balance the charge ok. So, what I am I doing? You see here the earlier that there was T 0 by 2 here and T 0 by 2 here. Now I am saying that let us make it T 0 by 2 plus delta and make this one T 0 by 2 minus delta ok. Make this will ensure that the sum here of the total sum of times is equal to T s as before ok. Only this degree of freedom we have utilized.

So, if the we change to T 0 by 2 plus delta, then the net charge which is flowing out of the midpoint is minus i A times T 0 by 2 plus delta and with the 0 minus minus, we have seen that the net midpoint current is plus i A. So, this is the charge which is flowing out of the midpoint ok; after we change T 0 by 2 to T 0 by 2 plus delta and T 0 by 2 minus delta.

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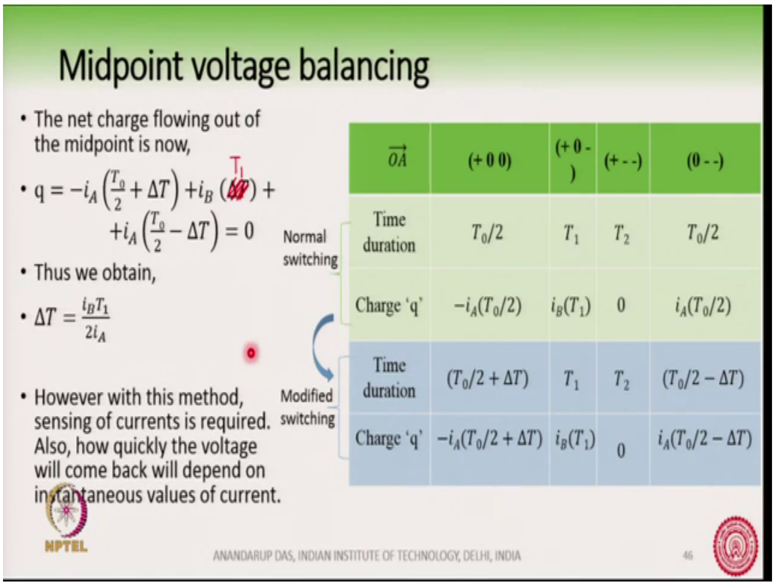

So, now we can equate. So, what we can equate? The net charge flowing out of the midpoint q is minus i A, T 0 by 2 plus delta. This is for the plus 0 0 duration here. For the plus 0 minus duration, we have i B into delta T this one coming.

For this duration there is no fluctuation so, we can ignore that one and then for 0 minus minus; we have i A current flowing for a duration of T 0 by 2 minus delta and this must be made equal to 0. So, that the net midpoint voltage fluctuation or the net charge which is flowing out of the midpoint over this time period T s is made equal to 0 ok. So, that is why we make it equal to 0.

So, therefore, if we quit this we will immediately find out what is the value of delta T needed. So, how much should be the delta T? How much the plus 0 0 and 0 minus minus should be change? How much delta T or how much time duration away from T 0 by 2 we should include in this switching states is given by this formula ok.

So, this is one way of ensuring that the this is one way of ensuring that the net charge is coming out to be 0 over a switching cycle T s ok. So, we add some delta T to this plus 0 0 state and we subtract the same time delta T from the 0 minus minus state. And the value of delta T will be equal to so much here. Yeah Sorry, there is a small mistake here which we should see here this is i B into T 1 ok. So, there is a small mistake here ok. i B into T 1, fine.

So, this is one strategy of making sure that the charges is equal to 0. However, although this is an attractive strategy, but we see that with this technique; we with this technique, the problem is we have to sense the currents. We have to always know what is i B and i A values ok. This is not a very big challenge because in any case for the converter, we always sense the output currents, i A, i B, i C for example, it is going to a motor drive. We always sense these currents yeah and if we can ensure that we know that i A plus i B plus i C is equal to 0, then this is not a very big challenge.

However, once the another challenge becomes that once suppose for some unforeseen circumstance, the midpoint voltage has fluctuate or deviated. How fast it will come back? Will of course, now depend on these instantaneous values of these quantities ok. So, this is 1 so, we have to depend on the instantaneous ratios of i B and i, i A. In order to see how quickly we can get the voltages back on track ok. So, this is one another kind of like limitation of this technique.

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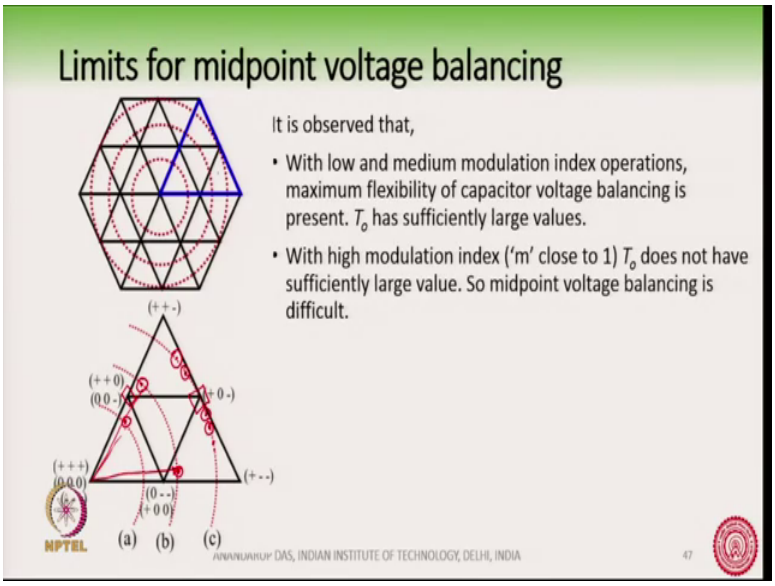

There is also one more limitation of this technique. And this can be understood from this space vector diagram. So, here you see that so, this is the space overall space vector diagram and I am drawing the 3 reference vectors means for different modulation index. So, this is like a for small modulation index, this is for medium modulation index and this is for large modulation index; the 3 reference vectors ok.

So, this is like for the small one. So, this is a small voltage that needs to be produced and for the medium one like more voltage and for the higher one the maximum voltage from the converter. Now you see the technique of this technique here relies means relies on one important factor and that factor is; we have sufficient amount of T 0 by 2 or to play around with the delta T ok. So, if we have sufficient amount of delta T available where we can play around.

So, this is basically this delta T and this delta T, we can apply if we have a sufficient amount of margin available. That means, T 0 by 2 and this T 0 by 2 should be quite good chunk of the total time period T s. But and this will be happening when the reference vector is close to these this vector. Suppose the reference vector is here ok, then it is very close to this vector here. So, this means that the T 0 time duration for this vector will be very large and there we have the chance to play around with the delta T ok.

This will also happen say for example, if my vector is here vector is here or vector is here, then this vector if the reference vectors are here. If I my reference vector is here or here then this vector here which is of duration T 0, this vector has a big chunk of the total time T s. And so, we can play around with the delta T ok so, that the capacitor voltages can be nicely balanced out. However, the there is one problem here. If the reference vector is very large; what happens then? Suppose, the reference vector is here or here ok.

Then you see that the weightage of this vector, this medium vector is maximum because the medium these reference vectors are very close to the medium vector here or the middle vector. So, this unfortunately this plus 0 minus, we have applied T 1 time period and so, that delta T, the T 0 time periods are small. And the delta T time is also small ok. So, that manipulation of delta T will also be small.

So, therefore, if the modulation index is very high, then unfortunately this technique has limitation ok. This technique the T 0, so when we are here when our reference vector is moving on this here, then there is not sufficient magnitude of T 0 and so, midpoint voltage balancing will be quite difficult.

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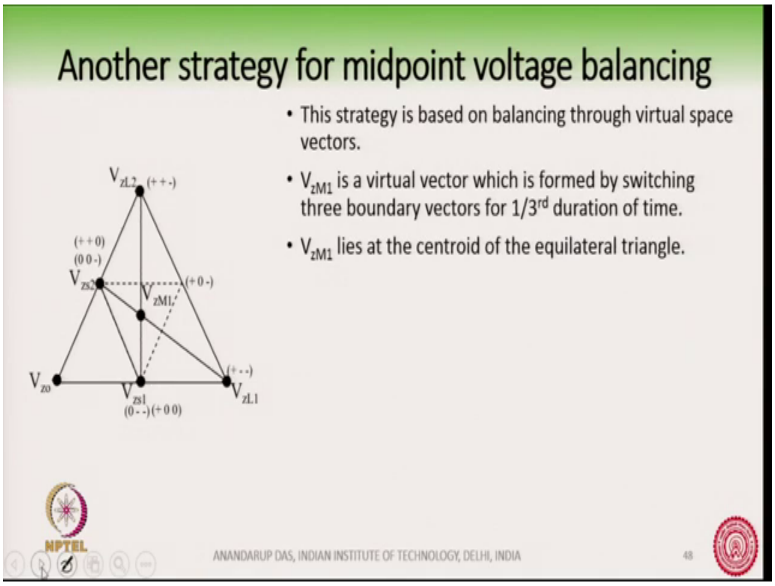

So, that is why people have gone for another strategy ok. This is for the midpoint voltage balancing using a virtual vector. So, we have seen one technique we have just seen one technique which has certain limitations in particular at the high modulation index. Now we will see a second strategy which has been called the use which uses the virtual space vector concept. It came in I triple E power electronics later probably in 2004. This is a very interesting technique which we will see for balancing the neutral point voltage.