High Power Multilevel Converters - Analysis, Design and Operational Issues
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Lecture – 30
NPC- Sinusoidal PWM and Space Vector PWM using Single Carrier Strategy

So, hello and welcome to another session of Neutral Point Clamp converter. In today's session we will talk about the Sinusoidal and Space Vector PWM strategies for switching this converter ok.

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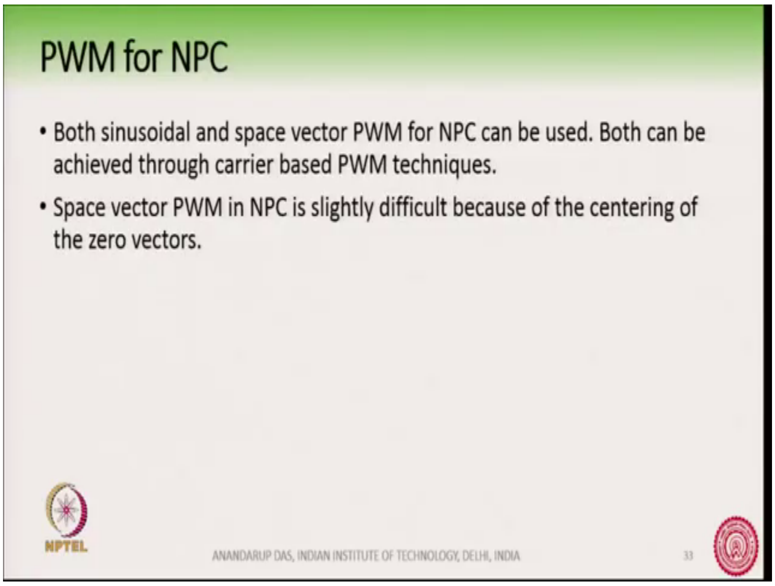

So, we look into now into the PWM or Pulse Width Modulation strategies for neutral point clamped converter specifically 3 level NPC. Now, for switching NPC we can use both sinusoidal as well as space vector PWM can be used both of them; and both of them can be achieved through carrier based PWM techniques ok. And in this case the space vector PWM in NPC is slightly difficult because of the centering of the zero vectors and for this we will see a strategy which we will see and we will elaborate in this session.

Now, we before I go here we I would like you to recollect that timing based calculations for space vector PWM or sinusoidal PWM with NPC is also possible. However, carrier based PWM technique is much easier to implement and we will only concentrate on carrier based PWM technique in this lecture. So, if you want to see the timing based PWM strategy you can refer to; you can refer to an earlier slide.

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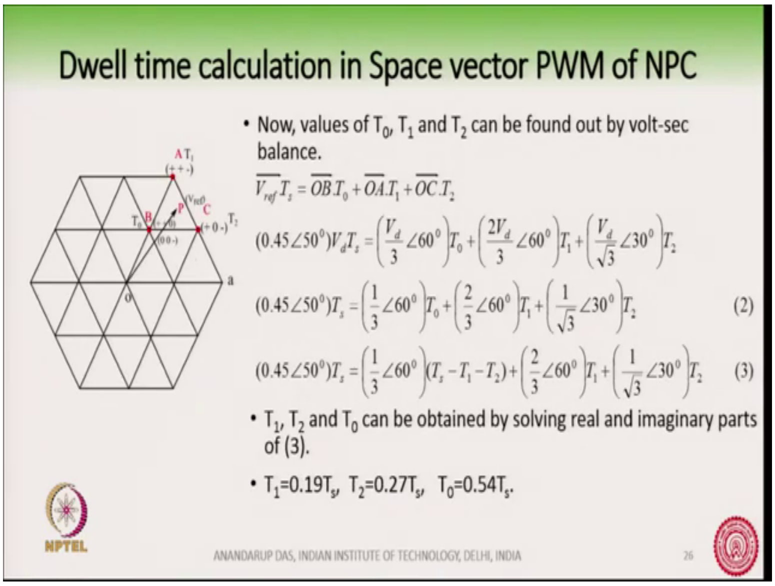

Where we had talked about that T 1, T 2 and T this slide you can refer to this slide and can find out how we can calculate the timings for the 3 nearest vectors. As you can see this requires a lot of calculations this requires a lot of calculations and this can be simplified much by using carrier based PWM technique ok.

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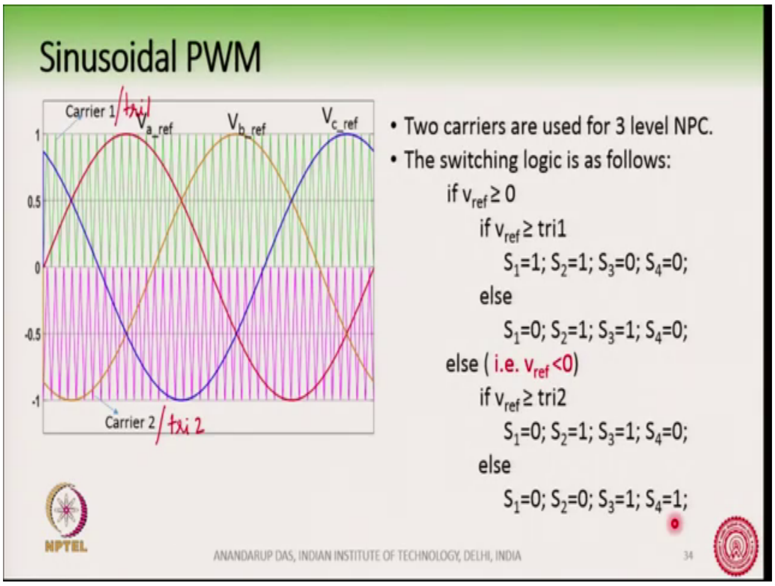

So, this is what we will see now. So, at first we will see the sinusoidal PWM strategy we will see the sinusoidal PWM strategy and then we will see the space vector PWM strategy. Now in sinusoidal PWM strategy for a 3 level NPC we see that we have a sinusoidal or we have 3 sets of sinusoidal modulating wave forms and carriers ok.

Now, both level sheet PWM and phase shift PWM can also be used in NPC; 3 level NPC since, it is a multi-level converter both these techniques can be used. However, the phase shift PWM is means the level shift PWM gives slightly better harmonic performance as compared to phase shift PWM. Because, sometimes in phase shift PWM the 0 magnitude vector is sometimes switched, for certain modulation index and that is why we will focus on the level shift PWM here ok.

So, you can see here in this diagram that there are 2 carriers being used one with a green carrier and one is a pink carrier and these are used for the 2 because of the 2 levels; because of the 3 levels present in the NPC. So, what is the switching logic in this in this one? So, if I name the switches from top to bottom as S 1, S 2, S 3, S 4 we see that if the reference waveform.

So, if so, the reference that there are 3 reference waveforms 3 are sinusoidal reference waveforms. If any of the reference waveform is greater than 0, so, we follow this logic here and when the reference waveform is less than 0 we follow this logic here ok.

So, if V ref is greater than equal to triangle 1. So, then we see that S 1 is 1, S 2 is 1, S 3 is 0 and S 4 is 0 ok. So, this means that in when V ref is greater than 0; that means, suppose you take the a phase reference then we are here ok. So, if this is greater than 0 and then if the same reference is greater than triangle 1; that means, this is the triangle 1 ok. So, we have written it carrier 1.

So, I can also write it as here instead of carrier 1, I can write it as triangle 1 and here I can write it as triangle 2 ok. So, if I have in this one if V ref is greater than 0 and if V ref is greater than triangle 1. So, that means for example in this region in this region here then I will switch on these the switches 4 switches in this fashion ok.

Note that here S 1 and S 3 are complementary and S 2 and S 4 are complementary else. So, the there comes the else logic. So, I have written this logic in as if like in a C code, but I mean in depends on the implementation how you will write this logic. So, we I have like written it in a like a c code. So, if V ref is greater than triangle 1.

So, S 1 is 1, S 2 1, S 3 equal to 0 and S 4 equal to 0. Otherwise, what happens S 1 is 0, S 2 1, S 3 1, S 4 0 ok. So, this means if I am suppose here that is when the red or the V a ref is less than the green triangle then this condition will happen here.

So, when the V ref is less than 0 that is when in during this part of the waveform we come to this section of the code. So, if V ref is greater than triangle 2. So, if V ref is greater than triangle 2 that is this area here V ref is greater than triangle 2 in that case this is the logic otherwise this is the logic ok.

So, if we follow this logic here then we can switch the 4 switches in sine PWM of 3 level NPC right.

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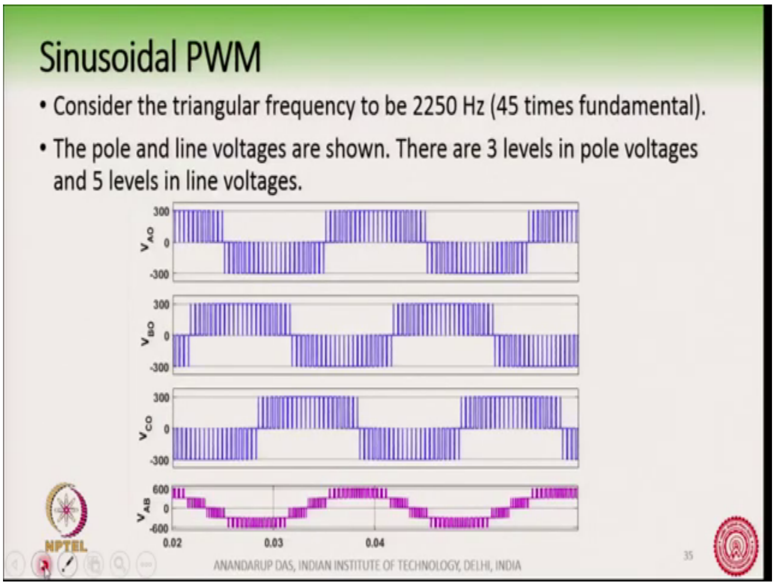

So, suppose if the triangular frequency is 2250 Hertz that is 45 times the fundamental where the fundamental frequency is taken as 50 Hertz ok. So, here we see the pole voltage and the line voltage waveforms based on the logic which we had just described in the last slide ok.

So, if I follow this. So, there are now 2 triangles the green and the pink triangles both are level shifted by means there is 1 upper triangle where is 1 lower triangle both having this frequency 2250 Hertz. So, we have switched this converter and the DC bus has been taken as 600 volts.

So, there are 3 levels of voltages 0, plus 300 and minus 300 ok. So, V Ao is switching like this, V Bo like this, and V cCo like this and. So, we get a V Ab voltage like this there is a line voltage. So, the pole voltage that is V Ao, V Bo, V Co these are having 3 levels whereas, there are 5 levels in the line voltage.

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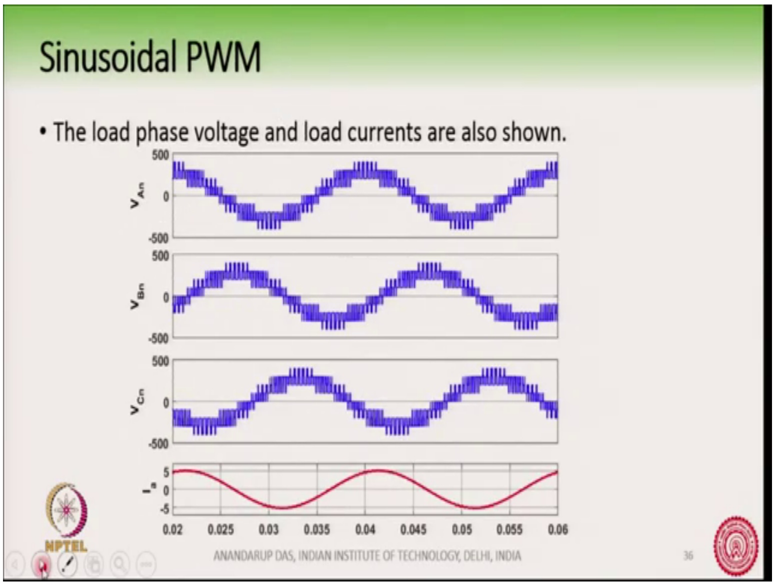

And the load phase voltage and the load currents are as shown here ok. So, this is the load current we had taken a I means an inductive RL load with a power factor close to unity like 0.9 or something close to that ok.

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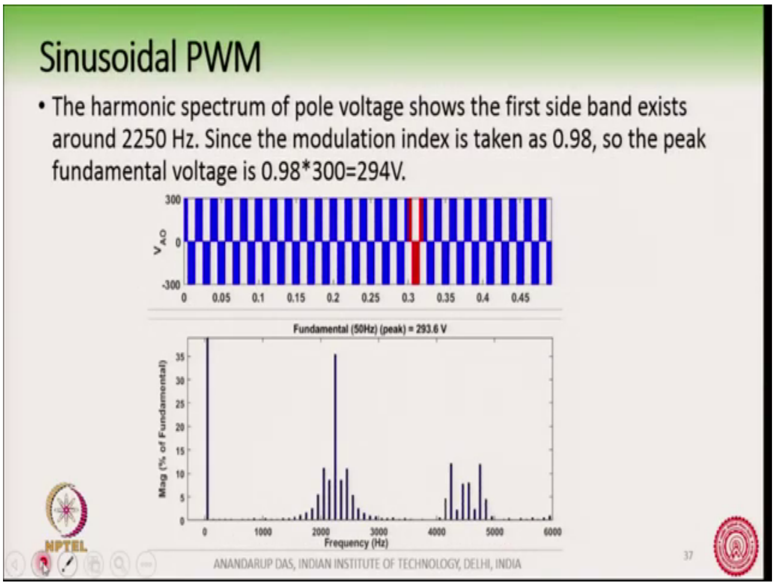

Now, if you do the harmonic analysis of the whole voltage. So, it shows that you see here the first band of harmonics reside around this 2250 Hertz ok. Which is 45 times the fundamental and this is what is expected ok. So, the harmonics are residing around the carrier frequency. Whereas, the second band exists around 4500 Hertz and third band will reside around 6750 Hertz and so on ok.

So, the modulation index here was taken as 0.98. So, the peak fundamental voltage is 0.98 times Vd by 2 that is 294 volts ok. This much of voltage is possible with a 600 volt DC bus and, but in this case the all the switches are rated for Vd by 2 that is 300 volts ok. Now, the note that I will we will note that this harmonics are exist around 2250 Hertz which we will now see a comparison ok.

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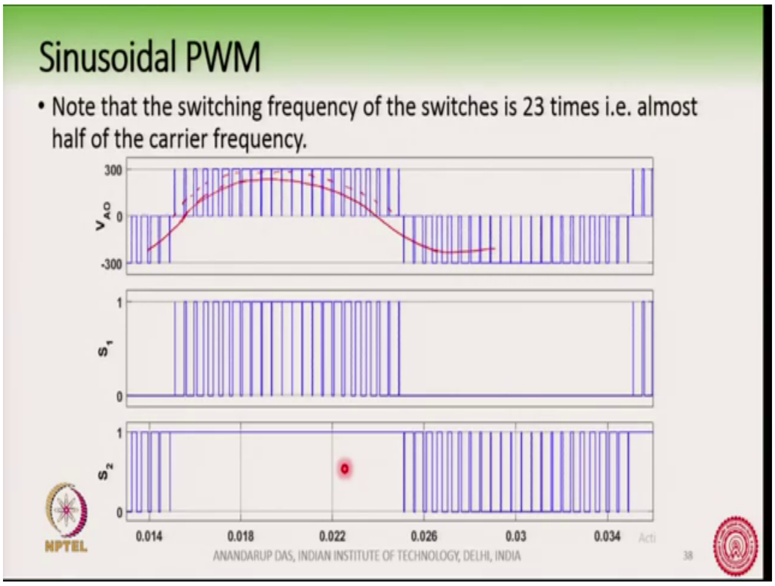

Now, here this waveform shows the V Ao voltage as well as the upper 2 switches S 1 and S 2 the pulse pattern given to this the gate pulse for S 1 and S 2 are given here ok. Now, in this case you see there is a change of pattern of the 2 switches S 1 and S 2, first let us observe how many times S 1 is switching in a cycle.

So, this is like this is the start of the cycle and this is the end of the cycle the sine wave is here; the sine wave is here, this is the start of the cycle and this is the end of the cycle. So, within the cycle as we have said that the carrier there are 45 number of carriers within this cycle. So, let us see how many times S 1 is switching.

So, we can count it. So, this is. So, when do we say that one switching when it goes from 0 goes to 1 and comes back to 0. So, from 0 to another 0 is 1 switching fine. So, we can count from there.

So, we can start from here 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23 ok. So, we see that this in this cycle in this one fundamental cycle the switch S 1 is given a pulse; given a gate pulse which is turning on and off 23 times. So, this switch will be turning on and off 23 times ok.

So, the switching frequency of this particular switch is almost half the carrier frequency ok. So, this is where you see the difference comes in between a conventional v si and the 3 level NPC. In a conventional v si if the carrier frequency was 45 times the switches all the switches would have switched also at 45 times.

But here the carrier frequencies as 45 times; however, the switch the switch S 1 for example, is switching only 23 times that is half. So, this is the advantage that we have a switch the rating of switch S 1 voltage rating of switch S 1 is half the DC link and it is also switching at almost half the carrier frequency right.

So, this you see the advantage of S 1. Now, similarly we will also see that S 2 will be almost switching that is 23 times around 23 times that is half the carrier frequency. However, note that there is a difference of pattern of S 1 and S 2 in case of S 1 you see that S 1 is off here S 1 is also off here and in between the S 1 is turning on and off several times here.

On the other hand you see S 2 is off throughout this period why it is sorry. S 2 is on throughout this period and then it is doing a lot of switching in this portion. Now, why should S 2 be on here? It S 2 should be on because we are trying to produce the plus level here ok. In order to produce the plus level S 1 and S 2 should both of them should be turned on at the same time in order to produce the plus level whereas, for the 0 level S 1 should be turned off and S 2 should be turned on.

So, we see that the different patterns of switching exists in switches S 1 and S 2 and this will create different switching and conduction losses in these devices ok. So, if you see here for example, S 1 see because V Ao is between 0 and v d by 2 here and then it is 0 and minus v d by 2 here.

So, S 1 is switching in this position throughout this time S 1 is switching while, S 2 is fully turned on because we are taking the plus level here right plus 0. So, when we are using the plus we have to turn on both S 1 and S 2. So, that is what is happening S 1 is switching continuously while S 2 is fully turned on ok.

Whereas, in this section you see when we are accessing the minus level then S 1 is fully turned off because we will not need S 1, but S 2 will be given pulses here. So, the pulse pattern of S 1 and S 2 are completely different in one fundamental cycle ok. Now, suppose the current we have a very high modulation index which is most likely to happen most of the time and the current is close to unity power factor ok.

Safe current power factor is like 0.9 or something like that then we can say that the current waveform is probably the current will be here somewhere 0.9 lagging power factor the current is here. Whereas, the fundamental component of the voltage is probably here somewhere ok. So, for this condition you can see that S 1 is having a both switching and conduction taking place during this time ok.

Whereas, S 2 has only conduction losses it is fully turned on. So, it has only conduction losses S 2. Whereas S 1 has both conduction and switching losses ok. So, this actually is going to create more losses in S 1 as compared to S 2. In general this is one of the challenge of NPC in general we see that for close to unity power factor and high modulation index the outer switches of NPC is switching much the outer switches have losses much more than the inner switches.

So, this is an uneven distribution of losses in the converter this again will require that we have heat sinks of different types for S 1 and S 2 and subsequently also for S 3 and S 4 which is kind of like challenging right. So, we see that for this operating condition S 1 will or S 1 that the outer switch will have more losses as compared to the inner switch ok.

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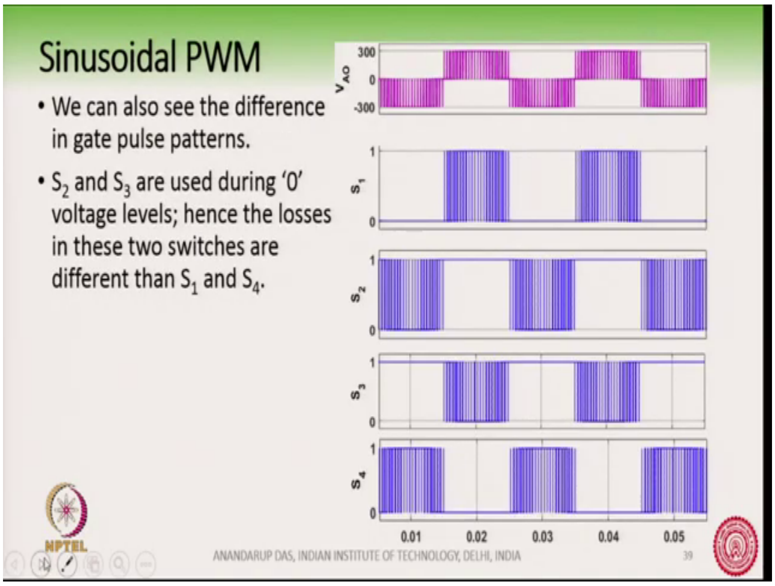

So, we can also see it here in this diagram. So, we can see therefore, that in NPC the uneven loss distribution in the switches is a challenge and for which we have other topologies where the loss distribution has been specially taken care of.

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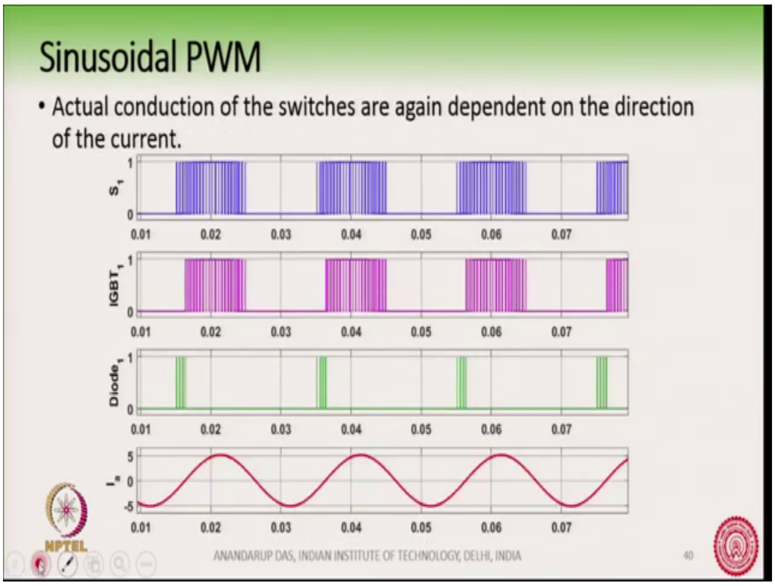

Now, again further if we go deep if we go one step inside the converter we can even see that for example, the actual conduction of the switches exactly which will be again dependent on the direction of the current ok.

For example we have taken a power factor like close to 0.9. So, this is the actual gate pattern of S 1 here you can see these are the gate pulses given to S 1, but actually the IGBT of S 1 will be conducting when the current is positive ok. So, in spite of giving the pulses for S 1 here the actual IGBT of the transistor will conduct only when the current is positive.

Whereas, if the current is negative the anti-parallel diode D 1 will be conducting. So, this is where D 1 will conduct and this is where the transistor will conduct ok. Now the losses in a transistor and the losses in the diode are different. For example, the turn on loss of diode is much less compared to the turn on loss of a transistor. So, even the power factor plays a role here now how much will be the turn on how much is the losses of the devices ok.

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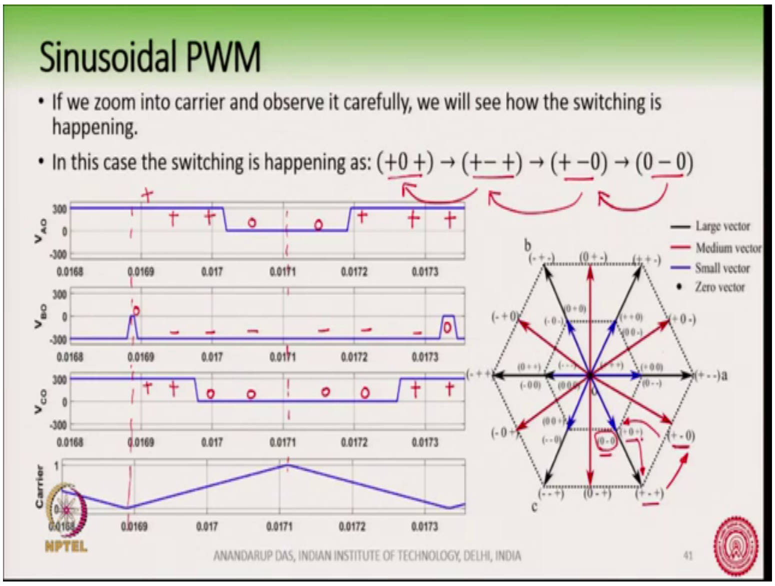

Now, we can also see one more important switching pattern here in by zooming into 1 carrier ok. If we zoom into 1 carrier suppose this is where. So, if we go back see the carrier wave form; see if we zoom into 1 small carrier here into 1 small carrier anywhere we zoom in into 1 carrier then we will see one interesting observation.

So, what we will observe here. So, this is 1 carrier which I have drawn and corresponding to that the V Ao, V Bo, and V Co these 3 pole voltages are drawn here ok. So, we have zoomed in into 1 carrier. What do we observed here ok. So, let us see how this is.

So, we can see for example, we let us see here from this point here this is the 1 carrier ok. So, we see here that the switching how is the switching happening the first switching is happening as plus 0 plus ok. So, you see here that the first switching is happening this is plus.

So, this is plus here this is 0 here and this is plus here ok. So, the first switching happening is plus 0 plus and where are we in the space vector diagram we are here this is the plus 0 plus ok. So, we are we have started. So, this is the start of the carrier and we have started our switching from plus 0 plus here right.

So, here this is the first one what happens the next? In the next one then we have we go up to this one then we have immediately here plus minus plus. So, this place we have plus minus plus ok. So, here so, this is where plus minus plus this switching state is happening. So, from here plus 0 plus we have now gone to plus minus minus.

So, we have gone from here to here we are now here we have covered here we have now here plus minus plus then from there we will come to this point here and we will see here that this is plus this is minus and this is 0 ok. So, plus minus 0 this is the third transition happening. So, from this one so, plus minus 0 this is this one.

So, plus minus 0 so, from here we go to here that is here right and then subsequently at the end of this carrier somewhere here we see that we are at you know. So, there is a transition here and so, we say that this is 0 minus 0. So, therefore, we come to 0 minus 0 that is the other complementary state we come here.

So, from here we come to here ok. So, we see that in this sinusoidal PWM also we have a centering over this vector plus 0 plus. So, we have a center here and then we moved in a clockwise direction. So, from here we went to there from there to there and from here to here ok. So, we made a clockwise rotation of vectors and if you now see here again it will go back ok.

So, from here the first So, after this one after this is the end so, then you go from here 0 minus 0. So, we have reached here now we are going back 0 minus 0 then we go from here this is again plus minus 0. So, we from this we plus minus 0 we are going back plus minus 0 and so, we started from here we went like this and now we are again coming back plus minus 0 we have come back here.

Then we have this state has plus minus plus. So, plus minus minus that is we are going from here to here and then ultimately we have this state plus 0 plus. So, plus 0 plus so, we have gone to here to here ok. So, we made a anti clockwise return ok.

So, you see here in this particular switching sequence; if we zoom in into 1 carrier, we can distinctly see how the movement of the space vectors in terms of switching is happening. First we go clockwise and then we go anti clockwise like that ok. So, one way like this and the other way like this ok.

So, this is very consistent with the space vector PWM strategy that we had also developed earlier for a 2 level converter, but now we are centering or center or pivot vector is here this is the start and end vector. So, as we said these are the 6 centers these are the 6 pivot vectors from which the switching starts and this is an example of such a switching ok.

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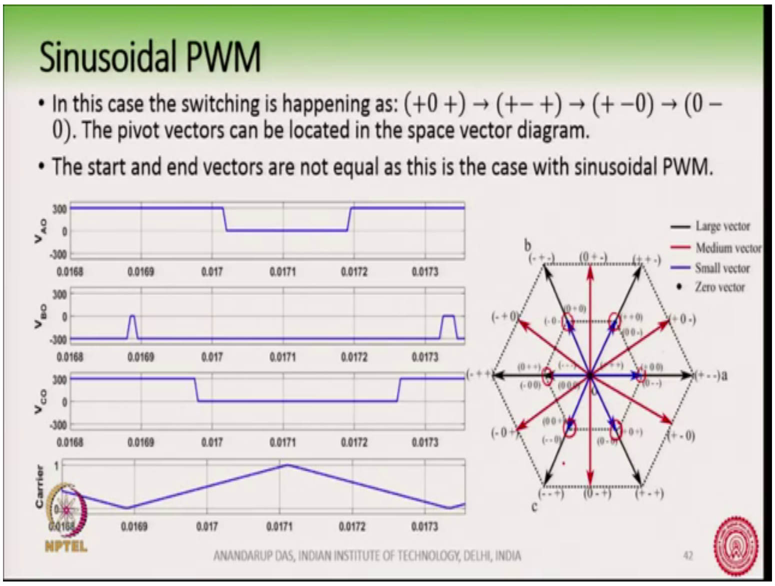

So, you can see that what is I have written the pivot vectors can be located in the space vector diagram. So, these so, you will see that the switching and the starting and ending vectors are all starting from this 6 pivot vectors; however, one thing that we must observe here is that the starting and ending vectors are not equal ok.

As this is the case with sinusoidal PWM that which is unfortunately sinusoidal PWM is like where the start and end vectors are not equal and we can see here also like right. So, you see here this is the end vector here is the end vector 0 minus 0 and its duration is much bigger than plus 0 plus ok.

So, you can see here also the start vector is here the start vector duration and the end vector duration they are substantially different ok; they are substantially different. And so their durations are not equal which is the; which is the drawback of sinusoidal PWM and that is why we can think of going into space vector PWM where we make the start and end vectors equal in duration equal in time duration ok.

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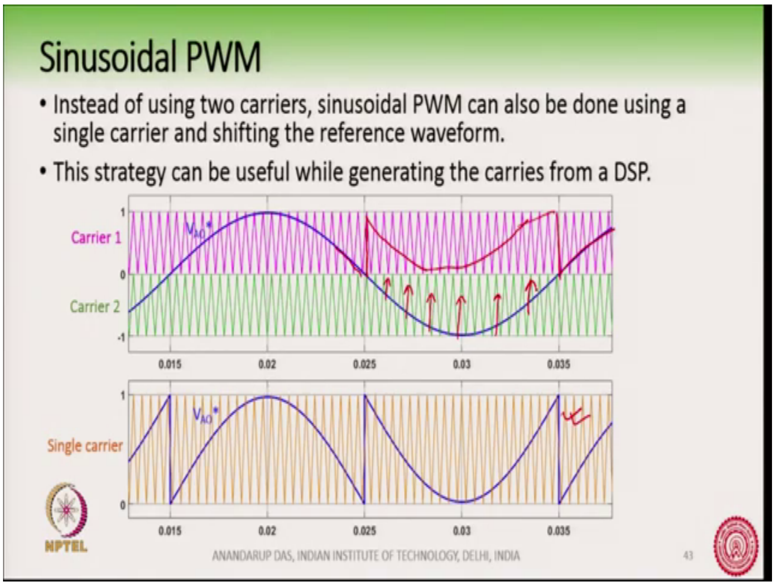

So, this is the drawback of sinusoidal PWM. So, before I go into space vector PWM before I would say that instead of using 2 carriers it is possible to use a single carrier also ok. So, you can see here there are 2 carriers, but you can also have a single carrier right. So, it is useful while generating the carriers from a DSP; because then we will need 1 carrier from the DSP.

When I do when I use a single carrier for example, like what I have shown here single carrier what we have to do is we have to shift the waveform we had seen this thing when using the level shift PWM we can shift and put the carriers put the reference waveform inside 1 carrier ok.

So, here you can see that this waveform once it was because suppose I use only the top carrier I have only 1 carrier which is the top one. So, what I have to do. So, this waveform was going down 0. So, what I have done here is we will shift this part here. So, I will put this one up shift this one. So, that I can get up to this and then and then there is a shift of this and so this is like this and then I will follow the waveform like this.

So, this is what the this waveform here this is the waveform after shifting ok. So, I shift the whole waveform upward inside 1 carrier, but I have to remember that well I have shifted the carrier ok. So, this is how the whole PWM sinusoidal PWM can also be implemented through a single carrier where the reference waveform is shifted and brought inside 1 carrier.

We will now see how we can implement space vector PWM in a 3 level NPC ok. Now, the space vector PWM can be implemented using different types of strategies like people have proposed different types of carrier based strategies here we will use a strategy which is based on this single carrier strategy and using 2 offsets ok. We will give you an example I will give you an example through which you will understand how this single carrier to offset based space vector PWM for 3 level NPC can be implemented ok.

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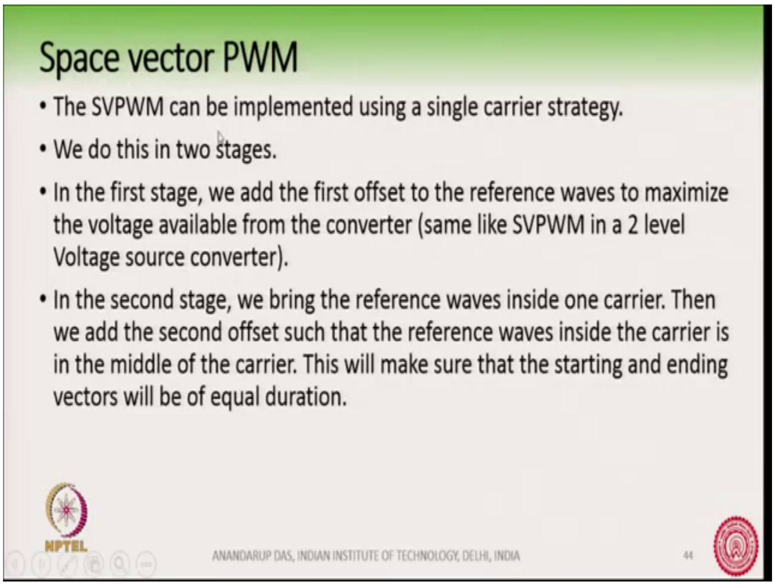

So, let us see. So, in space vector PWM with using a single carrier strategy we will do it in 2 stages ok. In the first stage we add the first offset and in the second stage we add the second offset ok. So, in the first stage we add the first offset. So, how much will be the offset? This offset is basically exactly like the conventional space vector PWM for a 2 level v si in a using carriers.

If you remember me what we did there we added an offset to all the 3 voltages in such a way that these voltages are placed in the middle of the carrier ok. So, the 0 vector and the N vector or the 2 0 vectors at the ends they were having equal duration of time.

So, that is how we said that there will be a max and there will be a min and by giving half of this V max plus V min what we did we were kind of like middling the reference waveforms inside the carrier ok. So, if you can go back to those slides for space vector PWM for 2 level converter and can refresh that idea.

So, in this case what we will do in the first stage we add the same offset that is the first offset. So, we add the first offset to the reference waves to maximize the voltage available from the converter which is same as like a SVPWM in a 2 level voltage source convertor exactly similar to that, but what comes next is the second stage where we bring these reference waveforms inside 1 carrier ok.

So, we bring the carrier we bring the reference waves inside 1 carrier and then we add the second offset ok. Now, what is the purpose of the second offset? The purpose of the second offset is that the reference waves inside this single carrier is now again in the middle of the carrier ok. So, this is like again doing the same job once more ok.

So, we bring all the carriers in the second stage we bring all the reference waveforms inside 1 carrier and then again middle or you make sure that the 3 reference waveforms are in the middle of this carrier. So, that the start and end vectors are equal in duration we will see an example and we will understand how this process happens.

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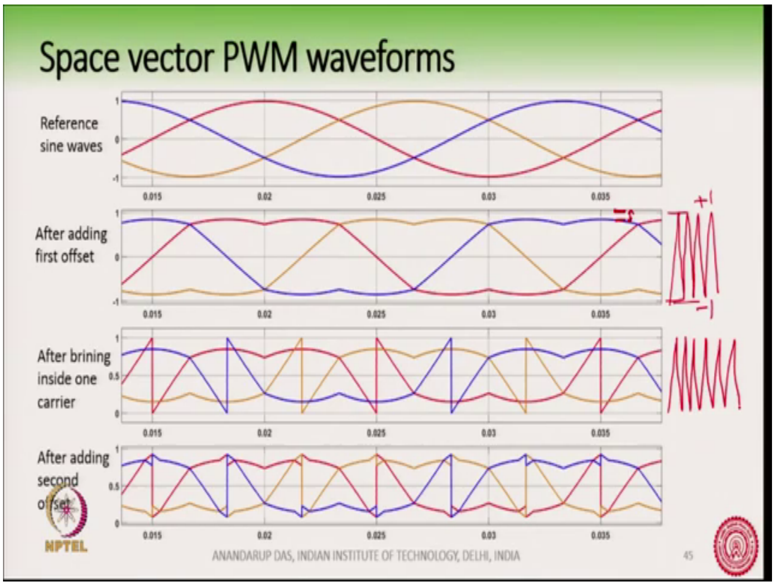

So, first let us start with this reference sine waves this is a sine wave as you can see here 3 sine wave references here we give the first offset. So, what we did in like a conventional voltage source converter after adding the first offset which is nothing, but this V max and V min divided by 2.

So, that this is like middle of the carrier the carrier is not shown here. So, the carrier I can draw for understanding the carrier is here between plus 1 and minus 1. So, the carrier is here high frequency carrier is here the carrier is in fact, not shown in this waveform in order to have clarity.

So, here are the carriers which is spanning between plus 1 and minus 1 ok. The carrier is here. So, you can see that after adding the first offset we get a margin here this is the additional space. So, the modulation index here is almost close to 1. In fact, I think it was 0.98 or something like that.

So, here we get this extra margin which we have seen that this is the benefit of having space vector PWM and this margin is almost close to 15 percent right that is why we get 15 percent more out of the space vector PWM. Now, after we added the first offset this becomes our reference waveforms.

Now, let us bring this inside 1 carrier ok. So, when we put it in 1 carrier. So, the carrier is again spanning here this is the 1 carrier right. So, this is the 1 carrier. So, I will remove this one this was for a 2 level v si carrier. So, this is the 1 carrier which is present here between 0 and 1.

So, now what we have done is this waveform here we have shifted at places wherever it was negative wherever it was less than 0 for example, from this to this point the blue waveform is negative. And so, we have pushed the blue waveform up. So, that the blue waveform is now so, from here onwards the push has happened.

So, the blue waveform is now you can see it has it is between 0 and 1 and therefore, it is spanning between 1 carrier; the single carrier we have shifted it up. Now, what happens after we have added after we have sorry after we have brought this; after we have brought to these waveforms into 1 carrier we see that the start and means the start and end vectors are not equal how can we know that?

We see here that this distance here for example, this distance and this distance are not equal ok. So, which means that these waveforms are not at the middle of the carrier. So, we have to middle it we have to bring all these carriers and middle it inside this.

So, we have to like we have to add the second offset such that the all the wave forms are at the middle of the carrier and that is exactly what I have done here ok. In this waveform if you see we have added the second offset in this waveform in the lower most one here and what we see here that at any point of time the distance of the highest waveform and the distance of the lowest waveform from 1 and 0 are equal; that means, we have middled all the waveforms inside the carrier.

So, you can see here for example, see you see here this distance from 1 and this distance from 0 are equal, this distance from 1 and this distance from 0 are equal, any place you take this distance from 1 and this distance from 0 these are equal. So, which means these reference 3 reference waveforms are always at the middle of the carrier.

So, this is the function of the second offset ok, but if you see here in the third waveform this distance is not equal to this distance ok; this distance is not equal to this distance. So, therefore, this is the function of the second offset and by which what we have done is we have ensured that the highest waveform from plus 1; the highest wave from plus 1 and the lowest waveform from 0 are have the equal magnitudes.

The distance from the plus one and distance from 0 are having equal magnitude this ensures that we are following the space vector PWM as we will see now.

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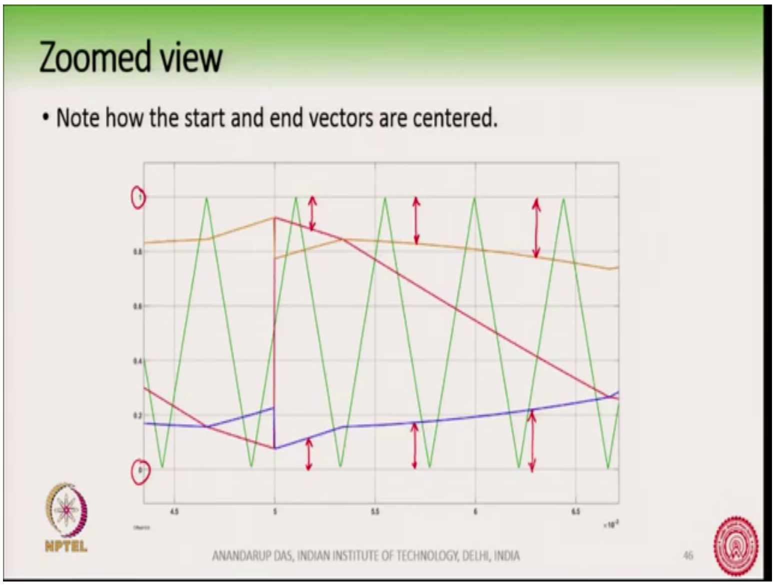

So, here we have zoomed in. So, this is a zoomed version of the same 3 waveforms, but now with the carriers you can see here you can note here carefully that you see that. So, this is where. So, we have zoomed in on the carrier versus 3 last waveform there and here you can see that this distance here and this distance here they are equal always it will be equal ok. The topmost waveform and bottommost waveform their distances from 1 and 0 this will be always equal ok.

So, here you see that this waveform this distance is equal to this distance ok; this distance the topmost and the distance is equal always right. So, this is the second offset note that second offset is also a common mode voltage it is added equally to all the 3 reference waveforms. So, that we are basically shifting up or down the whole set of 3 waveforms. So, that it becomes at the middle of the 0 to 1 this span of 0 to 1 ok. So, this is what we are doing.

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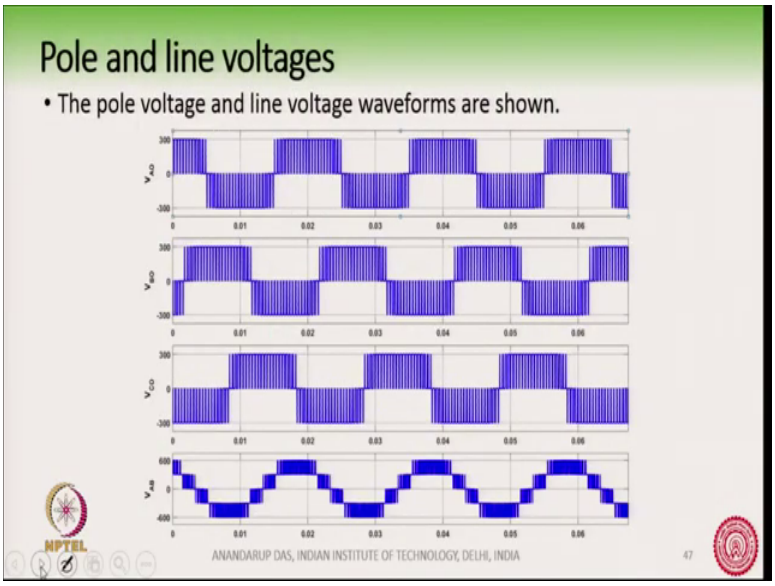

So, after we have done this. So, we can see the pole voltage and line voltage now we are in the space vector PWM. So, we have done the space vector PWM. So, we have ensured that we will see this now we will ensure that the start and end vectors in a cycle in a switching cycle Ts will be of equal duration of time that is how space vector PWM is ensured right. So, here you see the pole voltage and line voltages. So, these are the pole voltages these are the line voltages you cannot differentiate much from sine PWM.

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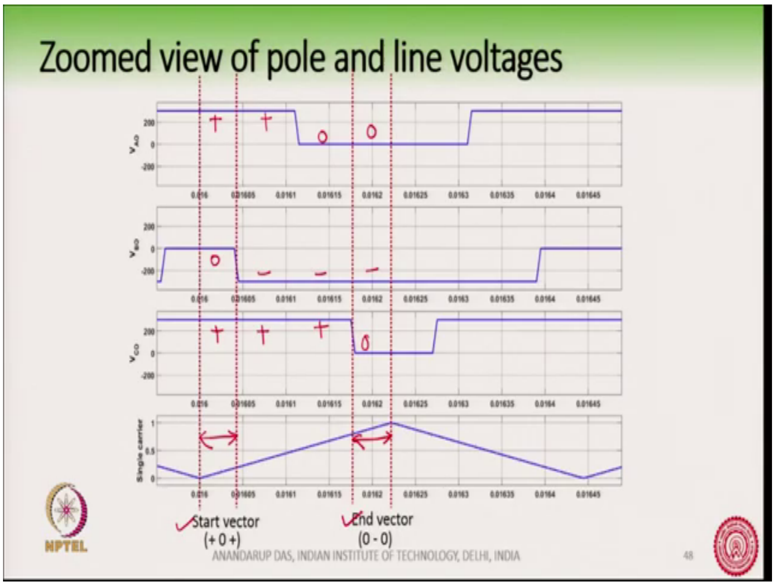

But when you zoom in into the pole voltage and line voltage there you will see what is the difference. So, here you see this is a very zoomed view of the pole and line voltages the same which we had shown in the last slide and you see here see this is the start vector because see here.

So, this is the; this is the carrier. So, this is the start vector then there are 2 intermediate vectors and then there is an end vector. So, what is the start vector? You can see this is plus this is 0 and this is plus. So, plus 0 plus is the start vector and then we have 2 vectors here one is plus one is minus and this is plus minus plus and then you have 0 minus plus and then you have 0 sorry 0 minus 0 ok.

So, your start and end vectors are plus 0 plus and 0 minus 0, but what is important to note here is that this duration the start vector this duration here this duration is equal to this duration these durations are equal this is what makes space vector PWM the start and end vectors are of equal duration of time.

So, this is the start vector and this is the end vector and both are again the P word vectors with the 2 different multiplicities, but they are of equal duration ok. So, that makes it space vector PWM.

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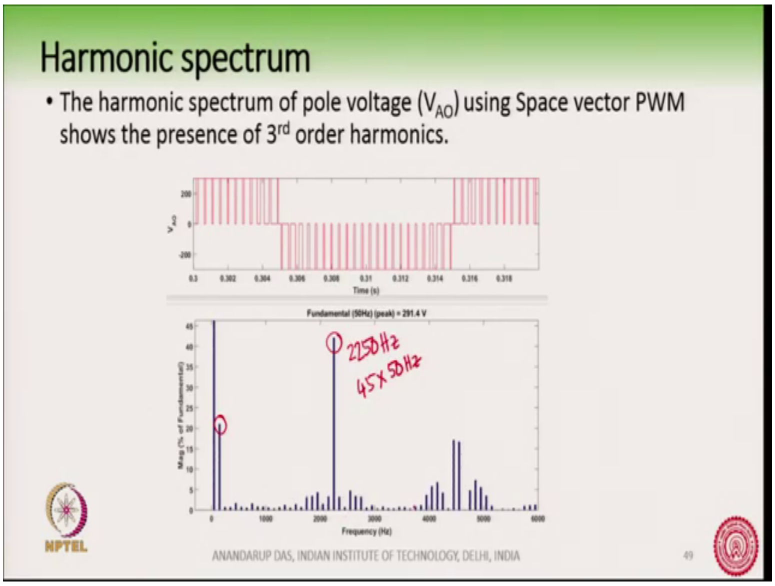

And so, now we can see the harmonic spectrum of the pole voltage when we use space vector PWM you can readily see that they there is a third order harmonic ok. So, this is where you have the triple end harmonics coming in 3 9 and all other waveforms will come and there is a peaky waveform which is again at I think 2250 Hertz this is what we have chosen which is 45 times fundamental waveform; 45 why we have taken this is a multiple of 3 or multiple of 3. So, this is where the first harmonics reside ok.

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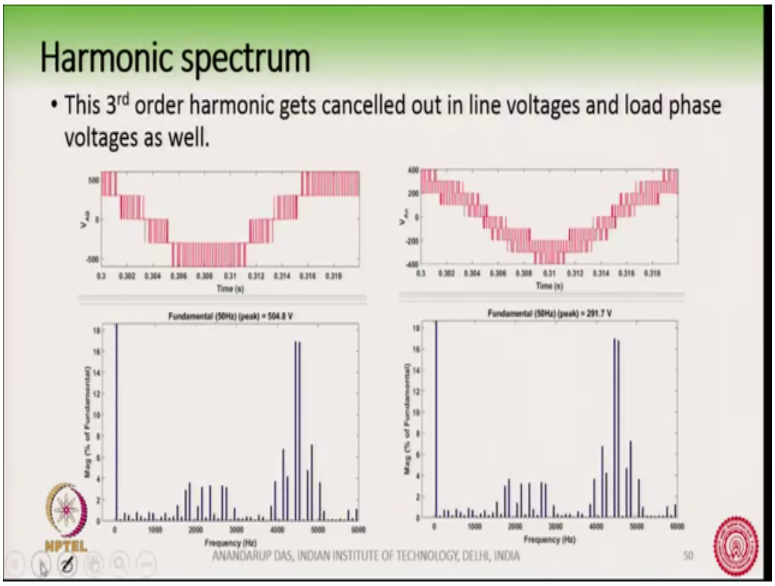

Of course since this is 45, I mean this is a multiple of 3 and we know that in the line voltage this third harmonic component will disappear ok. So, we will in the; so this is the line voltage waveform and this is the load phase voltage waveform and you can see that the 2250 that is a 45 th one has disappeared.

Because it is a multiple of 3 right and, but the sidebands do not disappear because they are not multiples of 3. So, they do exist in the line voltage as well as in the phase voltage but. So, we have the second set of harmonics around 4500 Hertz it is a double this one.

So, this is what happens in space vector PWM if I once more recap what I have done with space vector PWM is that we have added 2 offsets. So, this slide is important to understand space vector PWM of NPC we have added 2 offsets into this the first offset makes sure that we get 15 percent more out of the DC bus. And that is same as what we do in a conventional space vector PWM for a 2 level voltage source converter that is this step here from a sine wave we get after adding the offset like this.

So, that the start and end here also this is equal to this here ok; at any point this is equal to this all the places right ok. So, this is the first step the next step what we have done is bring all these waveforms into 1 carrier bring all the waveforms into 1 carrier when we do.

So, how we do this we shift the waveforms up or down in this case sorry in this case only up; so, we shift the waveforms up. So, that whenever they are less than 0 we put it up ok. So, after we have shifted it up the modified reference waveforms look like this. If we see this waveform for the 3 phases together we see that the upper and the lower lengths are not same.

As you can see for example, here if I again draw it clearly then we will see that this distance for example, this distance is not equal to this distance ok. So, this means that our start and end. So, if I give a comparison of this reference waveform with the high frequency carrier the start and end vectors will not be of equal duration of time ok. So, what we then do is add the second offset?

What is the function of the second offset? The second offset is kind of like again middling this 3 reference waveforms here inside 1 carrier and that is what we have done in the after addition of the second offset the waveforms look somewhat different. However, if we compare this with the carrier that is what we have done and shown you in this zoomed version if we compare it with the carrier we ensure that space vector PWM is done.

So, in this type of space vector PWM you do not need to identify the sector you do not need to find out the switching states or you do not even need to calculate the times. It is automatically taken care of that is the advantage of carrier based PWM techniques like you do not have to calculate this T 0, T 1, T 2 timing duration nothing.

So, you give it to the this carrier and the 3 reference waveforms that is this particular waveform; this fourth one after adding the offset you can directly give it to the means for comparison with the high frequency carrier. Once you have done that then you will immediately be able to get a waveform like this coming out of the converter ok.

So, then we get. So, if so, how to check whether you are correct is to see a zoomed version of the waveform and you will see that the starting and ending vectors are coming out to be equal in duration ok.

So, this is how space vector PWM for NPC is done. Space vector PWM with NPC along with capacitor balancing can also be done ok, but that requires a little bit of closed loop control where you sense the capacitor voltages ok. Which we will not cover in this course. So, we will keep it as an advanced study and so, we just covered space vector PWM for NPC.