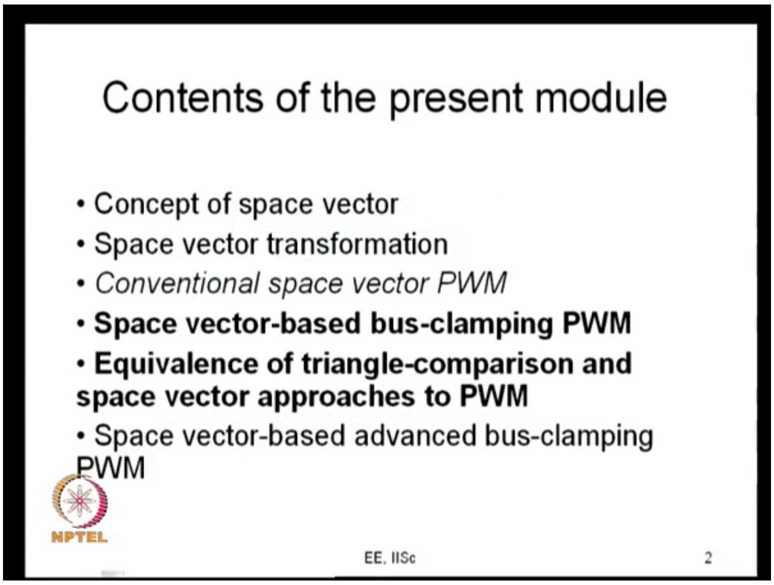
Pulsewidth Modulation for Power Electronic Converters
Prof. G. Narayanan
Department of Electrical Engineering
Indian Institute of Science, Bangalore

Lecture - 21
Space vector based bus-clamping PWM

Welcome back to this lecture series on Pulsewidth Modulation for Power Electronic Converters.

(Refer Slide Time: 00:25)



So, we have been looking at various modules earlier and now presently we are looking at this module on space vector based PWM. So, initially we looked at the concept of space vector and you know where it is like the rotating MMF in a machine and we went on to define you know look at three-phase currents, and how they can be transformed into equivalent 2 phase currents or current space vector and we looked at you know the transformation of three-phase voltages into a space vector and so on.

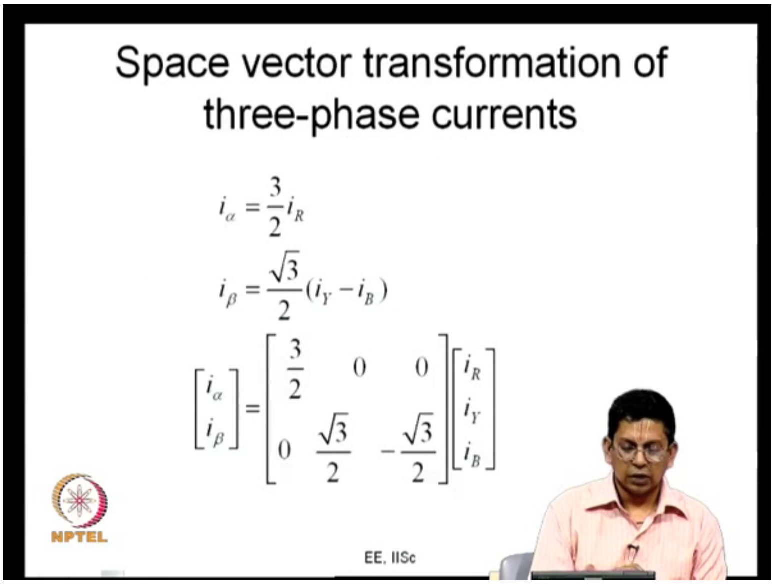
So, we just looked at the concept of space vector and space vector transformation and the last lecture we also looked at this conventional space vector PWM, which we would kind of review in this particular lecture. And this lecture would emphasis on space vector based bus clamping pulsewidth modulation, this bus clamping pulsewidth modulation are this discontinuous pulsewidth modulation is something we discussed in the earlier module on triangle-comparison PWM.

So, there were a few I mean couple of lectures where we discussed with this kind of a discontinuous bus clamping PWM. Today instead of space vector I mean instead of triangle-comparison we are going to do the same thing using space vector and we are also going to see how the 2 approaches are equivalent that is a triangle-comparison which we discuss in the previous module and space vector how they are equivalent. So, even in the last lecture we just slightly saw that in the context of space conventional space vector PWM. Today in the context of both conventional space vector PWM and the so called bus clamping PWM we will see the equivalence between these 2 approaches that is a triangle-comparison approach and the space vector approach right.

So, the next lecture we would hopefully look at space vector based advanced bus clamping PWM as we were saying you know the equivalence is well known and is widely understood and discussed in the literature, but what I would like to say a space vector approach is kind of more general than the triangle-comparison approach with space vector approach, you can produce certain PWM waveforms which cannot be produced by triangle-comparison approach. And some PWM methods is called this advanced bus clamping PWM are exclusive to space vector based approach so which we will hopefully discuss in the next lecture now.

So, let us quickly take a look at space vector transformation we are going to discuss on space vector based bus clamping PWM let us just start off with you know space vector transformation.

(Refer Slide Time: 02:45)

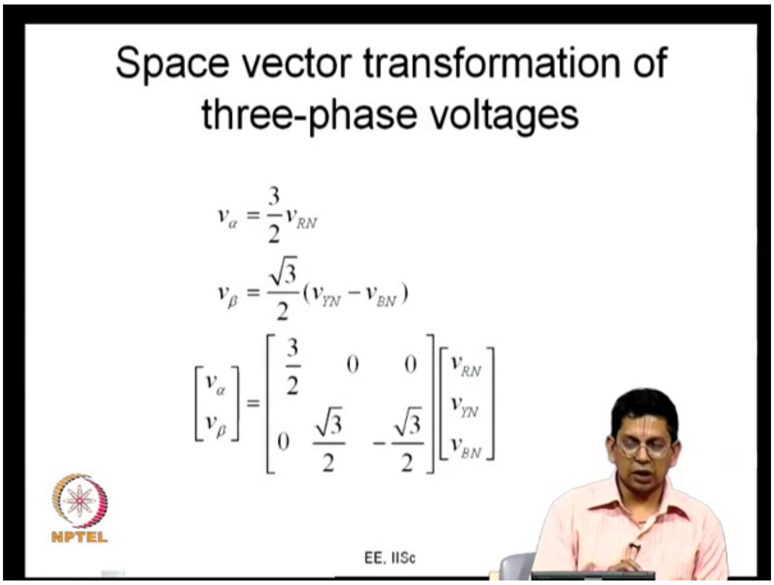


Let us say there are three-phase currents i R i Y and i B and which sum up to 0 that is i R plus i Y plus i B equal 0. In such a situation we have seen that i R i Y i B the three-phase currents can be transformed into 2 2 phase quantity because i R plus i Y plus i B equal 0 he is you know what he said it is it shows that i R i Y and i B are not independent right. And so they can be and i R plus i Y plus i B is equal 0, a similar to the equation of a plane x plus y plus z is equal to 0, and plane has only 2 dimensions and it can be spanned by 2 orthogonal vectors.

So, i R i Y i B though three-phase quantity can be represented by 2 independent quantities I alpha and I beta that is the idea and I alpha is simply equal to 3 by 2 times i R and I beta is equal to root 3 by 2 times i Y minus i B. And these orthogonal quantities we are taking them such that alpha axis is aligned with R phase axis and beta axis is 90 degrees ahead of alpha axis and so this is i alpha i beta return you know in terms of i R i Y i B as a in the matrix form.

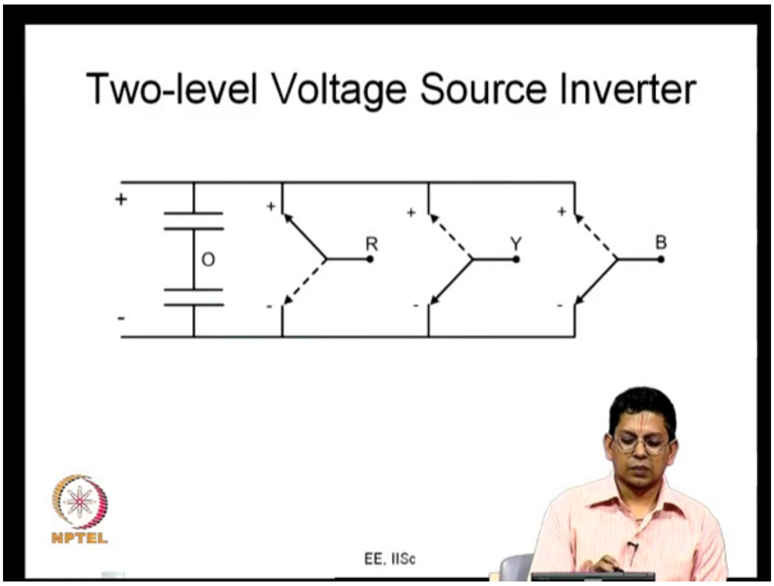
So, this matrix is the transformation matrix for space vector transformation right.

(Refer Slide Time: 04:02)



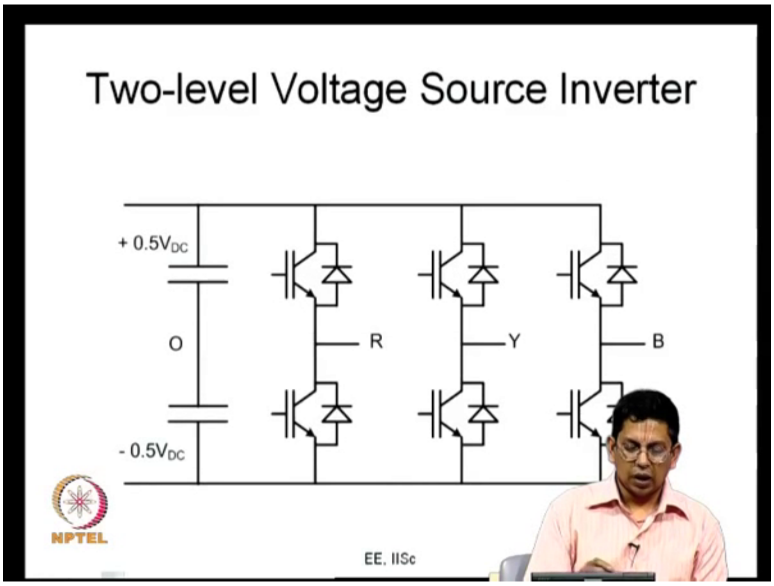
So, let us just. Similarly, you have three-phase voltages V R N V Y N and V B N which sum up to 0. Now these three-phase voltages can also be transformed into 2 phase voltages V alpha and V beta shown here. So, V alpha is equal to 3 by 2 times V RN and V beta is root 3 by 2 times the difference between V YN and V BN or V YN minus V BN. So, the same thing is written in the matrix from here.

(Refer Slide Time: 04:30)



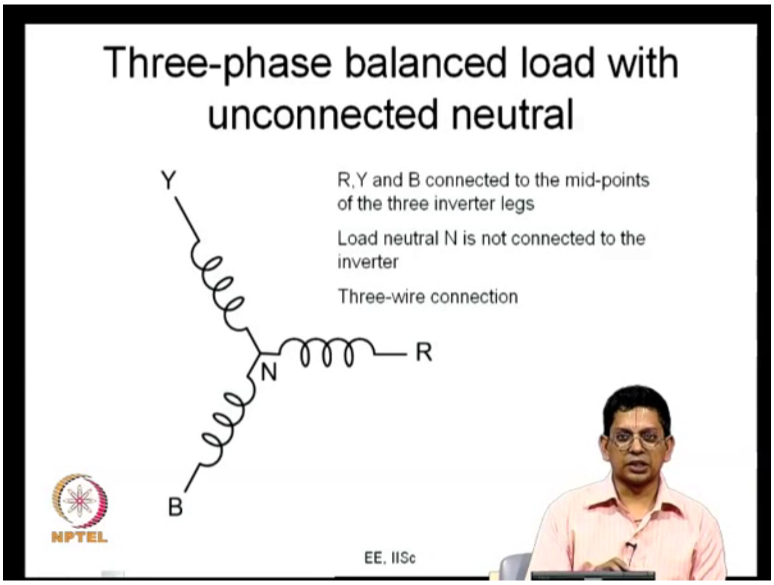
So, when we look at three-phase inverter the output voltages are fixed levels it has only 2 levels it is a 2 level inverter. So, it has only 2 levels here either plus V DC by 2 if it is connected to the top throw or minus V DC, but if it is connected to the bottom throw there are only 2 levels here now and so every voltage can have 2 different levels there are totally 8 sets of output voltages are possible.

(Refer Slide Time: 04:53)



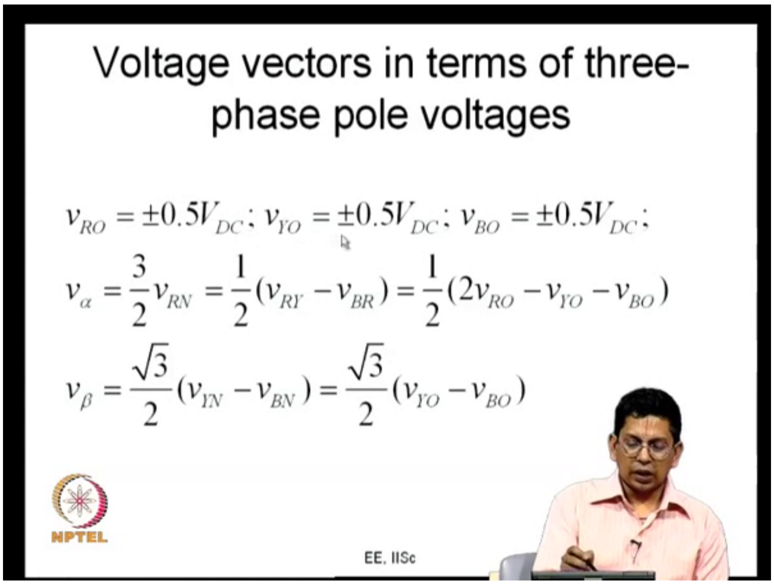
And these you know here again I have just shown that is top device and the bottom device here. So, your R Y and B can be either plus V D C by 2 or minus V D C by 2 with respect to this midpoint O.

(Refer Slide Time: 05:05)



So, 8 sets of output voltages are possible as I said before and you are applying this output the outputs are connected across a load you know, the load is taken like this R Y B A three-phase balanced load and it has a common point it has a neutral point n this neutral point N is not physically connected to the inverter. Sometimes it can be connected to the DC midpoint O or you know through some appropriate filters and many things are possible are some other components can be connected here and there some filtering and all that now, we are assuming that we are having a three-phase star connected load like this where the neutral is not connected anywhere right the only R Y B and be a connected to the inverter now that is the kind of load now.

(Refer Slide Time: 05:41)

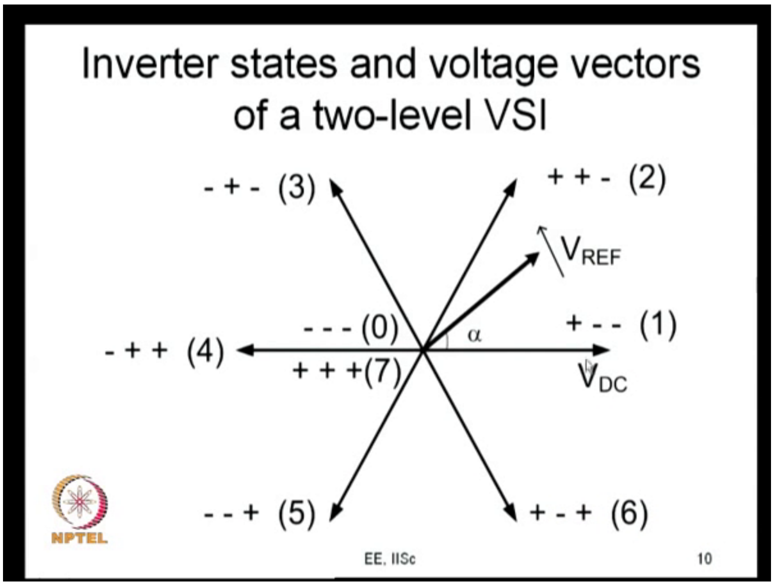


So, the V R O can take the values of plus or minus 0.5 V D C as I have been mentioning probably from my very you know one of the early lectures. And so corresponding now V alpha and V beta we have defined we have defined the space vector in the last 2 3 lectures we have been discussing this. So, that V alpha is equal to 3 by 2 times V R N I have pointed out to you that this is V R N this is the phase neutral voltage applied on the load it is not V R O this is not the R phase voltage measured with respect to the DC midpoint, but this is the R phase voltage measured with respect to the load neutral N same way V beta is root 3 by 2 times V Y N minus V B N this is space vector transformation now.

So, V R N can be replaced in terms of V R Y and V B R the line to line voltage is shown here they in turn can be replaced in terms of the pole voltages as shown here. So, this is V alpha in terms of pole voltages this is V beta in terms of pole voltages and you can see that V beta is independent of V R O. So, you know this is something that will have here, and we also looked at for 8 sets of values of V R O V Y O and V B O for 2 sets of them V R O V Y O and V B O are equal that is 0 state all 3 are equal to plus V D C by 2 or all 3 are equal to minus V D C by 2. It is easy to see that when V Y O and V B O are equal V beta is 0 and when all the 3 V R O V Y O V B O are 0 this is also equal to 0.

So, the 2 0 states lead to V alpha equal to 0 and V beta is equal to 0 that is the lead to a null vector, and the all the other states lead to vectors of magnitude V D C these are called active states and the corresponding vectors are called active vectors.

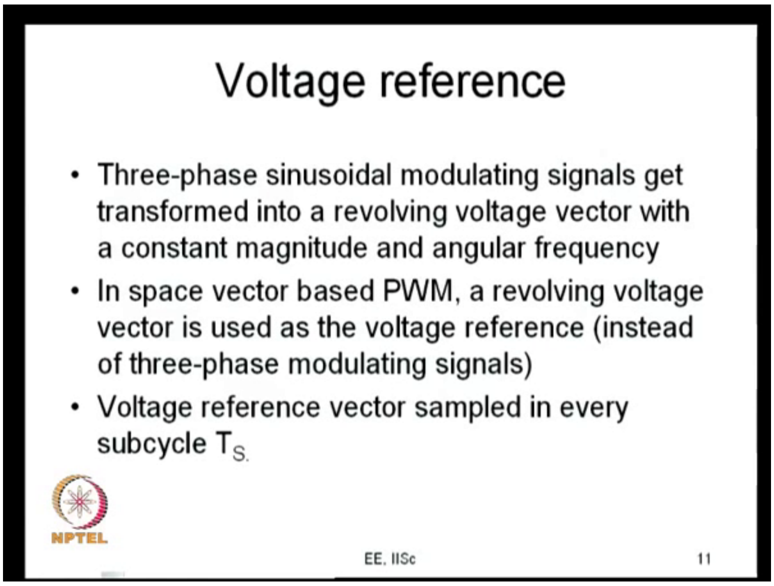
(Refer Slide Time: 07:26)



We saw this in some detail in the previous classes and we quickly reproduce here when R phase alone is connected to the positive bus and Y and B are connected to the negative bus the inverter produces a vector which is aligned with the R phase axis as shown here.

And when the state is inverted when R is negative and Y and B are positive you go around like this you get the negative vector now, like plus minus minus R alone is positive here, if Y alone is positive and the other 2 are negative you get a vector which is aligned along the Y phase axis. Similarly B alone is positive on the other 2 are negative you get a vector of the same magnitude V D C along the B phase axis now. So, thus you get these 6 vectors as we saw in the previous lectures now.

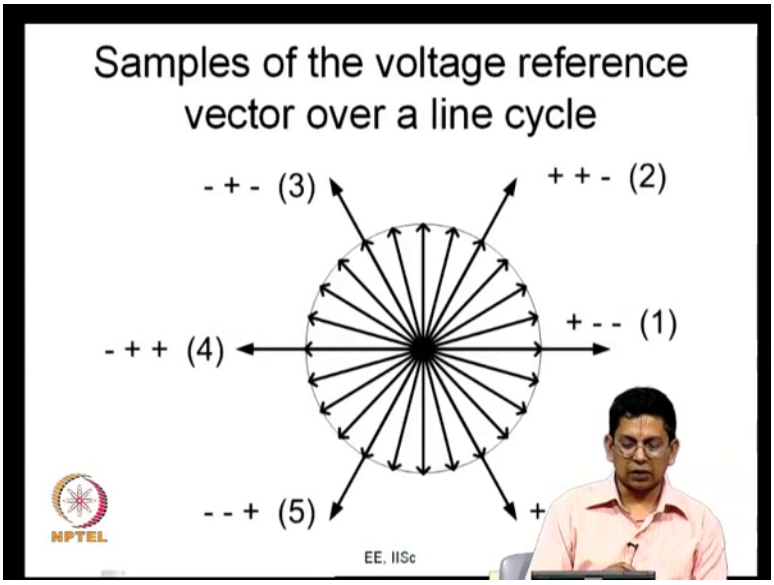
(Refer Slide Time: 08:10)



So, in space vector based PWM what we would do is we have this revolving voltage vector which we just saw here. So, this is the revolving voltage vector which is been indicated here. So, instead of using three-phase modulating signals we use 3 we use a revolving voltage vector which is having a constant magnitude and angular frequency at steady state. This magnitude is some give some measure of the amplitude of the ac voltage that you want and this angular frequency yes; it you know it is the modulation frequency that you wants a fundamental modulation frequency right omega which is equal to 2 pi f where f is the modulation frequency.

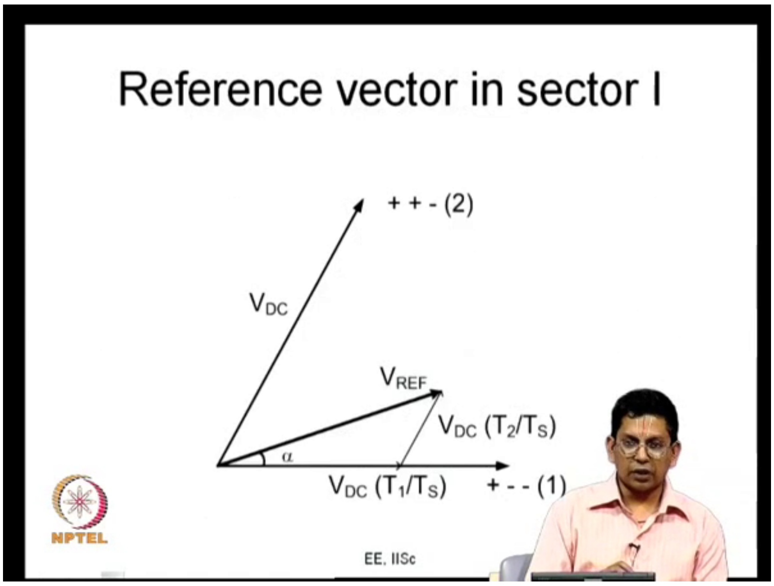
In space vector based PWM you use such a revolving voltage vector instead of three-phase modulating signals and this voltage reference vector is sampled every sub cycle and the sampled value of the reference vector gives the voltage command for the inverter.

(Refer Slide Time: 09:01)



And so if you consider the revolving voltage vector and it is sampled that equal intervals of time you are going to get samples like this as I had said before, and in any particular sub cycle you may have a command and reference vector say like this or say like this when you have a commanded reference vector.

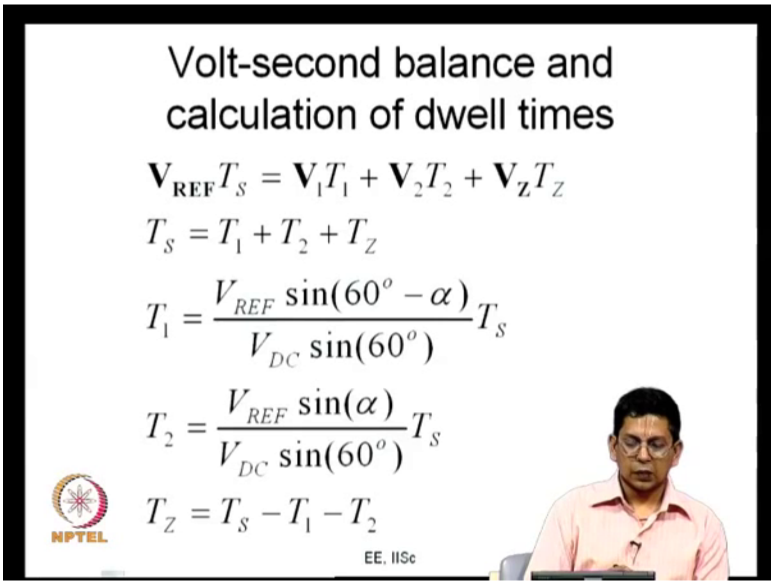
(Refer Slide Time: 09:15)



So, say this is the vector what you do is you try to produce this by time averaging these vectors V 1 V 2 and null vector.

So, if you apply V 1 vector for some T one seconds out of T S seconds and V 2 vector for T 2 seconds out of T S seconds. So and null vector for the remaining time what you get is you get this effective average vectors you want now first you can see that the time T 1 and T 2 should be related to this V ref an alpha. So, you can work that out.

(Refer Slide Time: 09:49)

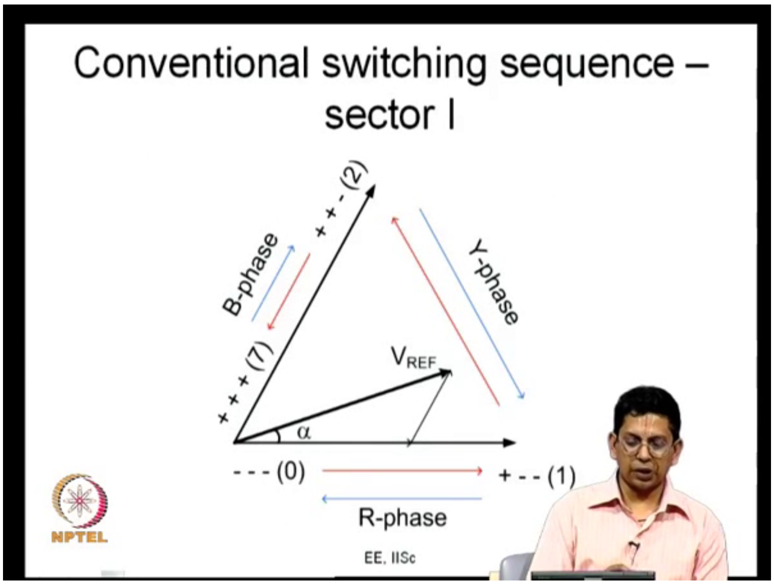


So, this is the volt second balance V reference into T S that is what is the required voltage and what is applied is V 1 41 seconds V 2 42 seconds and V Z 40 Z seconds these 2 have to be equal.

So, that is the volt seconds are equal over a sub cycle duration time. So, T S is T 1 plus T 2 plus T Z. So, this being a vectorial equation there are 2 equations here there is 1 equation 3 equations 3 equations 3 unknowns you can solve for them you can get T 1 T 2 and T Z T 1 and T 2 in terms of V ref and alpha like this and T Z is T S minus T one minus T 2 as we saw in the previous lectures now.

So, this is how you calculate the dwell times for all of them this is you know in space vector base PWM now.

(Refer Slide Time: 10:32)



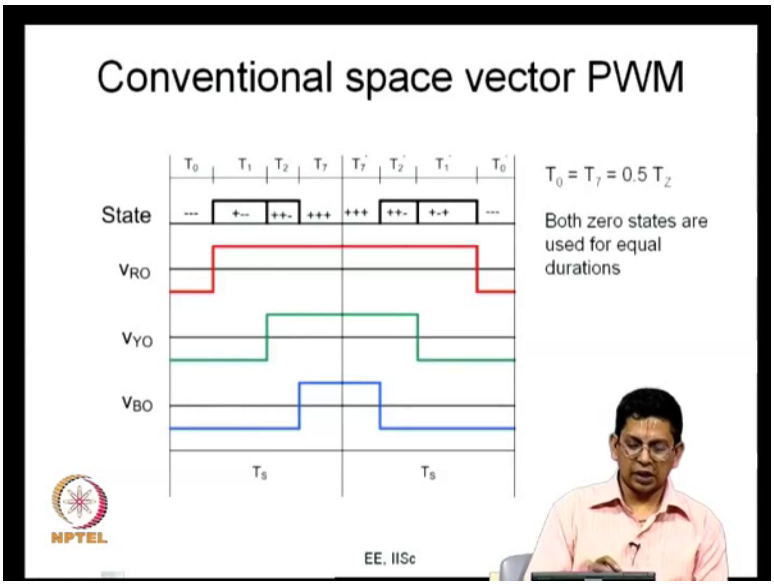
If you are using conventional space vector PWM what you would do is you want apply activator 1 activator 2 you would start from one of the null vector go to activator 1 activator 2 and come back to the null vector.

However this null vector is produced by 2 different null states 0 states 1 is minus minus minus which we designate as 0 and plus plus plus that is all the top device is being on which we designate as 7. So, what you do is. In fact, it is not just in conventional space vector PWM this is true about all continuous PWM wherever the modulation signals are continues I will emphasize this a little later also.

So, it is also true in sine triangle PWM as we saw last time you saw you start from say minus minus minus and then you switch 1 phase in this case it is R phase which gets switched first and you go to the vector 1 active vector. You switch the second phase you go to the next active vector, you switch the third phase you come back to the null vector, but you know it is not the same 0 state it is the other 0 state. In the next subcycle you start from this null state and switch in the reverse sequence you know B-phase first, Y-phase next, and R-phase third and you reach here now.

So, this is the kind of switching sequence you used now. So, you apply this 41 seconds you apply for this 42 seconds before going here you applied this minus minus minus for T Z by 2 seconds you stay here T Z by 2 seconds and go here and stay for T 1 seconds go here and stay for T 2 seconds and then come back here and stay on this plus plus plus for T Z by 2 seconds and do the reverse process. So, this is what is indicated in this diagram.

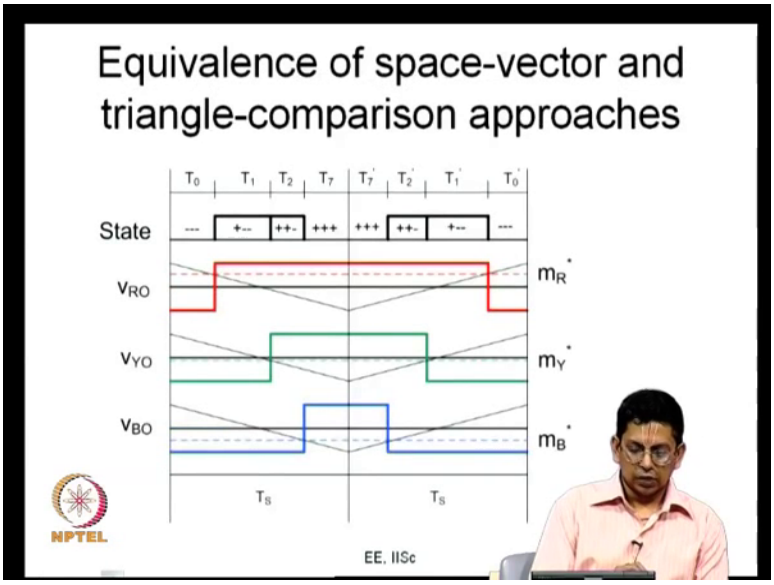
(Refer Slide Time: 12:09)



So, you are given a reference vector you are sampling it and once you have that sample you have the value of V ref an alpha using the values of V ref an alpha you are calculating T 1 T 2 and T Z and you are dividing this T Z equally between 0 and 7 T 0 is equal to T 7 is equal to 0.5 T Z and you are outputting the inverter states like this that is what you do in space vector base PWM. So, the R phase voltage in now it varies like shown here you see that it has the highest rate duty ratio of the three-phases here and Y phase as a duty ratio which is kind of close to 0.5 or an average voltage is close to 0 and VBO as the lowest rate duty ratio as you can see from here.

So, this happens because you know in this particular case the voltage reference vector is close to the R phase axis and it is close to the B phase negative axis R phase positive axis and B phase negative axis and it is also close to the Y phase 0 crossing or if you talk in terms of the three-phase sine waves this the three-phase sine waves are such that you know the R phase value is close to the positive peak the B phase value is close to negative peak and Y phase value is closer to a 0 crossing that is what you have and you get this kind of patterns here.

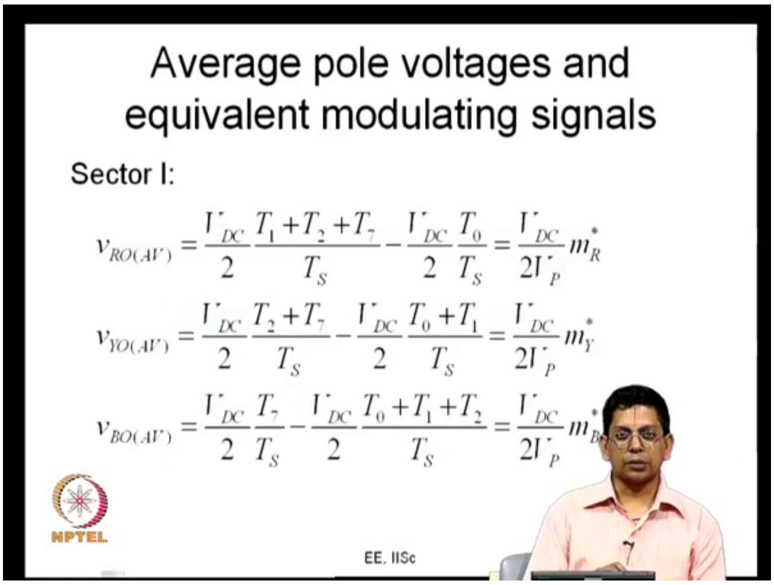
(Refer Slide Time: 13:23)



So, we emphasized on the equivalence now. So, once you have those things you can consider the average values V R O average and which is shown here in the red dashed lines and then you have this green line which are as stands for the yellow phase here and you take the average value is some average value very close to 0 and similarly V B O has some average value like this. Now you can take a scaled version of this average V R O average you can call it m R star and scaled version of V Y O average you can call it m Y star and scaled version of V B O average, you can called m B star you have m R star m Y star and m B star what you can do is you can compare them with the triangular carrier as you shown here now. If you compare these equivalent modulating signals with a triangular carrier you can get the same switching instance.

So, these switching instance can not only be arrived at by starting from the voltage reference vector the sample of the voltage reference vector and you know calculating the values of dwell times and outputting the inverter states you can also go the other way, you can also start from the equivalent modulating signals, and compare the equivalent modulating signals with triangular carrier. So, what are these equivalent modulating signals is a question which you can find out.

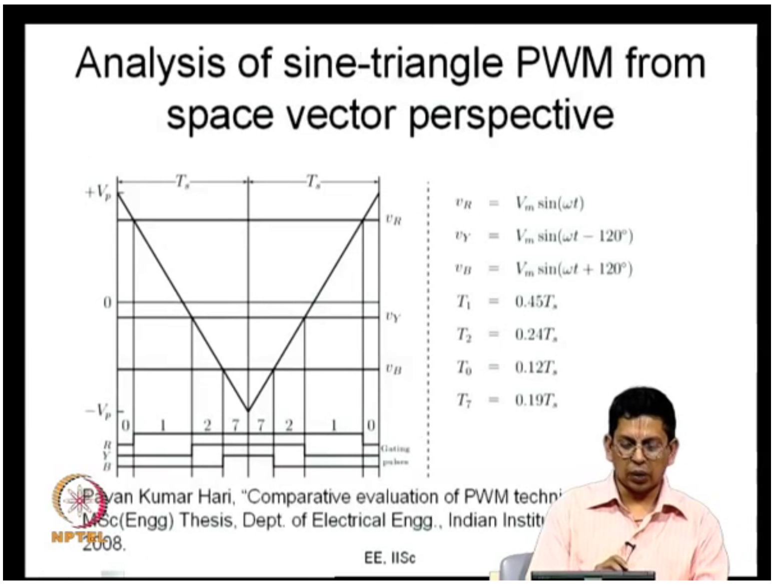
(Refer Slide Time: 14:29)



So, if you see is V R O average V R O average as I told is a scaled version of m R star and V Y O average is related to my star and so on now. So, the equation for V R O average is given to you now. So, far the time you know during the interval T 1 plus T 2 plus T 7 V R O average top devices on for during the I mean during the interval T 0 V R O S bottom device on therefore, the pole voltage here is minus V D C by 2 and this is the expression for the average voltage of V R O.

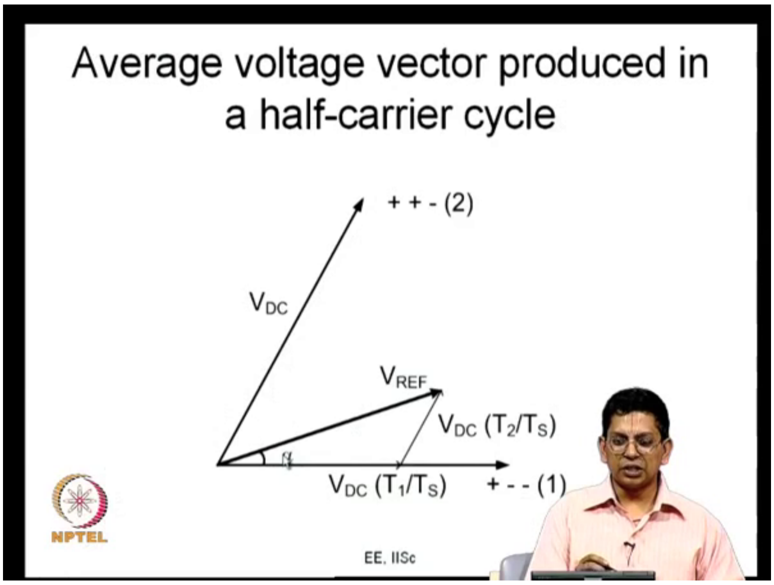
Similarly, for V Y O average the top devices on during T 2 plus T 7 and the bottom devices on for T 0 plus T 7 T 1. Therefore, this is the average voltage now again for V B O average the top devices on only during the interval T 7 this is on during the interval T 0 plus T 1 plus T 2. So, like this you can do the calculation now. So, you can just complete this. So, you will have different expressions for V R O average V Y O average and V B O average in the different sectors as I mentioned before and he can consider this as you know you can go about deriving an expression for this three-phase average pole voltage are the equivalent modulating signals as I mentioned earlier now I would still leave that as an exercise to you now.

(Refer Slide Time: 15:36)



So, you can you will find if you do that average voltages etcetera you will find that these three-phase average voltages or you know these are not sinusoidal waves these are sinusoidal waves m R star. For example, is not a sine wave, but sine wave with some common component added to that, now you can also start from rather than this space vector PWM conventional space vector PWM you can also start with sine triangle PWM consider one carrier cycle consider these signals these are the modulating signals for R phase Y phase and B phase right. So, these are the sampled values of sine waves these are the 3 sine waves during over one carrier cycle.

(Refer Slide Time: 19:15)



Now, you look at the switching instance now. So, these are wherever they intersect the carrier and the modulating signal intersects the switching instance now. And during the start of this carrier cycle which is the falling carrier cycle all the phases are low therefore, R is R in R phase bottom device on Y phase B phase are also the bottom devices are on. So, all the three-phases of bottom devices are on therefore, you have this. So, called 0 state 0 minus minus minus, then R phase alone switches then you have the state 1 plus minus minus. Then Y alone switches then you go to the state plus plus minus then B switches then you go to the state plus plus plus, then the same thing happens in the reverse direction and you see this is the exact sequence that you use like even little before we did this now.

So, this is exactly you start from 0 1 2 and 7 and you are coming back like this. So, this is been conventional space vector PWM we see we see that in sine triangle PWM also it is pretty much the same thing the only difference is in space vector PWM both are applied for equal durations T 0 is equal to T 7 is equal to 0.5 T Z whereas, in sine triangle PWM T 0 is not equal typically not equal to T 7. So, that is the difference now which has been pointed out here that is sorry you can see that this is not equal to this.

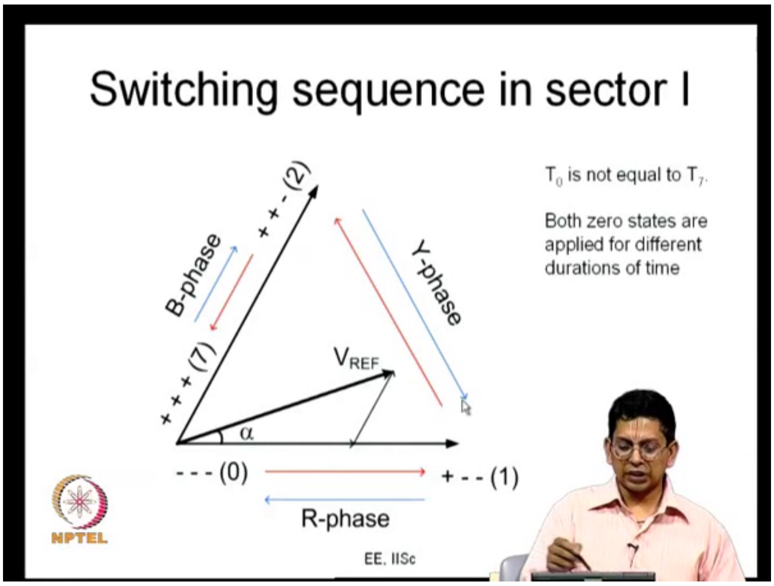
So, these can be made equal to 1 another, now we do not want to change T 1 and T 2 right we do not want to change T 1 and T 2, but we want to slightly add just T 0 and T 7 such that their sum does not change. Now what can we do we can add a small common-mode component.

Let us say I add a common-mode component to V R and V Y and V B a small delta V is added positive delta V is added to all the 3, what will happen V R will slightly go up V Y will also go up to the same extent V B will also go up to the same extent. Once all the 3 signals go up to the same extent what will happen here the 3 switching instance will move to the left to the same extent.

Now, T 0 will reduce this switching instant will also move, but T 1 would not change and again this switching instant will also move, but T 2 would not change. So, what will effectively happen is T 0 will reduce and T 7 will increase, but the sum of T 0 plus T 7 will remain the same T 1 is unchanged T 2 is unchanged. So, when you add a common-mode component the activator times do not change I will be making this statement again and again please bear with me, but that is very very important for us to realize when you add this common-mode components what happens is T 0 and T 7 change, but there some again wouldnt change.

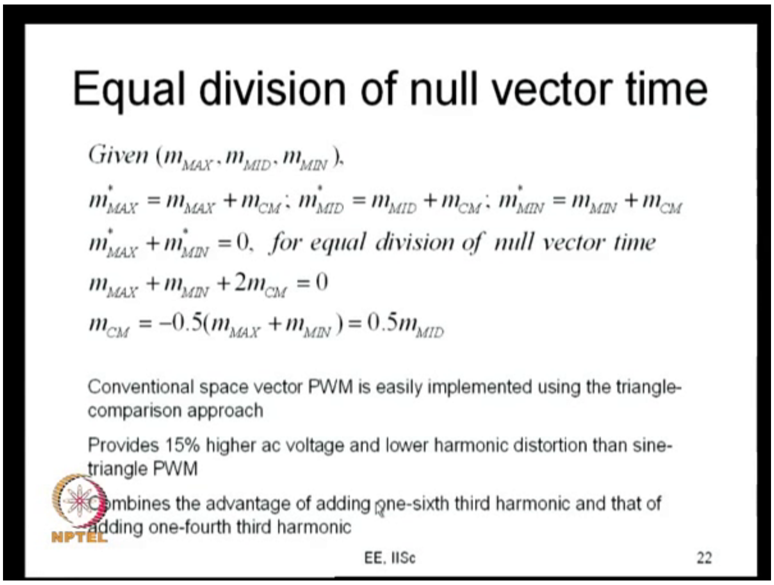
So, now what you can do is if you can see here T 7 is a little bigger than is a little longer than T 0. So, what you should do here is to add a small negative common-mode voltage to all the 3 you must add a negative common-mode voltage such that T 7 reduces and T 0 increase and both of them become equal. So, this is what you know you can see from this illustrative example and we can do this quantitatively we did this even in the last class which we will do this again now. So, as long as you know T 0 and T 7 may change, but T 0 plus T 7 there sum is unchanged. So, the null vector time T Z is not changed the active vectors times T 1 and T 2 are not changed. So, you will get the same reference vector right.

(Refer Slide Time: 19:31)



So, this is how the switching sequence goes as I just mentioned there, but only thing is T 0 is not equal to T 7 as I mentioned here.

(Refer Slide Time: 19:37)



If you want to make the null vector time equal this is what we are coming to. So, what we simply do is let us say this m R m Y and m B m R m Y and m B m R turns out to be the maximum value m Y turns to be the middle value and m B turns out to be the minimum value this is in sector one. In different sectors you know different things will be middle if you go to sector 2 for example, R phase will be the middle value if you go to sector 3 Y phase will be the middle I mean b phase would be the middle value and so on and so forth.

So, now in any phase you will have 3 signals one of them you will have the maximum value will be most positive another one will have the minimum value are the most negative value and the third one will be the closest to 0 and that is m mid. So, let us call this m MAX m MID and m MIN. Now you want to add common-mode. So, that common-mode is m CM. So, you define m MAX star, m MID star, and m MIN star which are obtained by adding m CM to m MAX m MID and m MIN respectively. So, as I have defined here now.

So, what do we want we want the null vector time to be equally divided between the 2 0 states if that has to be equally divided. Then m MAX star should be equal to the negative value of m min star that is what is needed. So, that you know your T 0 and T 7 times will be equal now. So, if m MAX star plus m MIN star should be equal to 0 will be the condition for a null vector time being equally divided. So, what is m MAX star it is m

MAX plus m CM; what is m MIN star it is m MIN plus m CM. Therefore, you get this equation m MAX plus m MIN plus 2 m CM is equal to 0. So, from this you get the expression m CM is minus 0.5 times m MAX plus m MIN and what is m MAX plus m MIN it is minus m MID because these are sinusoidal signals. So, m MAX plus m MID plus m MIN is 0. Therefore, you get 0.5 m MID remember m MAX plus m MID plus m MIN is equal to 0, but m MAX star plus m MID start plus m MIN star is not equal to 0 that is equal to 3 times the common-mode signal.

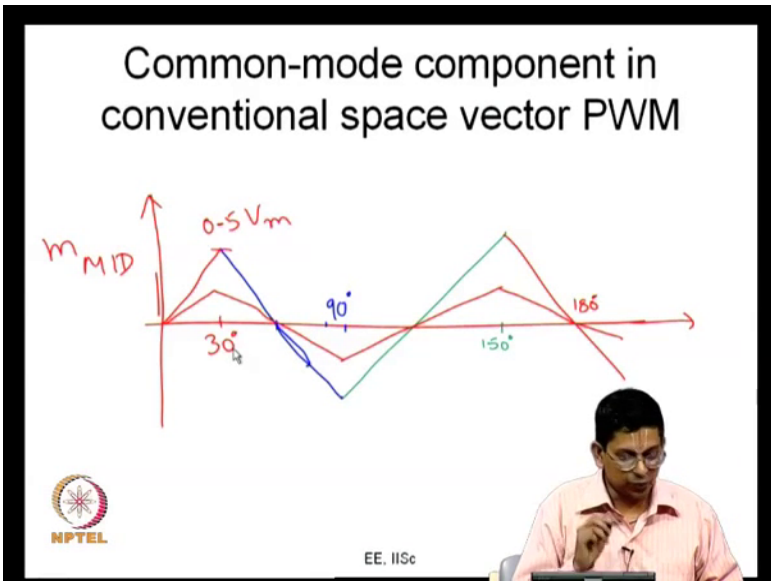
So, if you want the division of null vector time to be equal between the 2 0 states what you need to do is you have to add a common-mode component which is simply 0.5 times m MID, and this is what I have said before that you know if you want implement space vector PWM conventional space vector PWM rather than starting from the other end that is you know you know you start with revolving voltage vector and sample and then use the sample and calculate the times, if you have to calculate the times you it is sine 60 minus alpha and sine alpha are all needed.

So, you typically need sine tables. So, the values of the sine values of different angles from 0 degree to 60 degree need to be stored in a look up table etcetera. From that you have to do those calculations and then you have to output the waveform rather than doing all that you can easily implement using triangle-comparison approach how just as in sine triangle PWM you start with three-phase sinusoidal waves, and you always find out the middle value and take 50 percent of the middle value and add it and that will give you the signal and you compare that modified m R star, m Y star, m B star with your triangular carrier and that is your sine triangle PWM.

And this it provides 15 percentage higher voltage as I will also show you a little in a while and you know this actually combines the advantages of one-sixth third harmonic this 15 percent additional voltage, if you recollect the third harmonic injection if you had one-sixth third harmonic injection we can get 15 percent additional voltage. So, that is what I am saying here you are going to get that 15 percent again here and what happens is like in the 20 like in one-fourth third harmonic the T H D is also low actually the T H D is closely related to how the null vector time is divided between the 2 0 states we are dividing the null vector time equally here by doing this.

So, when the null vector time is and in the third harmonic case with one fourth third harmonic injection also the null vector time gets more or less divided equally. So, the T H D that you get is I know the line current distortion is pretty low in these 2 cases. So, conventional space vector PWM can be said to have the advantages of these 2 together of course, about the line current ripple etcetera we will look at it in the next module and we will particularly be dealing with the evaluation of line current ripple now.

(Refer Slide Time: 23:41)



So, what I was just trying to do is this previous one that you had this common-mode is equal to point 5 m mid let us just try and get feel for this one. So, what I will do is let me choose my horizontal axis and vertical axis now. So, I am starting from R phase and 0 crossing is where R phase has got it is 0 crossing plus trying to plot m MID. So, 0 degree to 30 degree if I look at 0 degree to 30 degree which phase has the lowest one, it is the R phase has the lowest one. So, let us say this goes like this now this is 0 to 30 degree now.

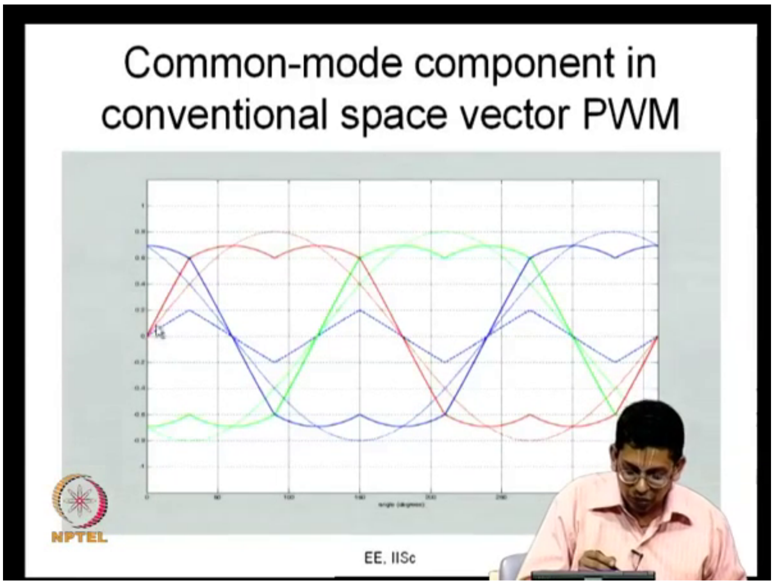
So, which is the other phase that is going to cross now the B phase would have a negative 0 crossing now let me just change it to color. So, the R phase would go like this the next middle value will be somewhere like this and this will see your 90 degrees. Then it would be the yellow phase let me choose a green color for that. So, the yellow phase would be the middle valued phase here this is like 100 and 50 degrees then 180 and goes still 2 10 now.

So, what I am trying to show say here is you have three-phase modulating signals, now in the first you know 0 to starting from 0 degree 0 to 30 degree of the three-phases it is the red phase that has the middle value. So, B and Y are you know one one higher and the other one is lower m MAX and m MID then at 30 degrees what happens the B phase you know R phase increases beyond some value and B phase reduces beyond this and this value is 0.5 times Vm the maximum peak of this now it is sine 30 whatever is your Vm sine 30 is this value now.

So, then the B phase has the middle value sine. So, of the 3 sins it is the B phase sine that has the middle value here and it comes something after this point let me also write this value sorry. So, this is going to be this is going to be 0.5 times Vm because it is Vm sine 30 degree and you know the initial portion between minus 30 and plus 30 degree sine wave is going to look almost like a straight line that is why I have drawn it almost like a straight line then it is B phase it is B phase then it is the yellow phase. So, 100 and 20 degrees is 0 crossing of the yellow phase waveform 90 degree and 150 degree between this yellow phase as the middle valued modulating signal the absolute value of the yellow phase is low in this region after that it is R phase again now. So, this is m MID and what is 0.5 m MID let us just draw that.

So, just 0.5 m MID is like this I am drawing throughout in a same color. So, this is 0.5 m MID in over half-carrier cycle I mean half a line cycle it goes on in the other places also right. So, you see this is the common-mode component this common-mode component looks roughly like a triangular wave it looks roughly like a triangular wave it has a peak value of something like 0.2 5 Vm it is not exactly a triangular wave it is a sinusoidal signal, but since sine closer to 0 crossing sine looks like a straight line. So, it is something like this now this is added as a common-mode to the three-phase sine waveforms which I am going to show now.

(Refer Slide Time: 27:43)



This is the original sine waveform say that this is the R phase sine waveform what is shown in the dotted line.

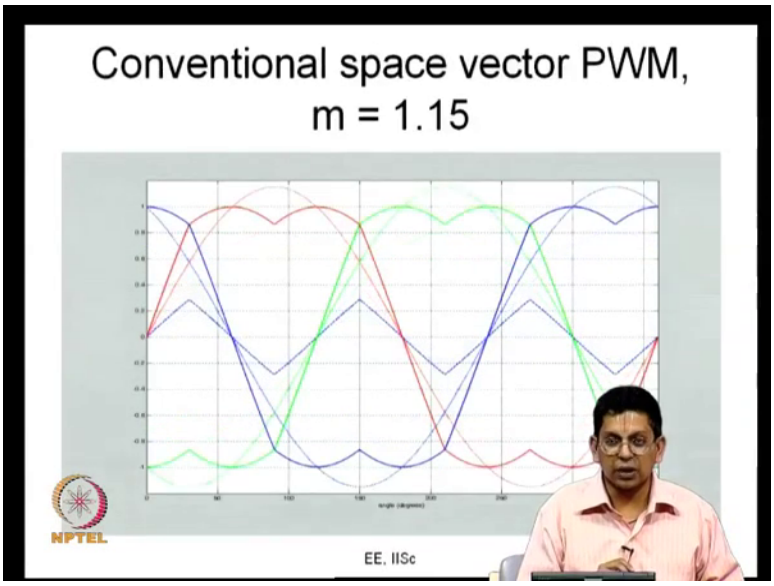
And this is the waveform that I hand drew earlier and this has been plotted using a computer program when I add up these 2 the R phase waveform on this common-mode component what happens is you know you see that, since the common-mode component is positive here this is more than that m R star is greater than m R and at this instant which is actually 60 degrees common-mode component is 0 and that instant m R star is equal to m R. Between 0 to 160 degree m R star is greater than m R because the common-mode component is positive and at 30 degrees you can see the change in slope, because the common-mode components slope changes change is there it is discontinuous the slope is discontinuous there this function MCM is in differentiable at that particular point right. So, you can see that here also.

And what happens then it becomes the same value and here it is negative peak. So, when m R is having it is positive peak and it is equal to V m MCM is having it is negative peak and this is how much V m and how much is this is 0.2 5 V m this is minus 0.2 5 V m now. So, V m sine 30 is 0.5 V m. So, this is half of that so in minus point to 5 V m. So, what you have here is something like 0.7 5 V m is what you have then and now so this is your m R star and once again you see that there something here say it has a turning point here and again it has a turning point here, and there is a change in slope and it comes back here this is m R star the same way you have my star and mb star which are all phase shifted time shifted by 90 degrees 100 and 20 degrees right.

So, now we can make a few clear observations you see this is your m R and it has some peak and I have taken it as pointed though it is not very clearly readable here it is pointed now. And m R star if you see has a lower peak value because whenever m R is going close to it is peak the corresponding common-mode voltage is negative and therefore, it brings down the value of m R star. So, this value is lower. So, what can you do it gives you the possibility of making this original sine waveforms peak greater than that of the triangular peak just as we did in third harmonic injection.

So, now we are analyzing conventional space vector PWM we have shown that it is equivalent and we are trying to do their analysis from the triangle-comparison approach and understand this better.

(Refer Slide Time: 30:32)

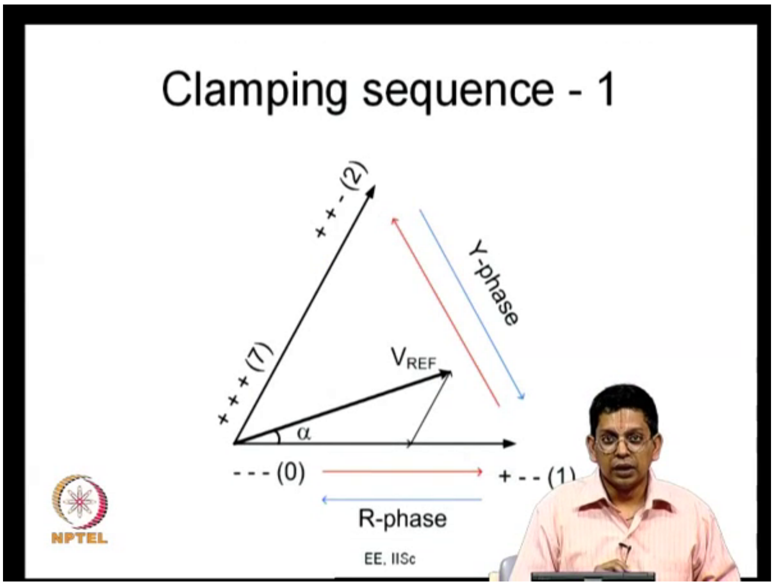


Now, here I am showing it for 1.15 which is roughly 2 by root 3. So, if I take it like this you see that now the sine wave goes about this horizontal line is one this is one actually if you can see that this is one and therefore, now this is this line is one you can see that it goes above that it goes something like 1.15, but what is happening you are adding a common-mode component like this because of adding this common-mode component this peak is coming down here and the peak of m R star is just touching 1 and 1 corresponds to the peak value of the positive peak of the carrier minus 1 corresponds to negative peak of carrier though the sine wave has peak value of 1.1 5 the you know or 2 by root 3 actually speaking, the m R star my star and m B star they only have values equal to 1 which is the peak of the carrier thus without going into over modulation you are able to increase your AC output.

So, your ac output increases by 15 percent this is a claim that I made a couple of slides back and even I made this claim in the last lecture also I am just demonstrating that I am proving that in one particular way this can also be proved in the space vector terms itself you can see what is the highest value of v ref which we will do it and from there you can come to this. In fact, for all the space vector base PWM methods the voltage can be 15 percent the ac voltage can be 15 percent higher than what you can get with sine triangle PWM not only for conventional space vector PWM will discuss this little later right.

So, this is what now you can see that this is from the looking at the 3 modulating signals are the 3 equivalent modulating signals you can very clearly understand that is conventional space vector PWM gives you 15 percent higher fundamental voltage than what sine triangle PWM can give for the same dc voltage right.

(Refer Slide Time: 32:16)



So, we just go into the variant which is what I actually want to discuss this class one of the main things is about bus clamping PWM the other thing is on the equivalence, I dealt with the conventional space vector PWM at some line today just to underline the equivalence between the triangle-comparison and the space vector approach.

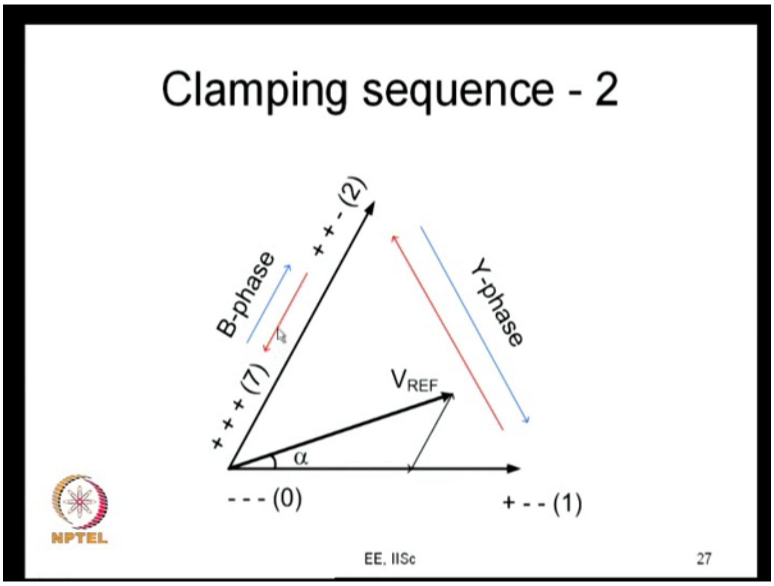
So, now let us look at what we call as a clamping sequence as you see you want apply null vector you want apply active vector for T 1 seconds, and active vector to for T 2 seconds, you want apply null vector for T Z seconds. It does not matter whether you apply 0 or 7 you can produce same average vector this average vector can be produce if you apply this for T 1 seconds and this for T 2 seconds, and the null vector for T Z seconds it is not necessary that you know you can apply both of them for equal this 0.5 T Z and 0.5 T Z are this can be 0.4 T Z, this can be 0.6 T Z, this can be 0.2 T Z that can be 0.8 T Z or as a special case only this state can be applied for the entire T Z are only this state can be applied for the entire T Z.

Now, we are considering a particular situation where we are totally ignoring this 0 state plus plus plus that is the 0 state 7 in a particular subcycle we want this reference vector we are trying to produce only with these 2 active vectors and this 0 state alone. So, how do you do you start from here let us say you apply this 0 state 0 for the entire T Z seconds not not half of T Z not 50 percent 60 percent or 70 percentage of T Z for the entire T Z you apply minus minus minus. Then at the end of T Z you switch your R phase and you go to plus minus minus and state this state for T 1 seconds and then you switch your Y phase and stay there for T 2 seconds that would be the end of your subcycle.

Now, in the next subcycle what you do is you stay here and apply this vector for T 2 seconds or T 2 dash seconds, then switch your Y phase and come here and apply the active state one stay here for T 1 dash seconds, then what you do your switch your R phase and go back here and apply the state for T Z dash seconds. So, you can you know this is what I would call as clamping sequence 1, this is a different sequence earlier sequence we call it as conventional sequence you start from this 0 state go to active state one active state 2 and go to the other 0 state.

Now, you are skipping one 0 state and I am calling this clamping sequence why I am a calling clamping sequence because you see here minus minus minus all the three-phases are connected to the negative bus, here R phase gets connected to positive bus and here Y phase also gets connected to positive bus, but you look at B phase it is negative here it is negative here it is also negative here what does it mean B phase is not switched at all B phase is clamped to the negative DC bus over the entire subcycle therefore, we call the sequence as clamping sequence this is clamping sequence this is one possible clamping sequence.

(Refer Slide Time: 35:04)



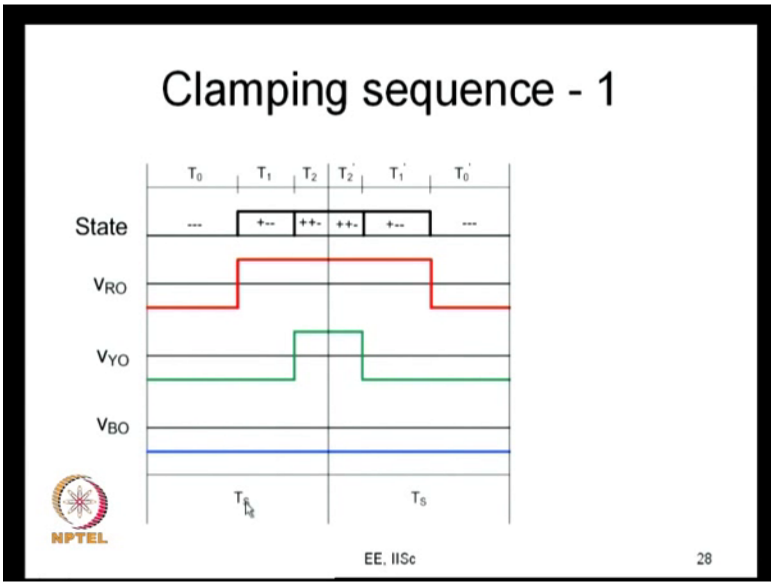
There is another kind of clamping sequence what is that you can totally ignore this 0 state minus minus minus instead you can use the 0 state plus plus plus.

So, let us say you start from plus plus plus you apply this for T Z seconds, then what do you do switch your B phase you go to plus plus minus stay there for T 2 seconds, then switch Y phase go to active state 1 and stay here for T1 seconds that is the end of subcycle. The next subcycle stay here for T 1 dash seconds switch Y phase go to this active state 2 and stay here for T 2 dash seconds and switch B phase and stay here for T Z dash seconds. So, this is again another clamping sequence.

Now, what happens minus minus minus is never used and only plus plus plus is used and therefore, you look at the 3 states now here all the all of them are positive here R and Y are positive here R alone is positive and you can see that R is positive everywhere and therefore, R phase is getting clamped to the positive DC bus here. So, the earlier case it was B phase getting clamp to the negative bus in this case it is the R phase getting clamp to the positive bus, this is I am calling as clamping sequence to you know just you have to give some name and you have to distinguish between this and that.

So, the earlier clamping state uses the 0 state minus minus minus this is the clamping sequence which uses a 0 state plus plus plus and the now I see other 1.

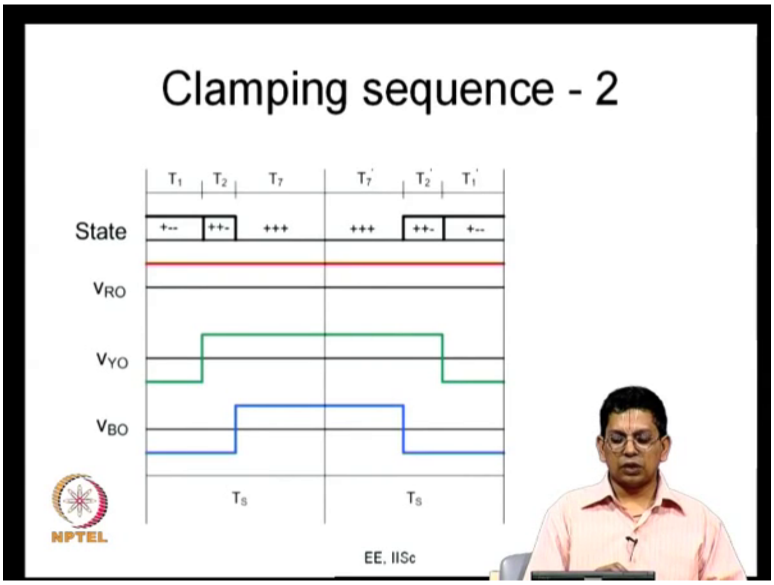
(Refer Slide Time: 36:29)



So, I am showing the same thing you know; what is the time the horizontal axis is time here. So, the states are applied 0 1 and 2 or applied for durations T 0 T 1 and T 2 and in the next subcycle it is applied first times T 2 dash T 1 dash and T 0 dash as I told you before you know at steady state the V ref will be same for both of these cases, but the alpha will be different and therefore, your T 2 dash and T 1 dash will slightly differ the delta is will differ that is why I am calling T 2 dash instead of T 2 and T 1 dash instead of that that the difference is of course, small and sometimes you can also use the same dwell times in and a pair of half-carrier cycles. So, that is that is also fine right.

So, one would be called an asymmetric sampling other one would be called a symmetric sampling this is asymmetric case, the other case when you have the same T 2 and T 1 used here you call it asymmetric sampling all right.

(Refer Slide Time: 37:21)

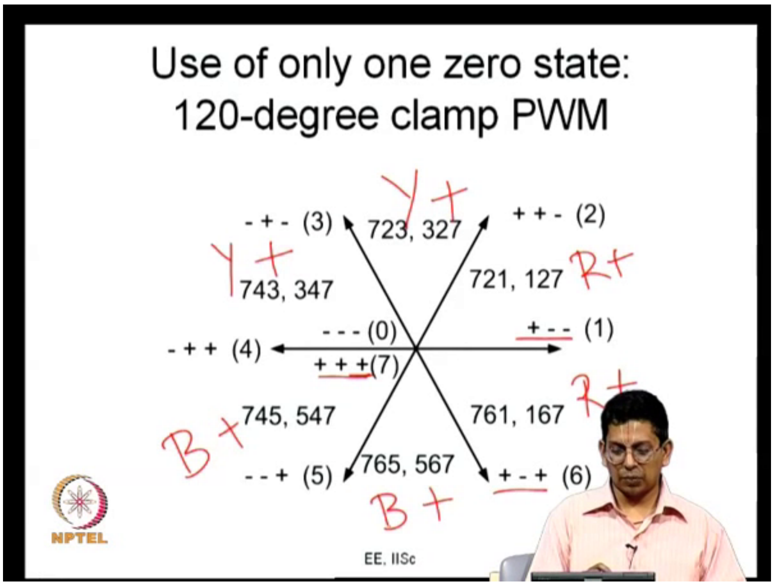


So, now let us say with the other clamping sequence again you get the same kind of situation now. So, difference let us go back and see R phase switches here like before except that except instead of T Z by 2 this is equal to T Z. So, for T Z seconds it is low and then like this now, how about Y phase it switches here the R phase duty ratio is lower than what it was with conventional sequence, the Y phase duty ratio is also lower than what it was it conventional sequence, and B phase duty ratio is also lower than what it was at the conventional sequence and the B phase duty ratio is 0 the B phase duty ratio is 0 it is always connected to the negative bus and it is average value is equal to minus V D C by 2.

So, you cannot go lower than that. So, you have to in like this is this is now B phase is getting clamped to the negative DC bus. In the other case you see the R phase is getting clamp to the positive DC bus what has happened here the conventional switching sequence, you know the difference between here and there the convention the duty ration of R phases increase and it has become equal to 1 you cannot go higher than that it is 1 and then the duty ratio Y phase is also increase in that of B phase is also increased now this is R phase getting clamp to the positive DC bus now.

So, now if I use only 1 0 state throughout this is only 1 0 state in one carrier half-carrier cycle this is 1 the same 0 state in the next half-carrier cycle also. So, you find that R phase is clamped here and you also find that R phase is clamped here now, if you kind of use the same kind of sequence everywhere what will happen R phase will continue to be clamp to the positive DC bus over that entire sector at least.

(Refer Slide Time: 38:54)



So, now this is what I am trying to do I am using 7 to 1 and 1 to 7 in alternate subcycles in sector 1.

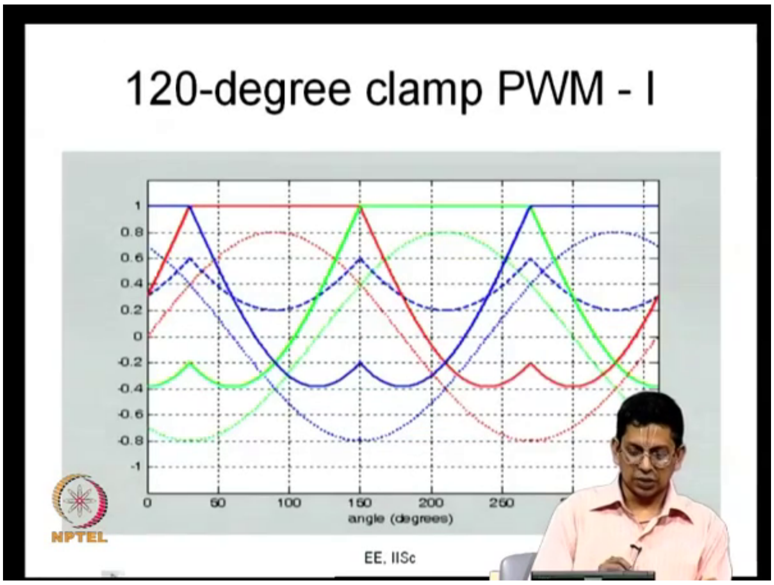
So, 7 meaning plus plus plus, 2 meaning plus plus minus, and 1 meaning plus minus minus so what happens is R phase is getting clamped to the positive DC bus here. Let me just write it down let me write down I am oh sorry R phase is clamped to the positive DC bus here, next what happens you just look at the previous case here 7 6 1 if it is 7 it is plus plus plus and if it is 6 this is plus plus plus 6 is also plus minus plus 1 is also plus minus minus. So, in all the cases R phase is clamped to the positive bus, R phase is clamped to the positive bus over the entire sector in every subcycle in sector 1 it is clamped to that in sector 6 also it is clamped to the positive bus now.

Let us go to the next sector 7 2 3 7 meaning plus plus plus, 2 meaning plus plus minus, and 3 is minus plus minus. Here you find that Y phase is clamped to the positive bus. So, this is Y phase is clamped to the positive bus in every subcycle in sector 2 and how about sector 3 7 4 3 7 is plus plus plus and 4 is minus plus plus and 3 is minus plus minus. Here again you find Y phase is clamped to the positive bus in every subcycle in this one. Therefore, you know just whatever what is remaining you know it is not very difficult to guess that in the other 2 sectors B phase is going to be clamped to the positive bus let us just check that 7 4 5 7 all of them are positive between 4 and 5 you look at. So, between 4 and 5 plus you know what is positive in both cases it is B is positive and plus plus plus also B is positive. So, B is clamped to the positive bus in this entire sector here again B is clamped to the positive bus in the whole sector this is what you get.

So, for entire 100 and 20 degree R phase is clamp to the positive bus Y phase is getting clamped to the positive bus for another 100 and 20 degree B phase is getting clamp to the positive bus for another 100 and 20 degree now. So, we can just also do the same thing using there is just to emphasize the equivalence between this and the triangle-comparison approaches, you can apply this 1 to 7 or 7 to 1 for example, if you are doing that what you get I showed you that V R O is always positive V Y O switches like this and V B O switches like this V B O switches like this and you can once again look at what is V R O average V R O average is same as V R O itself and you can consider an equivalent m R star and V Y O as this V Y O average is shown by the dashed line here and m m Y star is a scaled version of that equivalent modulating signal.

Similarly, V B O average is know something very close to 0 in this case and this m B star, now m R star my star and m B star can be compared with the triangular carrier as we did before and if you can start with m R star my star and m B star are you can start with m R m Y and m B and add a suitable common-mode component we do not know what it is exactly, but it if you can find out you can add that common-mode component m R star m Y and get m R star m Y star and m B star and you can simply compare with triangular carry.

(Refer Slide Time: 42:24)

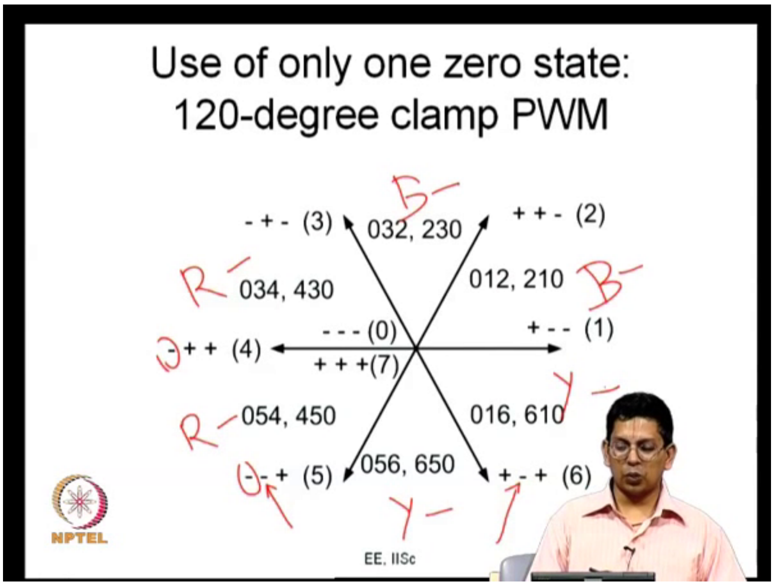


So, this switching instance can be determine in either from the space vector point of view or from the triangle-comparison point of view if you are using this sequence is now. So, how would you are equivalent modulating signals be this is how the equivalent modulating signals will be if you work it out and as I showed you R phase is positive in 2 sectors for 100 and 20 degrees here and you know this is Y phase is positive for the next 2 sectors and B phase is positive for the next 2 sectors, and what you are actually adding is a positive common-mode component as we were discussing earlier there is a positive common-mode component and there is a negative common-mode component is possible now.

So, here what I doing you are taking the phase which is going to the maximum value V max and you are subtracting V peak minus V max to get this common-mode component. And R phase has got the highest value between this 30 to 150 degrees as the most positive you are subtracting V peak minus R phase and that is your common-mode component, the next one 20 degree you are doing the same with Y phase instead of R phase, and the next one 20 degree with the B phase instead of R phase and. So, your common-mode component is like this is what we did as 100 and 20 degree clamp we saw one example here and this is what now and it is bad in one sense why you see that the duty ratio here it is very high and it never goes that negative that is the top device is continuously on here.

So, the conduction loss on the top device is much higher than the conduction loss on the bottom device and that is going to lead to an anyone loading of the top and bottom devices. So, what we studied as hundred and 20 degree clamp here is same as what we saw here a while back this is to show the sequences this is show that they are equivalent at a subcycle level and this is how the modulating signal is going to be here is m R star m Y star and m B star are there, this is only to indicate how m R star my star and m B star are and this is the common-mode component if you subtract that common-mode component from m R star you will get your original m R, or you start from m R my m B you add this common-mode component you get this m R star my star m B star compare you triangular carrier you can produce the same PWM signals.

(Refer Slide Time: 44:15)

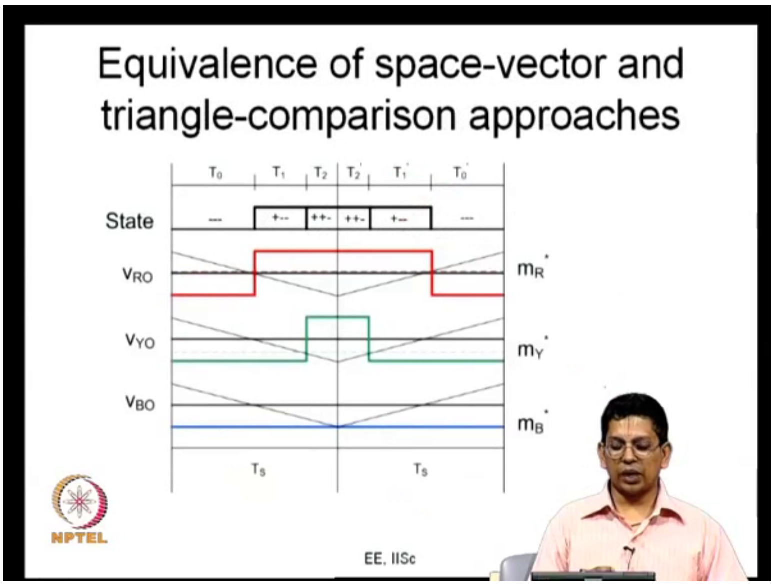


Next let us say instead of 0 state 7 I use only 0 state 0 throughout you see that everywhere it is 0 is written and 7 is never written in the sequences now in the entire sector 1 I use 0 one 2 2 10. So, 0 meaning minus minus minus say plus plus plus at all. So, here what will happen let us just write it down, which phase is going to be clamped, it is B phase which is going to be clamped, and B phase is going to be clamped to the negative bus how about here it is 0 2 3 0 meaning minus minus minus 2 meaning minus plus minus and here it is plus minus minus. So, here again it is b phase is going to be clamped to the negative bus.

Now you look at the next sector it is 0 3 4 0 is minus minus minus, 3 is minus plus minus and 4 is minus plus plus. So, R phase is always negative and therefore, here R phase would get clamp to the negative bus. And if you look at this sector 4 the states used are 0 5 and 4 0 meaning minus minus minus and 5 is minus minus plus and 4 is minus minus plus and it is always minus here everywhere this is B phase is always negative. Therefore, I mean I am sorry R phase is negative. So, R phase is negative here how about the next one you see that 0 5 6 and 6 5 0 zero is minus minus minus and 5 is minus plus minus this is minus and here in 6 also it is minus here.

So, why is negative everywhere here. So, in this if you use these sequences in every subcycle in sector 5 you have Y phase clamp to the negative bus and similarly in sector 6 also you will have Y phase clamp to the negative bus now. So, here instead of every phase getting clamped to the positive bus for one 20 degree you find a situation.

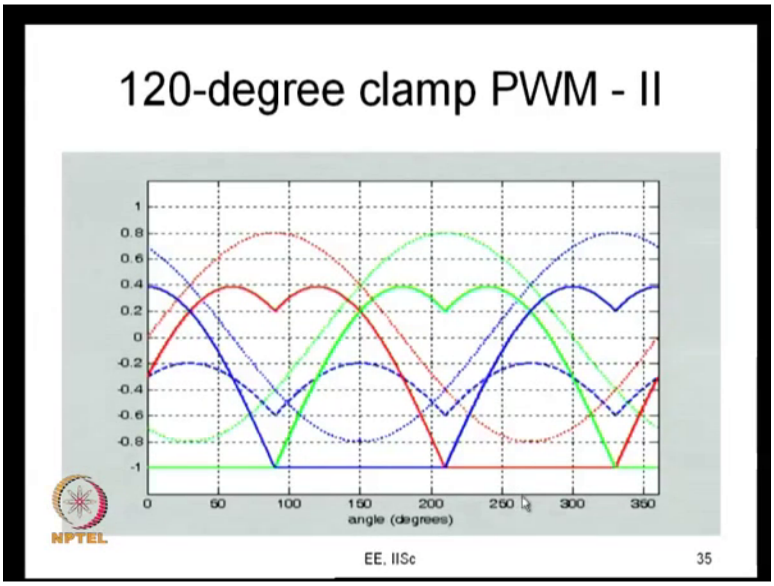
(Refer Slide Time: 46:04)



Where every phase is getting clamp to the negative bus for 120 degree very similar to the other 100 and 20 degree clamp method we saw before, just you know you can to emphasize the equivalence you produce 0 1 2 etcetera this you can come up from this phase vector point of view that is start from the revolving vector and sample and calculate the dwell times and output the states, from there you get VRO VYO and VBO as indicated here the same three-phase pole voltages can be produced by considering these m R star m Y star.

Now, this is V R O average V Y O average and V B O average m R star m Y star and m B star are scaled versions of that you can start with m R, m Y, m B add some common-mode component such that you get this m R star m Y star and m B star and you can compare with the triangular carrier now. So, the only question is; what is this m R star m Y star m B star and what is the common-mode component to be added the answer is here.

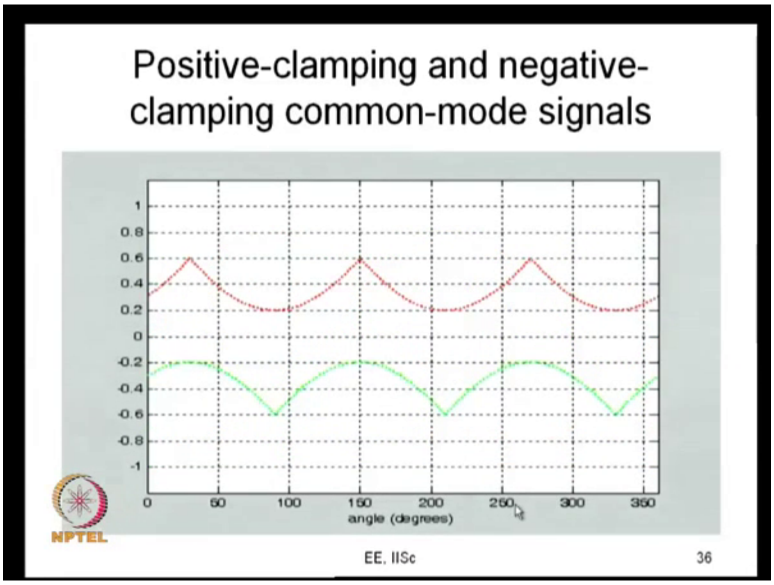
(Refer Slide Time: 46:51)



Your m R star is actually this while this sine wave is the original m R your m R star is this.

Similarly m Y star m B star and what is the common-mode component, this is the common-mode component, this is the negative common-mode component, this is again bad in one sense because the bottom devices will have greater conduction losses than the top device would have and the top on the bottom devices will have unequal loading will have different levels of dissipation now.

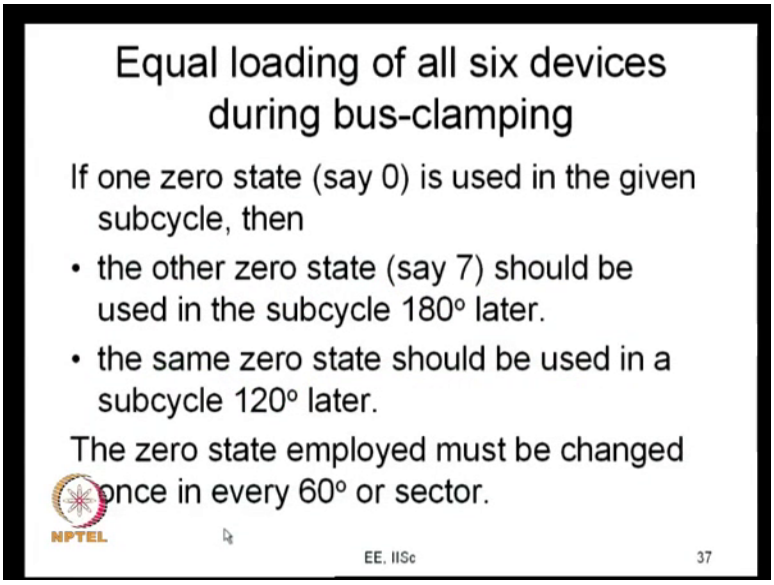
(Refer Slide Time: 47:18)



So, as we saw earlier the common-mode component; if you want to do bus clamping you should either add the positive common-mode component. So, that one of the phases will get clamped to the positive bus are the negative common-mode component. So, that the one of the phases are the m min would get clamp to the negative DC bus.

Now, what we saw was if you if you add this throughout what happens the average value itself shifts to the positive or if you add the negative common-mode every throughout negative gets shifted to negative value and therefore, it is either you know the top and the bottom devices are going to be loaded unequally. So, this is what happens now we are looking at the same thing from the space vector point of view.

(Refer Slide Time: 47:55)

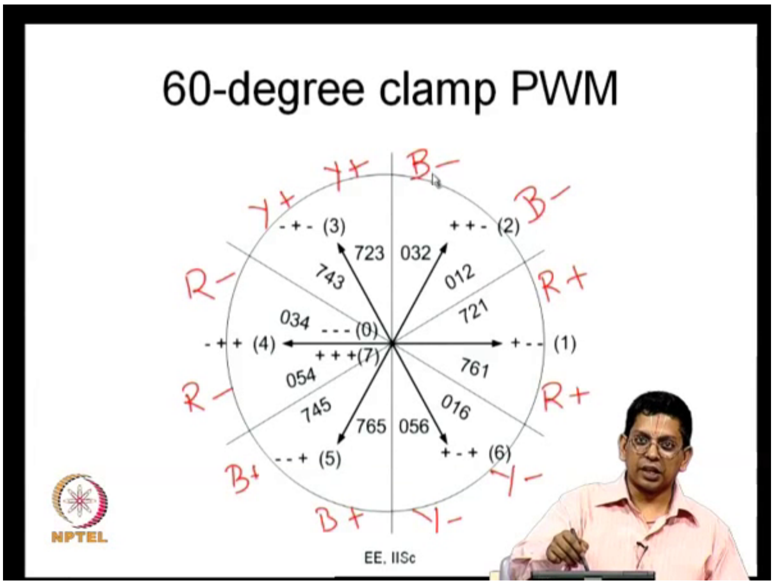


So, if we do not want this unequal loading you want equal loading of all 6 devices during bus clamping, now when you are doing bus clamping that is you are going to use only 1 0 state in a subcycle still you want equal loading what you should do if you use 1 0 state let us say 0 or minus minus minus in a particular subcycle then you should use the other 0 state 180 degrees later.

So, this must be needed for half wave only then the top on the bottom we know will have the same amount of losses and the same way if you are using a particular 0 state 0 in this subcycle 120 degrees later you must use the same 0 state only then whatever is condition subjected to R phase, the same condition Y phase will also be subjected to and the B phase will also be subjected to that now the first condition is a half wave symmetry condition and the second condition is a three-phase symmetry condition.

So, you combine these 2 what you will get is the 0 state employed must be changed once in every 60 degree or sector it must be changed once in every 60 degree or sector that is the rule. Now earlier we can say that you should follow this for 60 degree and follow this for 60 etcetera etcetera. Now I am just trying to put that idea in terms of 0 state the 0 state must be used once in every 60 degrees.

(Refer Slide Time: 49:09)



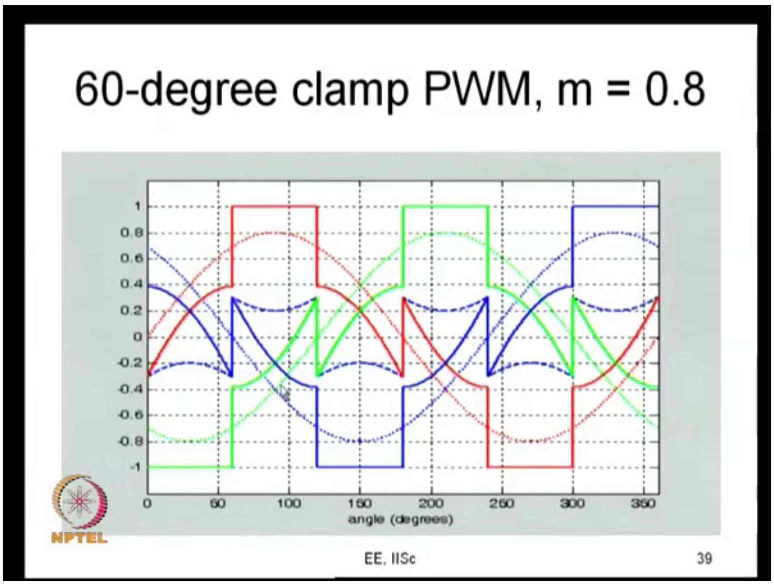
And how are you going do that one example is the 60 degree clamp we are going to change the 0 state in every 60 degree where am I changing now let us say I use the 0 state 7, 7 2 1, 1 2 7 etcetera is used in the alternate subcycles here I am just writing 7 to 1 what do I mean by 7 to 1, if I use 7 2 1 in the subcycle in the next subcycle I will use 1 2 7. So, 7 to 1 and 1 to 7 will be used in the alternate subcycle this is the meaning here.

So, I use 0 state 7 I change the 0 state from 7 to 0 at the middle of sector 1, this is a 30 degree line right then I start using 0 1 2 0 1 2 2 1 0 I move to sector 2, but I still continue to use the same 0 state 0. So, I use 0 3 2 2 3 0 would be the switching sequences I will use now at the middle of sector 2 I change from 0 to 7. So, again at the middle of sector 3 I changed from 7 to 0. So, you can see that you know I go on like this 0 state 7 is used here 0 state 0 is used here 7 is used for 60 degree 0 is used for 60 degree.

So, I am changing once in every sector where I am changing I am changing at the middle I am changing at the middle I am changing from 7 to 0 in sector 1 I am changing at the middle if I do this what will happen let us just see. So, if you say 7 to 1 what happens is R phase is getting clamped to the positive bus you are avoiding the 0 state 0 that is minus minus minus. So, R phase will get clamped to the positive bus and here also what will happen R phase will get clamped to the positive bus and if you go around you can see that is 0 1 2. So, minus minus minus 1 is plus minus minus and here plus minus minus you can see that B is clamped to the negative bus here. Again in this 30 degrees also B is clamped to negative bus here, you go little further now this is R phase is clamped here around activator 1 around activator 3 Y phase should be clamped that is what is three-phase symmetry right. So, it will be Y plus and Y plus here, the same way you can see from half wave symmetry if it is R plus and R plus here around vector 1 it will be R minus and R minus here the same way you can say this is going to be B plus and B plus here and what do you have here Y minus and Y minus.

So, you can see that every phase is now getting clamped to a bus for 60 degree duration now. R phase is getting clamped to the positive bus or 60 degree followed by B phase to the negative bus for 60 degree and then Y phase 60 degree and R phase to negative bus for 60 degree and. So, you go around both these things.

(Refer Slide Time: 51:42)

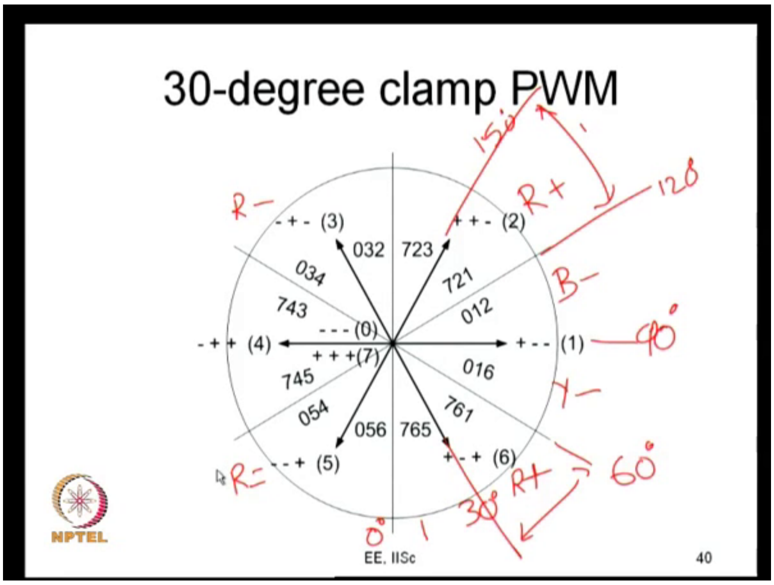


Now, what is this is the earlier 60 degree clamped we saw.

So, this is nothing, but you are following the positive common-mode and the negative common-mode alternatively like in this fashion and you see that R phase is clamped during the middle 60 degree duration Y phase is clamped during the I mean every phase is getting clamped during the middle 60 degree duration of a positive of cycle. Now, this is R phase it is the positive of cycle of R phase this is the middle 60 degree duration of the R phase it is getting clamp to the positive bus.

Similarly, this is the negative half cycle of R phase during the middle 60 degree duration is getting clamped to the negative DC bus similarly R Y and B. So, what we did a 60 degree clamp by adding common-mode component is the same thing being done this way right.

(Refer Slide Time: 52:27)



Then now you look at the other way again I am changing the 0 state at the middle of every sector, but the change is now from 0 to 7 at the other way now. So, if I do like this you can see what the states are now.

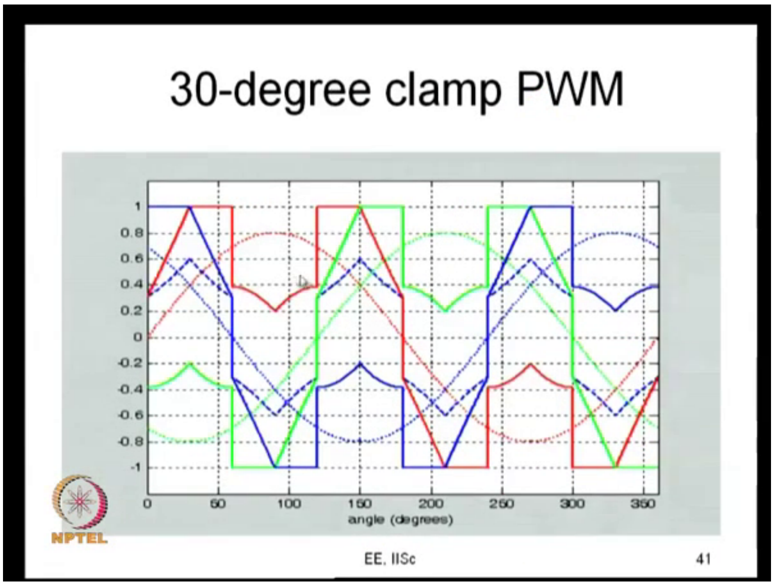
So, in this case what will happen in sector 1 R is getting clamped to positive bus here and this is getting clamped to negative bus here, but some more study you can also find that R would get clamped to the positive bus here and in this case it would be Y getting in 0 1 6 if 0 is minus minus minus 1 is plus minus minus and here it is plus minus minus it would be Y getting clamp to the negative bus here.

So, you can go about doing the same thing in various situations you will find that it is R will be minus here and here again R would be minus here now. So, if you look at this line corresponds to 90 degrees this line corresponds to 90 degrees that is the R phase is going through the peak. So, that is the instant 90 degree now. So, this line is 60 degrees that is at the instant 60 degree the vector will be aligned here and this is 0 degree at the instant 0 degree the vector will be aligned here at the instant 30 degree the vector will be along this axis and this is 60 degree this is 90 degree and so on.

So, what you find is R phase is clamped between 30 and 60 degree and similarly R phase is clamped between 120 and 150 degree this is 150 degree is clamped between 120 and 150 degree. So, R phase is clamped during if you take this is 1 quarter cycle just one quarter cycle 0 to 90 degree R phase is clamp during the middle 30 degree duration of every quarter cycle, again it is clamped during the middle thirty degree duration of this quarter cycle.

Similarly, R phase is clamped during the middle thirty degree duration to the negative bus here again R phase is clamped to the negative bus.

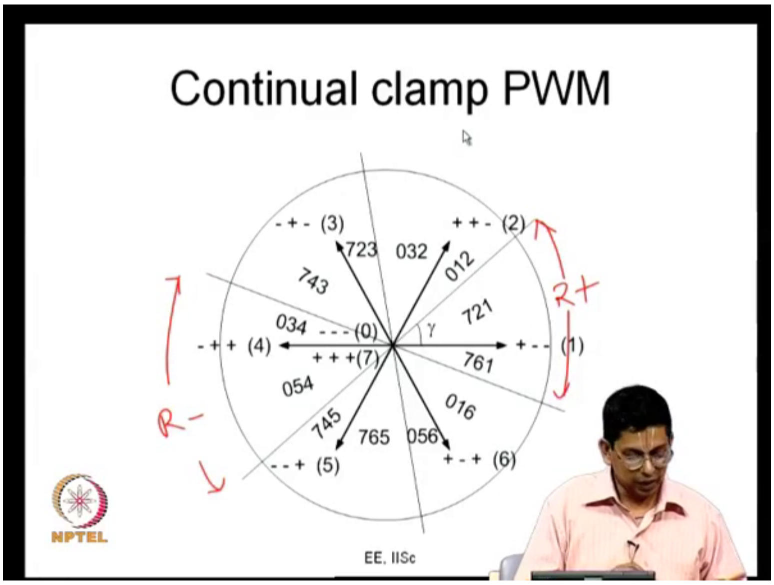
(Refer Slide Time: 54:24)



So, the PWM signal would look like this the m R star m Y start the equivalent modulating signals would look like this you see that the R phase is clamped like this to the positive bus here, it is clamped to the negative bus and the modulating signal added is shown here this dashed line blue line this dashed blue line.

So, this is 30 degree clamp you can start from the three-phase sine waves and add this common-mode component and get these modulating signals and compare them with triangular carrier and do the generation or you can do is the same way. So, either you do it from the space vector point of view are the triangle-comparison point of view you are going to generate the same PWM waveforms at the end.

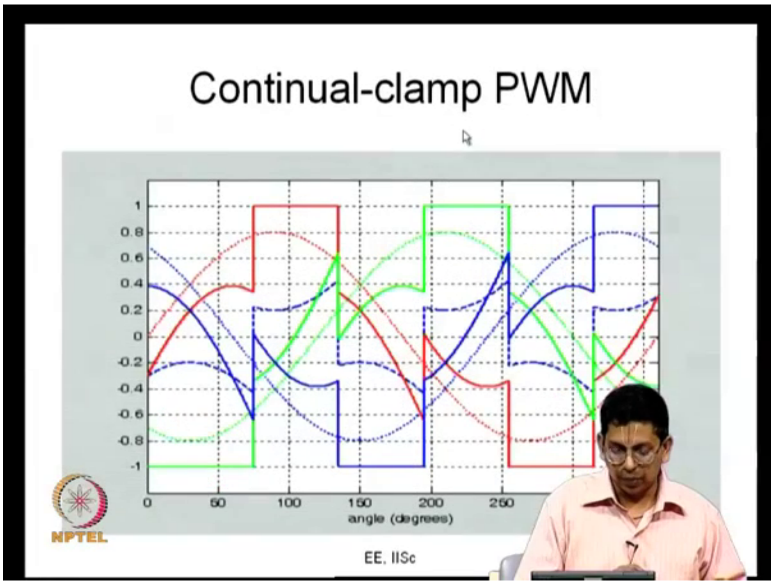
(Refer Slide Time: 55:06)



This is what you are going to get now. The 60 degree and 30 degree are special cases now continual clamp is general case of our earlier 30 degree clamp I mean 60 degree clamp earlier from 7 2 1 to 0 1 2 we change exactly at the middle 7 2 1 to 0 1 2 we change in the middle of the sector now it does not have to be at the middle of the sector you decide certain angle gamma, this gamma is equal to 30 degrees a special case the gamma can be anywhere between 0 and 60 degrees it can take any value between 0 and 60 degree now.

So, this would lead to r phase getting clamped where would R phase get clamped you can see that R phase would be clamped over this interval R phase will be clamped over this interval and R phase clamp to the positive bus. Similarly R phase will get clamp to the negative DC bus over this particular interval now. Again so R phase is continuously clamped for 60 degree duration it is continuously clamped for 60 degree duration here again it is continuously clamp for 60 degree duration to the negative bus therefore, we call it continual clamp PWM, and the modulating signal would look like this now.

(Refer Slide Time: 56:05)

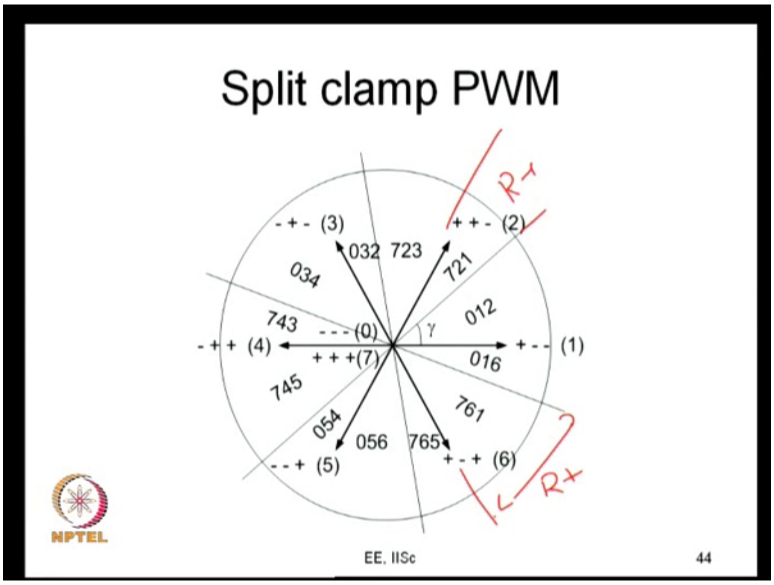


So, this depends on the value of gamma where exactly and you know this it can start from here over a 60 degree duration, this can be as low as 30 and as low here 90 degree and this instant can be as low as 90 and as low as 100 and 50 degrees now. So, this is your R phase signal this is the m R and this is the m R star this is the modified R phase modulating signal.

So, what you can do is again you can start from sine wave as shown here and then add a common-mode component as shown in the dashed line which we discussed before and get these kind of modulating signals as shown in the solid red line and so on. And compared with triangular carrier or you can do it from the space vector approach start with a circulating revolving rotating revolving reference vector sample and find out the nearest active vectors calculated the dwell times and output the states you can do that again.

So, this way or that way is the same for you, you will get of the same PWM waveform.

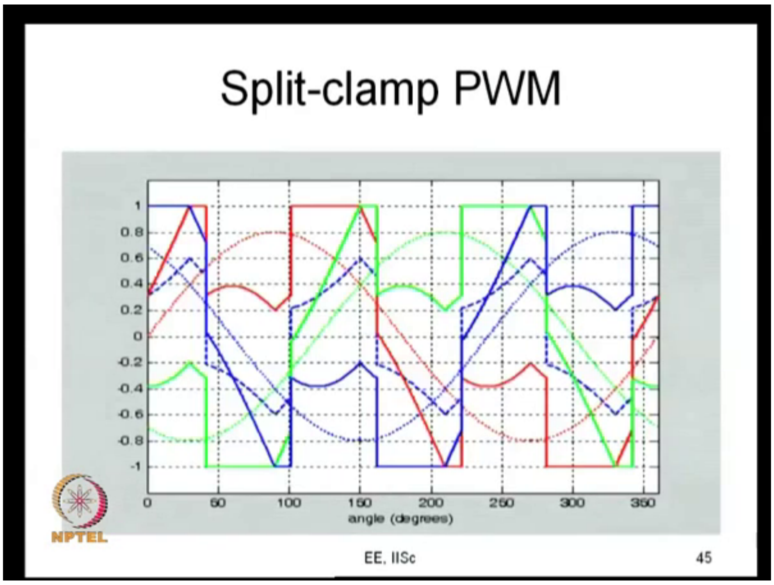
(Refer Slide Time: 57:01)



The same thing about split clamp PWM method. So, what we did here was we had 7 to 1 here and 0 1 2 first and here instead we have 0 1 2 first and 7 2 1 next those are the only 2 possibilities and the changeover can occur at any gamma the gamma can be anywhere between 0 and 60 degrees. Now, what will happen you have R phase this R phase is clamped to the positive bus in this interval and here again R phase is clamp to the positive bus.

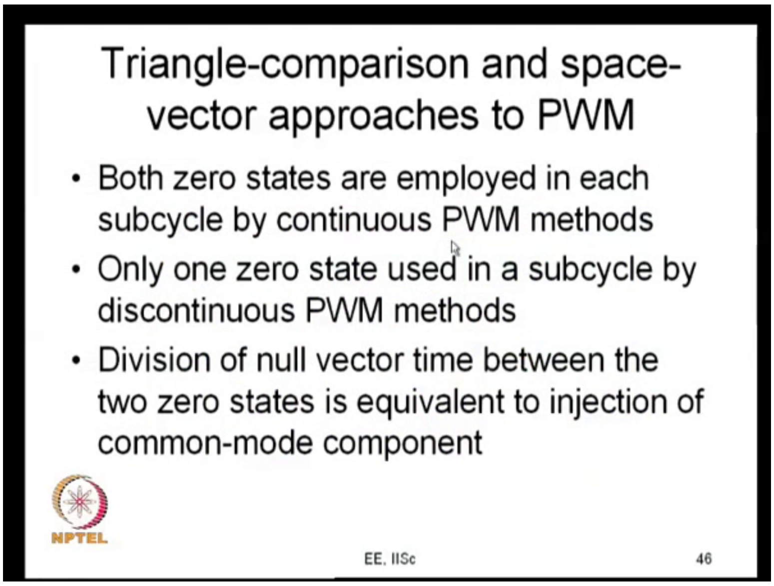
So, this interval these 2 intervals are not equal as a special case there can be equal to 30 degree this interval is equal to gamma this interval is equal to 60 minus gamma. So, for some interval gamma and some interval 60 minus gamma R phase is clamped to the positive bus. And you will find the same thing symmetrically everywhere and the equivalent modulating signals would look something like this.

(Refer Slide Time: 57:47)



So, this is split clamp PWM and you can see how they are equivalent it is easy to see the idea of continual clamp and split clamp from the space vector point of view because you have to change the 0 state once in a sector and you know that is at an angle gamma you can use 0 1 2 first and 7 2 one next and so on and so forth.

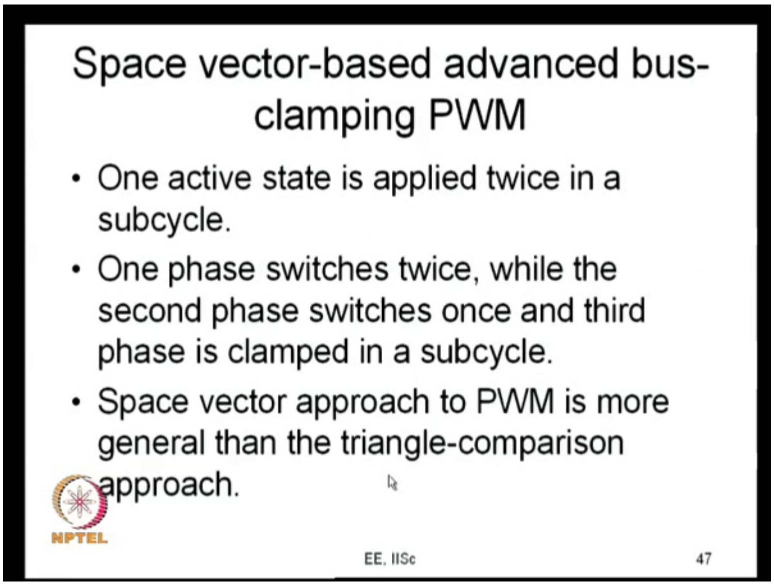
(Refer Slide Time: 58:05)



So, this is split clamp PWM and this is I am just trying to say that the 2 are equivalent.

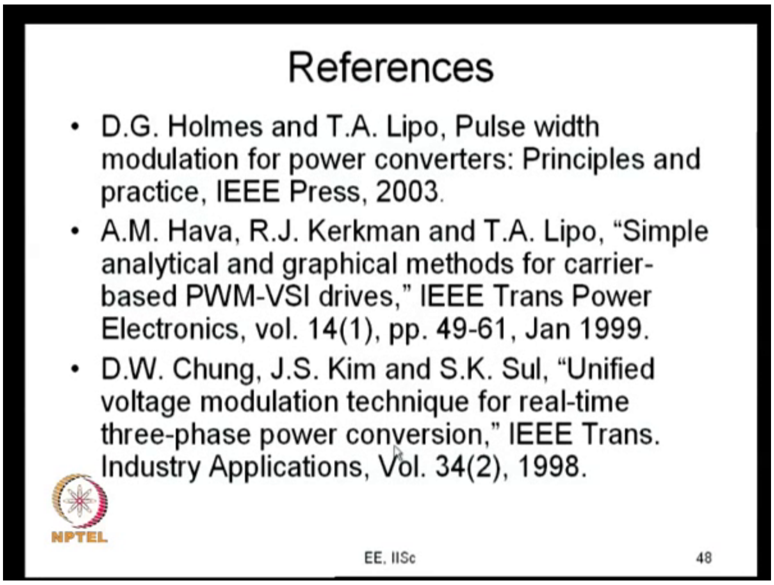
So, they are approaches you both the 0 states are used by continuous PWM methods only 1 0 state is used by discontinuous PWM method and the null vector time division is is what determines the equivalent common-mode component now.

(Refer Slide Time: 58:23)



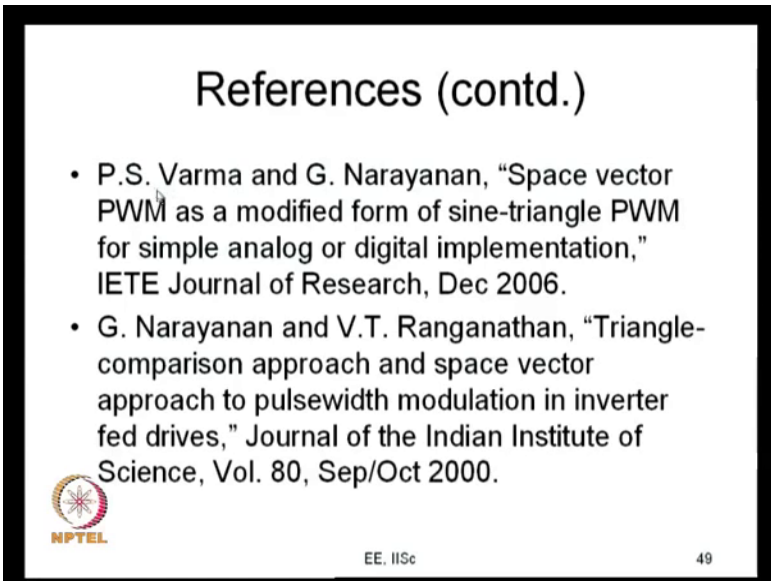
We will be emphasizing these points again and again for a while and in the space vector PWM, what we want to say is 1 active state is applied twice in a subcycle there are some advanced bus clamping PWM which we will discuss specifically in the next one this is a more general version of you know to show the space vector approach is more general than triangle-comparison approach. So, this is what we will do here.

(Refer Slide Time: 58:43)



Quickly some references here these are some papers or this is a book and these 2 references are papers on this area.

(Refer Slide Time: 58:50)



And this is a kind of which I have shown earlier also this is a tutorial paper on this and this paper is on the triangle-comparison and the space vector approach thank you very much for your interest. And, I am hoping to see you again in the next lecture.

Thank you very much.