Power Electronics

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Lecture - 27

Space Vector PWM

Part # 2

In last class we introduced the concept of space vector and for a sinusoidal excitation, the voltage space vector will rotate with uniform velocity and the tip of the vector will trace a circle. So, in our PWM operation, we want the average variation of the voltage space vector.

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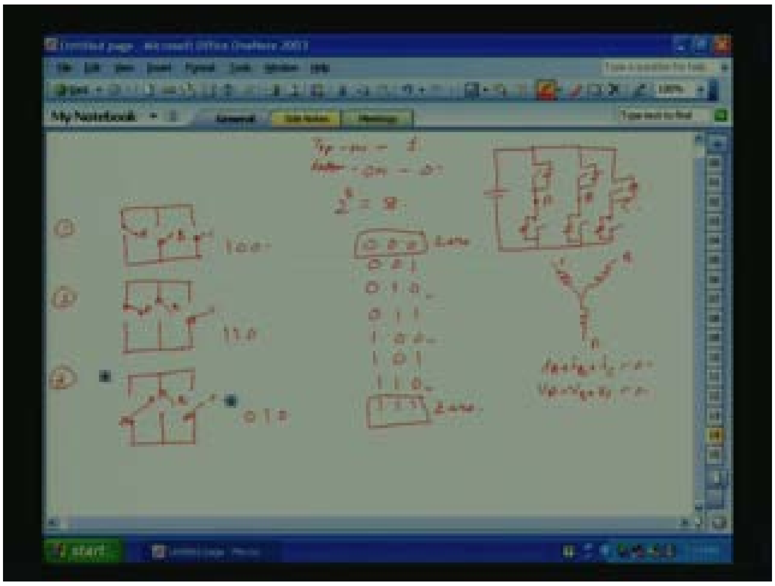

Now, let us draw our inverter. So, inverter is this is our dc link voltage and you have 6 bidirectional switches, here we connect the A, B, here we will connect C such that the load three phase load when it is represented; let us take this is ABC such that i_A plus i_B plus i_C is equal to 0 that means for a three phase system, this shows the triple end currents are absent here. So, triplen currents are absent here; that will not be contributing to the flux space phasor. So, we are only talking about, the moment we are talking about the space vector, we are talking about the harmonics for which the sum of three phases should be equal to 0 whether voltage or current V_A plus V_B plus V_C is equal to 0.

Now, these are bidirectional switches, diodes will be there that I have not marked it before just for clarity. Now, if you see the ABC phases or the poles, A can have two positions, either to the top or to the bottom. So, this will represent as if top switch is on, top on, we will mark as one; for the bottom switch is on, we will mark as 0. So, for each pole, there are two states possible either 0 or 0. So, there are three poles. So, you will have 2 raised to 3 sets, 8.

Now, what are the states? Let us see. So, this is only possible. Using these combinations of, alternatively using these 8 states, we have to generate the PWM wave from such that the average variation in the phase will be sinusoidal. So, the switches with the pole let us say, let us take this way, I will draw it here; so state one, now this is our A, B, C. So, let us take the conditions 000, 001, 010, 011, then 100, 101, 110, 111. As I told, these two are zero states that means all the top switches are on, all the ABC phases will be shorted to the positively.

Zero means this means all the bottom switches are on and the all ABC will be shorted to the bottom. So, these are called zero states, zero inverter states. Now ABC, let us start with 100. 100 means this A phase will be connected to this one. What about the B and C? B and C will be connected to the bottom switch that means bottom device is on; this is 100. Now, let us take, next is let us take, 110. So, 110 will be A B C; this is A, this is B, C. So, 110 means both A and B is connected to the top. So, this will come like this and C will be connected to the bottom right; so this is 110.

Now, let us take three, the three, let us take this is 0, let us take this one, 3 is equal to 010. So again, we will draw the inverted poles. How or where it is connected A B C? Now, we are talking about is 010, so A will be connected to 0, bottom. B will be connected to the top, C pole will be connected to the bottom; so this is 010, so three. Now, let us go to the next page.

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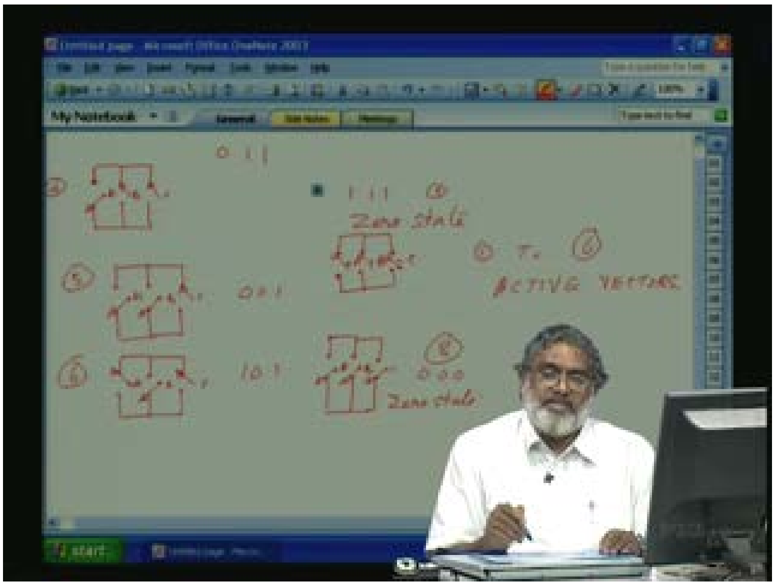

Now, let us take the fourth state, fourth state we will take as 011. So here, the inverter poles are connected, so from this pole states 011 it clear clearly indicates where we have to connect the inverter poles that is ABC poles. A will be connected to zero that is bottom side, B will be connected to the positive, so top switch is on in the B leg; this is 011, this is our fourth state.

Now, let us take our fifth state; fifth is 001. Here, it will be like this; A phase will be connected to 0, B phase also connected to 0, C phase connected to A B C. A phase is connected to 0; by connecting means bottom switch is turned on, B is also connected here, C is connected to top; these are fifth.

Let us take our sixth one; sixth one is 101. This ABC, see A phase is all A is connected to the top rail and B is connected to the bottom rail that means the bottom switch is on and C is again connected to bottom top here. This is 101, sixth. Now, six are over; the next are the zero states that is 7 and 8. 7 and 8 let us take that is 111, seven is 111 that means all the legs or the pole ABC are shorted to the positive rail that means ABC, ABC. So, 111 so that means it is connected here, this is connected here, this connected here.

So here, if you see here, connected here means all the ABC shorted to the top rail; this is zero state, zero state, inverter state. Now, one more is there; that is 00 that will term as the number 8. So here, ABC, here all the three poles ABC is connected to the bottom rails that is bottom switch is on. This is also called a zero state.

So, for PWM operation, we can have only; during one operation, we can only have one out of this 8. So, how do you use these states such that the average variation in phase is sinusoidal or the voltage space vector will tip of the voltage space vector, the average voltage space vector will trace a circle? So here, now let us see, if you are in a sequence starting from 1 2 3 4 5 6 here, these are the active vectors; the states 1 2 6 are called active states that means this can only produce a non-zero output voltage space vector. These are called active vectors.

Now, before coming to PWM, let us say in the X Y plane, where this voltage space vector lays all the eight? Let us see.

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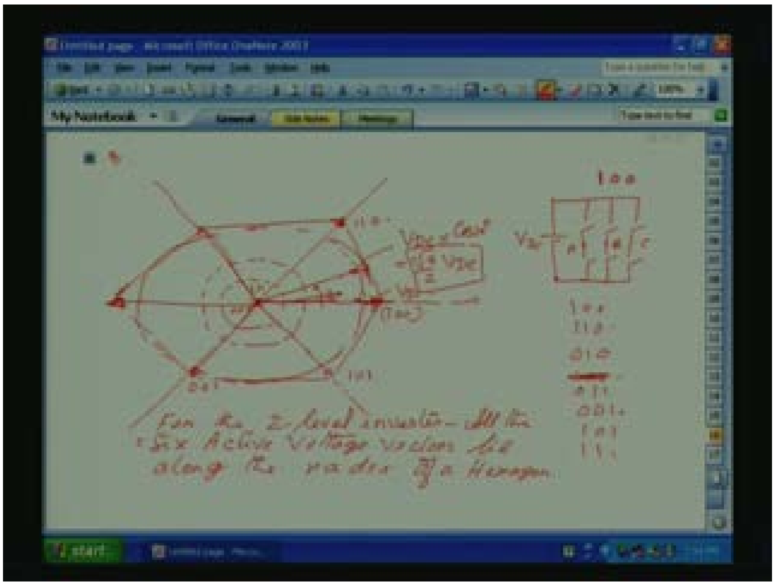

Let us start with 100, 100. If it is 100 that means A phase is to the positive rail and B and 0 are 0. So, let us we take the switch sequence like this; A, B, C, A is connected to the top, B and C are 0. Now, let us take the let us draw the combined effect of all the three phase voltages that pole voltages, that will give the vector. So, if you see here, this is our A phase axis, A phase; 120 degree phase shifted, we will get the B. Then we will have the C, this is the B axis, this is C.

So, when A is turned on, A will be no A leg is, 100 A is connected to the top B and 0 are the 0. So, let us measure the pole voltage with respect to that is the bottom rail. So, A is positive;

So, this is V_{BC}, B and C are 0. So, B and 0 are when we are measuring with respect to the bottom rail, the voltage pole voltage of B and C are 0, pole voltage of A is V_{DC}. So, A is let us say, this is V_{DC}, the vector will be here, this is the vector. So 100, this is here.

Now, let us take 100, 110 that means A and B are at V_{DC}; A is here, B is also at V_{DC}. So, the vector sum, this plus B is also positive, so somewhere here it will come. See, A plus B is minus C; so, along the minus C axis. So, here it will come, this is our vector. So, A here, B, this vector, parallel to B and it will be here; this is 110, vector lies here. Now, let us take 010. That means both A and C are 0, B is 1. So, B is V_{DC}, it will be here, this. So, these all these amplitudes are V_{DC}; this, this vector, this is V_{DC}.

Now, let us take the next one; 011. That means B and C are V_{DC}; V is already V_{DC}, C is also V_{DC}, so take a vector sum. It will be negative of A phase axis, here it will happen. So, the vector is here because B plus C is equal to minus A. So, this is also V_{DC}, this is also V_{DC}, so here it will come, minus V_{DC}. Now, let us take the next one, 001. Now C is 1, A and B are 0, so it will be here V_{DC} here; this is 001.

Then next one is 101, 101 means A and C are 0, so it has to be along the minus B axis because A plus B is equal to minus A plus C is equal to minus C. So, along this axis; by parallel this vector, we put it here, so it will come here. So, if you see here, this is 101. Now, 111 means all are 0, ABC. A is in this direction, B is in this direction, so parallel; B is also V_{DC}, C is also V_{DC}, so in this direction, so it will sum upto 0 that is 111. So, A is also V_{DC}, so A we added, then B is also V_{DC}, so V_{DC} added parallel to B, then C is also V_{DC}, so C is in this direction, so that will be 0. Similarly, zero vectors also, all are 0. So, this is the zero vector state.

Now, if you see here, see in this diagram, this one is a hexagon, hexagon and radii of the hexagon is equal to the voltage space vector structure for the three level inverter. See, here if you say, no sorry this is a two level inverter pole that means each pole can have either this level plus or minus. So, this is called a conventional two level inverter. So, level is with respect to one pole; so two level inverter, for the two level inverter, all the all the 6 active, active voltage vectors lie along the radii of a hexagon; hexagonal radii is this one, radii of a hexagon. So, for one cycle of operation, activator if you switch, it will 1 2 3 4 5 6. So, this is also two level inverter is also called as six step inverter. So, when the activators are switched, it will take six steps to make one complete revolution. This is also called a six step inverter.

Now, we want the voltage with PWM, the radii of or the average variation of the voltage space vector or the tip of the voltage space vector should move along a circle or projector. So, how can we generate? We can only use these combinations; with these combinations, how do you get a voltage or average variation of the voltage space vector for which the tip of the voltage space vector trace a circle with a uniform velocity? So, in this hexagon, we can have different circle with different vary average variation; this is one circle, this is one circle. Now, what is the maximum circle we can inscribe? That means which does touch this point; this is the maximum radii passing.

Now, if you see here sorry it has to touch here, so this is the maximum radii passing. So radii, what are the maximum radii of the voltage space vector or the amplitude of the average variation for the rotating voltage space vector? So, this angle is equal to 30 degree, this angle is equal to 60 degree, this amplitude is equal to V_{DC}; so this radii, maximum is equal to V_{DC}

into cos 30 that is equal to root 3 by 2 V_{DC}. So, this is the maximum radii possible root 3 by 2 V_{DC}.

Now, let us take a motor drive application, motor drive application with V by f control which we will study later; as the frequency varies, the V also should vary proportional. That means frequency zero, V should be zero. When the frequency is 25 and varying frequency is 50, the frequency is doubled, so the amplitude or the radii of the voltage reference space should also be doubled. That means within this hexagon, we should have different circles inscribed circles with different radiation should be possible. Then how to generate? See, let us draw our hexagon once again, approximately.

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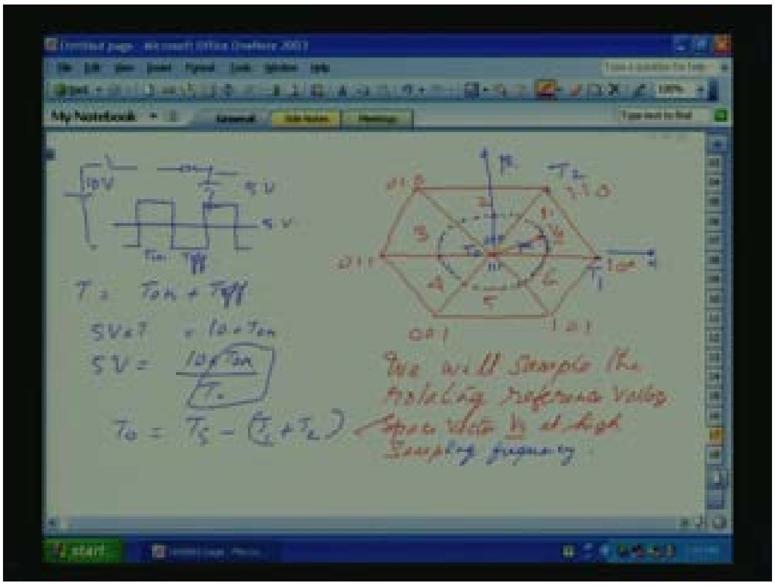

Approximately I have drawn the hexagon; this is plus 00, this plus plus 0 or we have used or instead of plus, we have used 110, so we will use that one that is 100, 110 then 010, 011, 001, 101. Now, let us take for particular radii, some radii; this is the one we have to generate, average variation of the voltage space vector.

Now, let us take for a moment, the V the reference space vector, so with a reference space vector, this has a space vector V, underscore we will put it that it has a magnitude and radii. Let at one instant if V_S is here; how to generate VS here? See, if you see here, in this hexagon space vector, there are six sectors; sector 1, sector 2, sector 3, sector 4, sector 5, sector 6. In these sectors, suppose the V_S the reference space voltage reads sector 1 and our reference space vector is rotating with uniform of speed; so what we will do?

We will sample this rotating reference space vector, we will sample that means sample the rotating reference voltage space vector V_S with work, sampling means the sampling frequency, so the sampling frequency let be much more than the fundamental frequency high sampling frequency, V_S at high sampling frequencies or we can say low sampling periods that means as quickly as possible. Instead of it is circle, we will sample at with low sampling periods low sampling periods that means here we are sampling here, we are sampling here, we are sampling here, sample is here that means in a sector, we have sampled so many times.

So, that means when you sample this one, the average variation is as close as to a sinusoidal. Continuous sinusoidal variations if it is required, then we require very high frequency sampling. So, very high simple sample, it has sets of problem, we have to control the inverter with very high sampling frequency. So, that will also lead to losses. So, there is a limit with which we can sample; that depends on the inverter. So, that means it is continuously rotating vector, we sample along with the low sampling periods, so high sampling frequency. This sampling frequency, we can relate to our sin triangle equivalent to the carrier frequency, triangle frequency where the frequency of the sin is proportional to our continuously rotating reference space vector and the sampling period is proportional to a triangle period, we can relate that one.

So, when you sample it, till the sampling period is over that means till the next sampling period, we will assume the V_S is stationary. That means V_S is making, instead of continuously tracing, we can see V_S is making small jumps as shown the dots here. So, that jump depends on our sampling period. So, what I mean here? During a sampling period, once it is sampled, till the next sample we have assumed, the V_S is amplitude and the angle is stationary there.

Then, this V_S, we will generate by switching, suppose V_S is in sector one, we will switch between 100, 110 and the zero vectors, 00, 11 vectors such that the volt second using volts second balance; see what is meant by volt second balance? Let us take we have 10 volt dc, this is our 10 volt. Now, I want 5 volt. So, what I will do? I will choke this waveform. So, 5 volt means 50% duration I will make it on using a switch here and the output where the voltage is required, then next 50% it will be 0, so it will go like this. So, this is the T_{on} period, this is the T_{off} period and we want 5 volt, average value is 5 volt.

So, in a period, period T is equal to T_{on} plus T_{off}. So, volts second balance that means if it is voltage is there; the area, volt second, 5 into T_{on} should be equal to, so 5 into T, not T_{on} because 5 is there, it will be there for full period, volt second, this should be equal to 10 into T_{on} because 10 is only for T_{on} period so that now the 5 volt is equal to 10 into T_{on} by T. So, T_{on} by T is called the duty ratio. So, by using this volt second balancing, we can average variation of 5 volt is we can generate. So, 5 volt we can chop, then after this one, you put the filter and you will get the 5 volt here. So, filter means harmonics we can remove it and dc value we can, this way we can generate it.

So, here also we will use the volt second that means the volt second that V_S into t, the volt second, so here if you see, these are vectors, these are scalars here. So, we have to take the volt second along the alpha axis and the beta axis orthogonal axes so that component of V_S along alpha beta axis volt second, so V_S for T period, the sampling period T_S that V_S, the component of the V_S along alpha beta multiplied by the sampling period that is a volt second of the reference voltage along the alpha beta should be equal to that volt second of 100, 110 and the zero vector along the alpha beta. So, if the volt second is matching, same way by switching that average variation of V_S is generated.

So, let us see how this volts seconds, we can generate. So, let us go to one sector. The same thing, we can use it for other sectors also. Other sectors for a particular angle alpha is the angle with which the start of the sector V_S makes. For other sectors also, alpha will be the same; only the switching vectors are different. The periods, let us take 100, in a sampling period 100 is making period T_1 and 110 is making T_2 and T_0 period. So, T_0 period is equal to sampling period T_S minus T_1 plus T_2. First order period, it will be 0.

Now, we have to find out T_1 and T_2 such that the volt seconds along alpha beta should be matching. So, let us, how to find out this one? Let us go to the next page.

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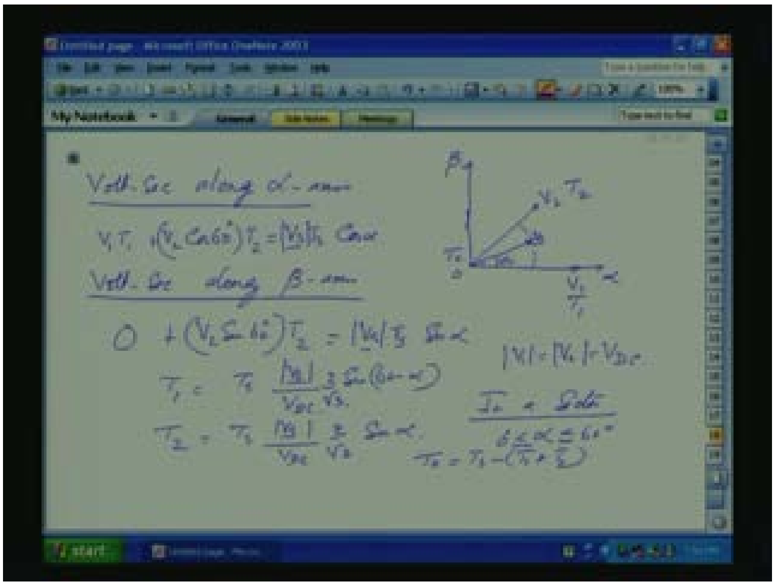

So, let us draw our alpha beta axis; this is alpha, this is beta. Let us say, it is in sector one; sector one means this is V_{DC}, after 60 degree another radius. So, we are going to derive the general rule. So, we will take the vector, each sector, the start of the vector we will call V_1, this we will call V_2, this is called the zero vector. Now, this is our V_S, voltage sampled voltage space vector which is tracing a circle. During this period sampled, for a particular sampled period, let us make V_S is making alpha with respect to the start of the sector V_1. In sector one, V_1 is equal to 100.

Now, let us find out the volt second along the alpha axis, volts second along alpha axis and V_1 is switching for a period T_1, V_2 is switching for a period T_2, this is for T_0 periods. So, a volt second along alpha axis is equal V_1 into T_1. When V_2 is switched for T_2 period; what is the volt second along alpha axis? The component of V_2 is this is 60 degree, a sector is 60 degree. So, this is equal to V_2 cos 60 degree into T_2. This should be equal to and V_S we are saying during the full T_S period, sampling period V_S is stationary there. So, V_S into T_S and the component along the alpha axis is equal to cos alpha.

Now, what we want to find out? We want to find out during a sampling period, sampling period is fixed by us; the T_1 and T_2 we have to find out. That depends on V_S magnitude and the angle. So, we have to find T_1 and T_2 for particular V_S that is a voltage space vector that is a particular magnitude as well as angle. We have to find out T_1 T_2, so we require two equations. The next equation, we can get from along the beta axis, beta axis, volts second along beta axis.

See, this is alpha beta 90 degree, so when V_1 is switched, it will not contribute anything along the beta axis. So, that will be 0 but V_2, V_2will be sin 60 that component of the V_2 along the beta is equal to sin 60. So, V_2 sin 60 into T_2 is equal to V_S T_S into sin alpha that is the component of the V_S along the beta axis.

Now, from these equations, you see two equations, we can find out T_1 and T_2, this we can solve it. Solving T_1 will be equal to T_1 is equal to T_S into V_S, V_S is the magnitude of the V_S. See, here V_S is the magnitude of the V_S we are taking; V_S divided by V_{DC}. Why V_{DC} it comes? The magnitude of V_1, magnitude of V_1 is equal to magnitude of V_2 is equal to V_{DC}. So, this we will miss out, V_{DC} is equal to sin 60 minus alpha divided by sin 60, sine 60 is equal to how much? Sine 60 will be equal to root 3 by 2. So, this will become divided by 2 by root 3, it will come.

Similarly, T_2 will be equal to T_S into V_S divided by V_{DC} into 2 by root 3. Again, denominator of sin 60 it comes, it will come to sin alpha; this is the equation. So, in a sector, in a sector, alpha varies between less than or equal to 60 greater than or equal to 0. That means it varies from 0 to 60 degree. So, we have to compute; for alpha varies from 0 to 60, what is T_1 T_2? And, as the V_S traces a circular trajectory, this is true in our sectors also but only for the alpha, alpha means alpha measured from the start of the sector but only the vectors V_1 V_2 will vary in different sectors. Now, if T_1 T_2 you know, we know is T_0; T_0 is equal to T_0 is equal to T_S minus T_1 plus T_2. So, rest of the period T_0 period, we will switch the zero state.

Now, as we go from 0 V_1 V_2 that means inverter switchings are there. So, inverter switching means there is always switching losses associated with it because switchings are not instantaneous. So, we want to insure minimum switchings during a transition that means as it go from V_1 to V_2 to 0. These are called sub intervals that means T_1 T_2 are called, T_0 are all called subintervals. That means the intervals within period T_S. So, during these sub intervals, we want minimum inverter switching.

So, how it can be done? Let us go back to our sector again.

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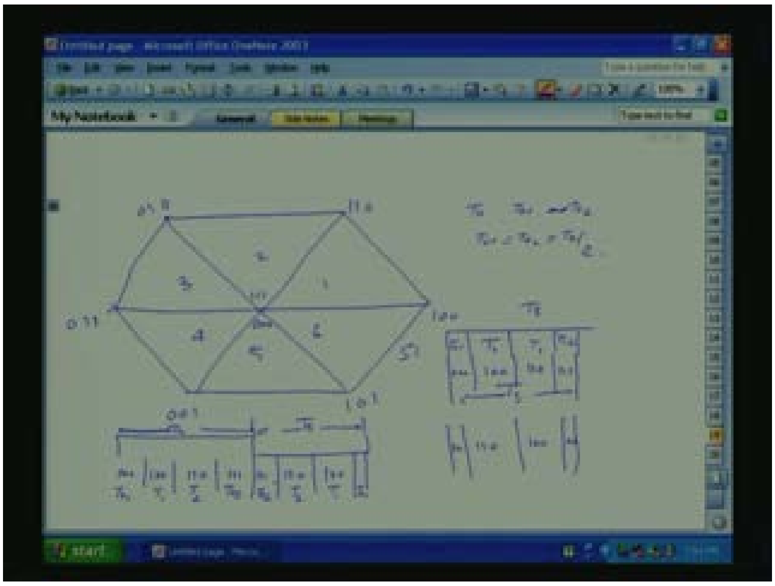

Let us draw the sector again; this is sector 1, 2, 3, 4, 5, 6; 100, 110, 010 if you see, these are opposites; 011. So, 110 means this has to be 001. This is 010 means this should be 101. The zeros are 111 and 000. Now, in sector one, this is; we are going from, so minimum switching means how it can go? See, it is done the T_0 period is divided into two intervals that is T_{01} and T_{02}. So, T_{01} T_{02} will be equal to T_0 by 2. That means two zeros are split during the sampling period; let us take the sampling period, during sampling period T_S. Let us take in sector one, S_1 the sequence will let us start, it is starting from 000 that is first T_{01}, T_{01} is 000. Then it will go to 100. Here means only A phase is switching, then 100 to 110 it will go, so here B phase is switching.

Now, the last zero period 110, it will go to 11. That means during a sampling period, minimum inverter switching, there is only one inverter transition takes place. That means let us take the T_{01} with this is T_{01} period, let us this is the T_1 T_2 and next T_0 period. So, if you see here, this is our T_S. So, this is T_{01}, T_{01} and sorry T_{01} and T_{02} are same. This is T_1, this is T_2. So in sector one, we will start from 000, then 100, then 110, then 111; these are zero period and the next sampling interval, then the next sampling interval we will find out T_1 T_2 T_0 in sector one itself but the previous state is 11. Then we will reverse the sequence that means the next sampling period, we will start with 111, then 110, then 100, 000.

So, we will go sequence if you see here, there is which has a positive sequence and the negative sequence, this way we will go; that we will ensure. So, this is Ts period, the first T_S period, this is the second T_S period. So here, we will start with 000, then 100, then 110, then 111. Then the next sampling interval start with 11, first T_0, then 110, then we will go to 100 and the last zero part. So, the sequence if you say, this is the T_{01}, T_{01} T_1 T_2 T_{02}. Now here, it will start T_{02} T_2 T_1 T_{01}, so this way it will go. So, that will ensure minimum inverter switching.

Now, let us say, if this type of switching; what is the volt second? What is the average variation? So, let us see how the switching sequence will be there in sector one. Let us go to the next page.

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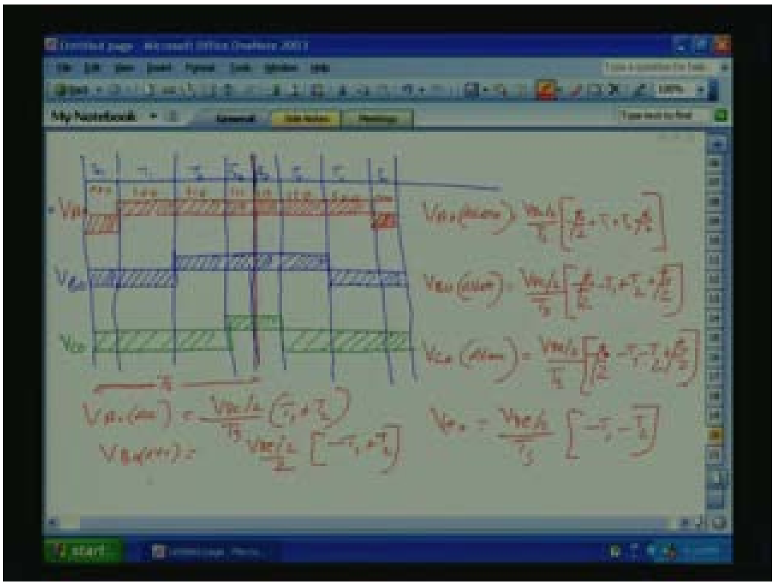

So, let us see the switching. As I told, sector one; so we are dividing T_{01}, let us say this is the T_0 period, let us say this is the T_1 period, let us say this is the T_2 period, this is the T_0 by 2 period. Each T_S period, we divide the different colour. Then happens the next; T_0 by 2, T_2, T_1 and the next T_0 by 2. So, this is T_{01}, T_1, T_2, T_{02}, T_{02}, T_2, T_1, T_{01} in sector one.

Sector one, we are starting with 0. So, let us take the pole voltage that is V_{A0}. See, here, the pole voltage we have already introduced what you mean by pole voltage. This is A, this is B, this is C. See, when the top switch is on, match up with respect to the fictitious centre point zero. So, that means this is V_{DC} by 2, this is V_{DC} by 2. So, when the top switch is on, all zero ((… not audible)). Now, let us take T_{01} is equal to we looked this period is equal to we will write with a different colour, red, T_{01} is equal to 000. This is 100, 110, 111, this is 111, then T_1 is equal to 110, 100, 000. So, let us see, according this one, how the pole voltages.

Now, the pole voltages we are measuring with respect to the fictitious centre tap. So, when the top switch is on, it is V_{DC} by 2; bottom switch is on, any pole it will be minus V_{DC} by 2. That means zero means minus V_{DC} by 2, one means one indicates V_{DC} by 2, zero indicates minus V_{DC} by 2. So, let us take for a general T_1 T_2 period, how the volts or how the pole voltage vary from the V_{A0}. So, V_{A0} we will draw it; we will draw with a, V_{A0} we will draw with a red colour. So, during the T_{01} period, V_A will be negative. So, the pole voltage is during this period is negative.

Now T_1 period, it is positive because one. Again, T_2 period is also it is high. So, it will continue there. Then 11 means again it is here. So, the first sampling period; so, that is the first sampling period from here to here, only once the inverter leg is switching, on the next sampling period again one continues, again 110 it will go like this, again one, next is zero.

So, if you see here, the switching sequence during the sampling period using volts second, the switching the switching transitions during various intervals sub intervals are selected in such a way that in one sampling internal, one phase is only changing state only once even though the space vectors are changing from 00 100 110 11, four space vectors are involved; two zeros are two active vectors. This is for the A phase that is the V_{A0}. Let us draw, this is the V_{A0}.

Now, let us draw the V_{B0}, V will be let us take blue, so B again it will start with 0. 100 means B is also zero here during the T_1 period, zero. Now, here B goes positive that is one, V_{DC} by 2. So, it comes during the T_0 period also it is like this. Now, next sampling interval also it is like this. Here 2 T_2 B is positive, then the moment last zero, here, the T_1 period and the last zero period is negative that is 0. So, this is the V_{B0}.

Now, let us take the V_{C0}. Let us take green, V_{C0} that is this is zero, this is zero, this is zero; till this period, it is zero. Here, it will go positive because 111, here it will come down, again if you see here, it will go like this till the negative. So, if you see in the sector, the pole voltages V_{C0} with space vector PWM you can see these type of nested waveform and in a sampling interval, each phase only be changing, each pole will be changed at a once.

Now, let us find out, so we know the positive and negative; so, during the sampling period, we can find out the volts second and we can average it by T_S. So, in a sampling period, same like what you have done for sin triangle, let us see how to find out the average value. Now, let us find out the average values. That means V_{A0} average. Let us draw the V_{A0} average that is equal to see either positive or negative, the amplitude is V_{DC} by 2.

So, average value you have to divide by T_S into see during the T_0, first T_{01} period, so T_0 periods are equal, so we will make it the duration T_0 by 2. So, first T_0 it is negative. So, it is minus T_0 by 2 and then you have T_1, it is the period plus T_2, then during the next 0 also it is positive V_{DC} by 2. So, it will be plus T_0 by 2 here. So, we are taking the duration for V_{A0} average.

Now, let us take V_{B0} average; again this is equal to V_{DC} into we are taking the volt second and we are averaging that means V_{DC} by 2, here also minus T_0 by 2, then minus T_1 because during T_1 period it is minus T_1, then comes plus T_2 and plus last T_0 by 2.

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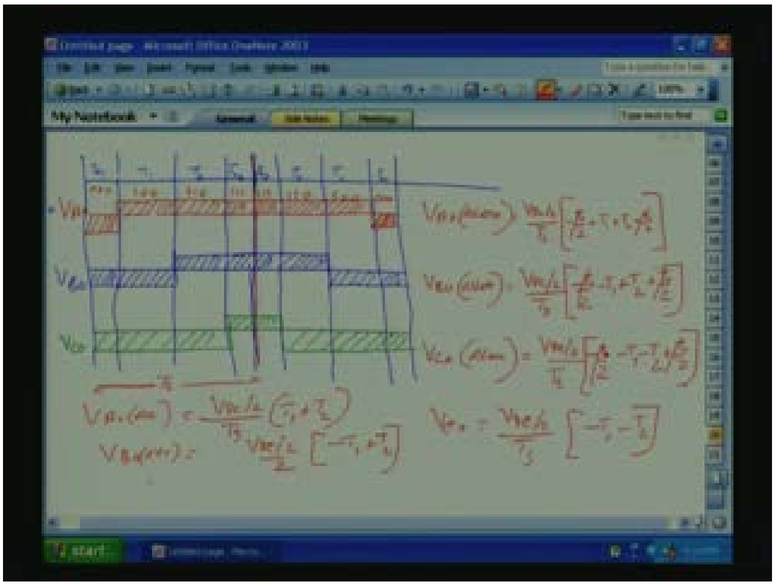

Similarly, V_{C0} average is equal to V_{DC} by 2 into T_S into minus T_0 by 2 minus T_1 minus T_2 plus T_0 by 2. So, during the T_0 by 2 period, first sampling interval, if you take all the three phases, that pole voltages are in the opposite levels; first T_0 if it is minus V_{DC} by 2, the top side it will be in the last T_0 by 2 V_{DC} by 2. So, this we can cancel. So, the volt second, the zero vectors are not contributing to the average variation; this is all only by the T_1 T_2. So, for V_{A0} average, V_0 average is equal to V_{DC} by 2 divided by T_S into T_1 plus T_2 and what is for and what is V_{B0} average? V_{DC} by 2 into minus T_1 plus T_2 and V_{C0} is equal to minus of V_{A0}. So, that is equal to V_{DC} by 2 divide by T_S into minus T_1 minus T_2. In a sector, T_1 T_2 periods are zero, the V_{C0} average is equal to minus of V_{A0} average.

Now, what we have to do? T_1 T_2 in a sector we have found out for a general angle alpha. That you substitute and we can find out V_{A0} V_{B0} V_{C0} average for alpha varies for 0 to 60 degree, how the variations happens. Then we can also find out how it happens for other sectors and if you know the average variation for 90 degree, we can repeat it for other sector because it is a circular, average variation is tracing circular space vector that means the sinusoidal one is but the phase voltage average variation is sinusoidal. So, 0 to 90 is sufficient.

So this way, substituting the these values into the equation, we can find out the average voltage variation and from the average voltage variation, we can find out whether the average minus space vector is tracing a circle or the average voltage variation for the phases are sinusoidal, then our PWM is achieved, space vector PWM is achieved. So this way, so our analysis show that the space vector PWM.

So, appropriately choosing or selecting the T_1 T_2 for a particular V_S that is the reference space vector of particular amplitude and alpha for difference frequencies of operation, we can have different amplitudes and alpha, also alpha varies when it trace the circular trajectory but the frequency only varies. So, this way we can find or the space vector PWM can be implemented.

Now, the question is how to find out T_1 T_2 and how to implement? During T_1 T_2 inner sector, how to output the sector? This we will study later. So here we will see, in the next class we will see, let the average variation for a phase V_{A0} V_{B0} V_{C0} is a sinusoidal one. If that is the case, then the voltage space vector will be tracing a circle. So average variation, the average variation of the voltage space vector will be tracing a circle. This we will study in the next class.