**Advance Power Electronics and Control**
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**Lecture - 31**
**SVM II and AC to AC Converters**

Welcome to our lectures on NPTEL lectures on advance power electronics and control. Today, we shall continue with the space vector modulations we have started in the previous class. There we shall see a different type of direct AC to AC or indirect AC to AC conversion technique. So we have already discussed you know actually depending on the switches, please refer to our previous discussions.

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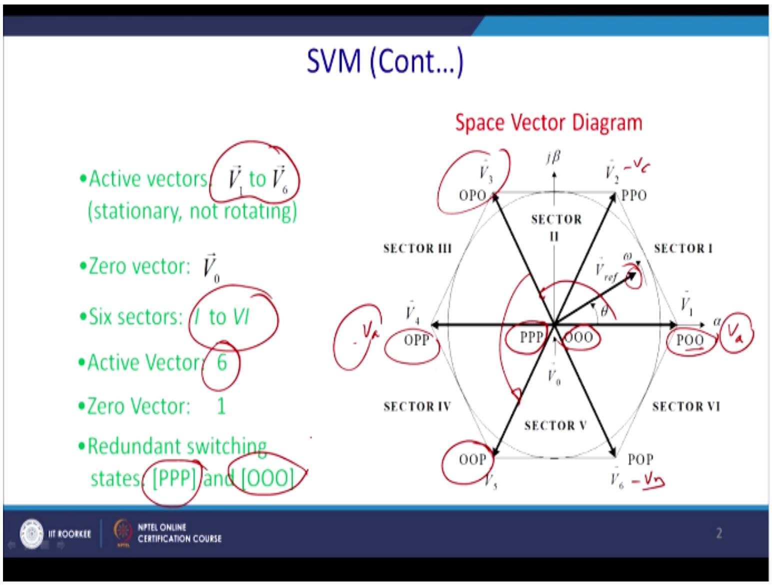


So we can you know actually you have a three-phase voltages and you know that actually we can represent in terms of polar coordinate that is some resultant vector and theta and this is the reference you required to generate and you will be generating with the switches when actually it is POO that means your first leg is switched on and other two legs lower switches on. So PPP we have discussed and OOO other to null vector.

PPP means all the upper switches on and OOO means all the lower switches on. Now if you wish to get Va totally then you will apply POO. If you wish to get -Va you will apply basically the voltage of OPP. Similarly, 120 degree apart the phase b you can apply 010 or OPO similarly after 120 degree apart so these are actually the line voltages so OOP and thereafter you know actually if all these three are positive voltages and if it Va if you write it will be –Va.

Similarly, if you write this one as +Vb it will be –Vb. Similarly, if you write it is +Vc it will be –Vc. Now you have to identify a sector and accordingly the switching will be done. So for this is to generate this voltages it can be in any quadrant, V1 to V6 are the active vectors and they are stationary vector, they are not rotating vector mind it. Rotating vector is your actual reference and we shall take a snapshot.

During the snapshot, we shall consider that we V reference and this theta is actually the constant. So we have actually identified 6 sectors. This is sector 1, sector 2, sector 3, sector 4, sector 5, sector 6 and so they have a 6 active vectors and thereafter a zero vector and reduced redundant switching states are PPP then all the switching states on and 000 or OOO all the lower switches are on.

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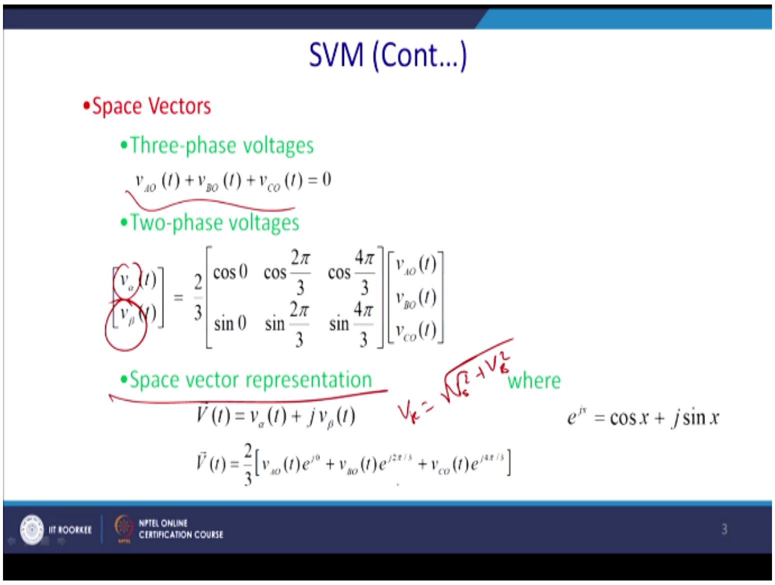


Now we know that actually for 3-phase 3-wire system what is the basic of actually putting this V ref and these things because you know that we have only all this vAO, vBO, vCO. If you have 3-phase 3-wire system, its simultaneous value will be equal to zero and we shall convert 3-phase to 2-phase conversion. What we have done actually resolver of force for two perpendicular coordinate is the same thing.

So this is be your stationery alpha beta frame and this will be the transformations that will be the 3-phase to 2-phase transformation and once we get these transformations you know, we can write like this. That is Vt=v alpha+j v beta and we should align one of the vector with the vector alpha. V1 can be aligned with the vector alpha and 90 degree to be it will be the j beta. So this kind of polar representation is valid by it can be established by this theory.

So we can write essentially the reference vector equal to v alpha+j v beta or it can have a polar representation under root of V square alpha+actually Vr will be actually underscore of v alpha square+v beta square. Similarly, so Vt can be actually inverse transform that is 2/3 vAO actually vBO e to the power +120 degree and vCO e to the power 240 degree or -120 degree. Now you see this.

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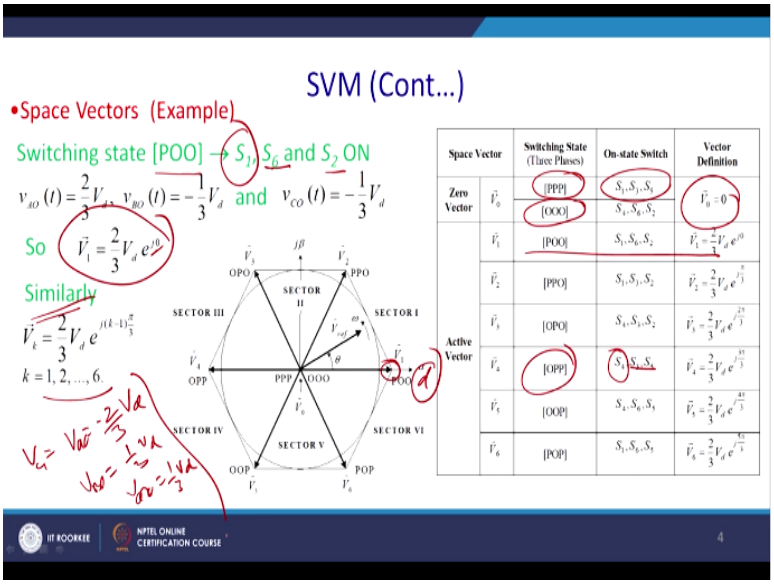


| Space Vector | | Switching State (Three Phases) | On-state Switch | Vector Definition |
|---|---|---|---|---|
| Zero Vector | $\vec{V}_0$ | [PPP] | $S_1, S_3, S_5$ | $\vec{V}_0 = 0$ |
| | | [OOO] | $S_4, S_6, S_2$ | |
| Active Vector | $\vec{V}_1$ | [POO] | $S_1, S_6, S_2$ | $\vec{V}_1 = \frac{2}{3}V_d e^{j0}$ |
| | $\vec{V}_2$ | [PPO] | $S_1, S_3, S_2$ | $\vec{V}_2 = \frac{2}{3}V_d e^{j\frac{\pi}{3}}$ |
| | $\vec{V}_3$ | [OPO] | $S_4, S_3, S_2$ | $\vec{V}_3 = \frac{2}{3}V_d e^{j\frac{2\pi}{3}}$ |
| | $\vec{V}_4$ | [OPP] | $S_4, S_3, S_5$ | $\vec{V}_4 = \frac{2}{3}V_d e^{j\frac{3\pi}{3}}$ |
| | $\vec{V}_5$ | [OOP] | $S_4, S_6, S_5$ | $\vec{V}_5 = \frac{2}{3}V_d e^{j\frac{4\pi}{3}}$ |
| | $\vec{V}_6$ | [POP] | $S_1, S_6, S_5$ | $\vec{V}_6 = \frac{2}{3}V_d e^{j\frac{5\pi}{3}}$ |

Please recall in our previous classes actually upper 3 switches+abc are S1, S3, S5 and that will be represented here as all the positive phase on that is PPP and ultimately you will get a null vector and once all the lower switches are on that means 000 or OOO that is S4, S6 and S2 you will get essentially also the zero voltage. The switching state let us see that what happen in a switching state when it is POO that when you are here.

So essentially what does it signify? From the upper part of the inverter S1 will be on, S6 and S2 will be on. So once upper part of the switch is on, vAO will be 2/3 of Vdc, you can actually draw the geometry and vOB will be actually 1/3 of Vd and similarly vCO will be 1/3 of Vd, you can add and you get zero voltage and so V1 essentially you know we can write that this axis also you can write d axis if you rotate it.

So we can write that is V1=2/3 Vd*angle is basically 0 you have aligned alpha with this reference. So similarly for any vector you can have that is if it is a second vector k=1, 2, 6 here will be 2/3 Vd e to the power j k-1 pi/3 where k can take any value 0 to 1, 2, 6. So similarly this vector has been explained similarly you know just opposite will be this vector. Then, what will happen, will find that actually S4 is on from the lower side.

And S3 and S5 are on from the upper side. So here essentially you will get in this combinations V4, V4 will be actually vAO will be -2Vd and other two values will be actually vBO will be again 1/3 Vd and vCO also will be 1/3 Vd. So in this way all the voltages can be calculated.

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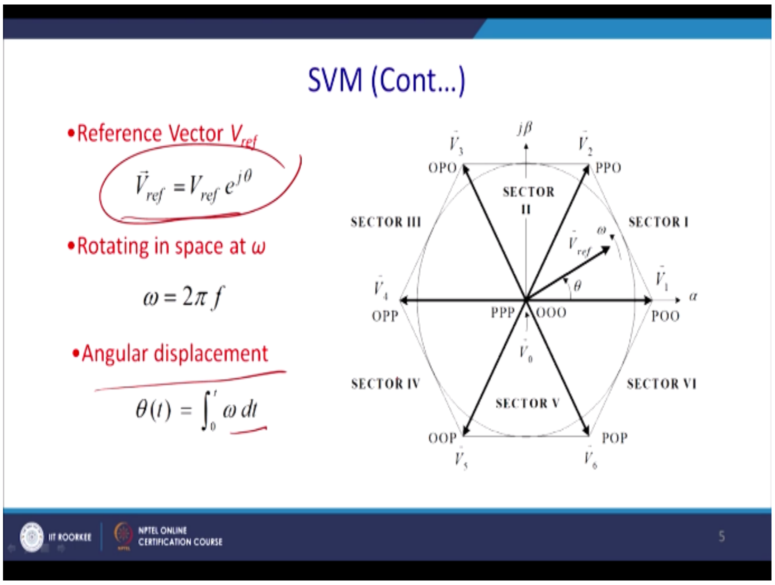


So then our task is basically to find it out the theta and thereafter the theta and V reference will be told to you or to find it out which vector will be applied to generate this voltage state or whatever the electrical quantity you are asking. So we can have a polar substitutions and will write V ref=V ref e to the power j theta and rotating space omega=2 pi f, angular displacement theta t=0 to t omega dt, so you can actually integrate and we can find it out what is the value of theta.

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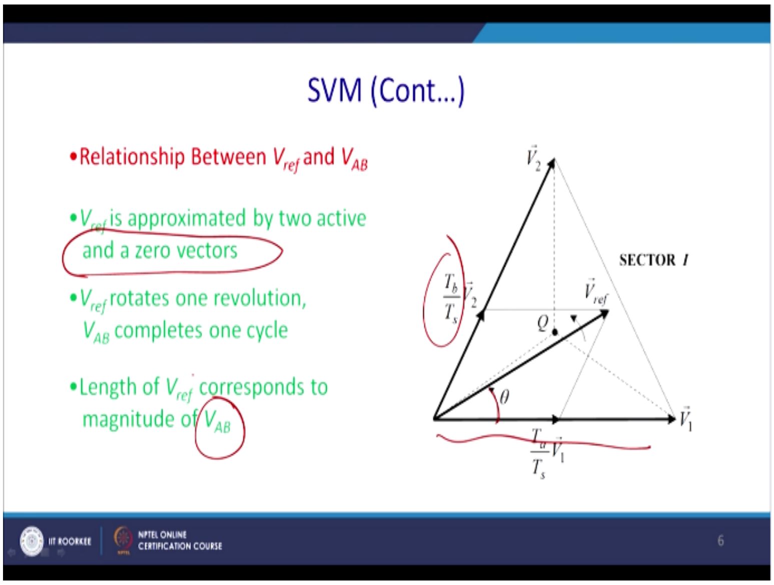


Now you can see if you that actually V ref actually this angle is theta and this is been actually can be manufactured by the combination of V1 and V2 and for some instant of the time let us say T1 or Ta so V1 will be applied and another portion of the time actually let us say Tb so you will apply the voltage V2 and rest of the combinations you know then you have to apply the null vector to fill this actually filler of Ts.

So let us find it out the relationship between V ref and VAB. V ref is approximately approximated by two active vectors and a combination of the zero vectors actually PPP or 000. V ref rotates one revolutions and VAB completes one cycle so length of V ref corresponds to the magnitude of VAB.

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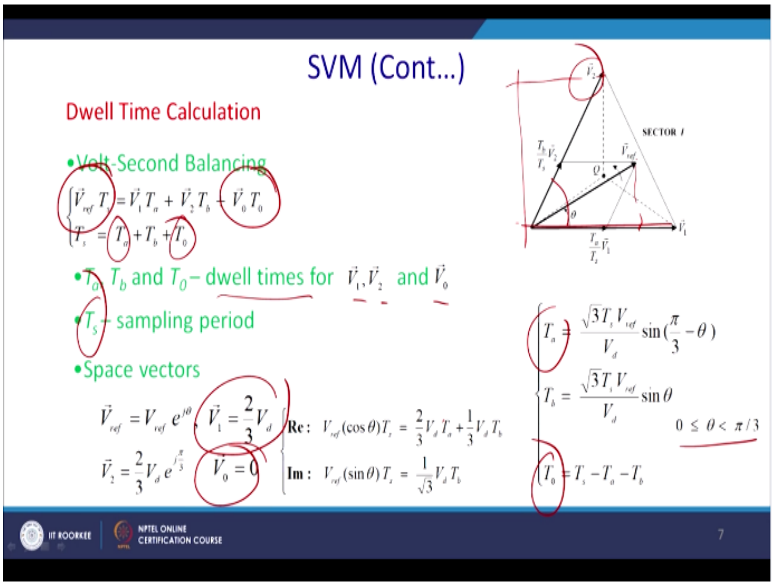

Now see that then we shall go for the Volt balance method that would basically balancing the flux. So V ref*Ts we can write that should be equal to V1*Ta+V2*Tb and rest of the time you will apply the null vector to balance the value of the Ts. So Ts=Ta+Tb and rest of the time you will be applying a null vector. So Ta, Tb and T0 dwell time for V1, V2 and V0 where Ts is the sampling time.

So it can be actually 100 microsecond let us say if it is actually if your switching frequency is 10 kilohertz, it can be 100 microseconds, Ta can be actually 30 microsecond, it can be 40 microsecond, 30+40=70 and rest of this things will be the null vector that is also will be 30 microseconds that is something like that. So V ref=V ref e to the power j theta we know that actually it is V1 2/3 of the DC link voltage and this value essentially will be 0.

So we have to take the imaginary and the real part into the account and we have to balance it. So real part in alpha axis, V ref cos theta*Ts should be equal to 2/3 Vd*Ta+you can see that you know how this component has been made you know so you know you will have 1/3 of Vd Tb. Similarly, for the y-axis, you have to take a component of it. So in y-axis what you can see that it is essentially it is made by only these vectors.

There is no entity of this V1 across the beta axis so for this reason V ref sin theta*Ts will be 1/3 Vd*Tb, it is a simple mathematics you know actually this is this angle in 60 degree. So you know you get if you take a position it is sin 60. So Ta essentially if you can substitute, you can find it out, so root 3 Ts V ref/Vd*sin 60-theta and Tb will be equal to root 3 Ts V ref/Vd sin theta.

So ultimately you get T0=Ts-Tb-Ta so that will be the amount of duration where null vector is applied. This is a very simple problem; you will be given this actually the V ref value and the angle you require to find it out Ta, Tb. So V ref location versus dual timing, how you will actually switch it on, this is one of the requirements you have to keep in mind.

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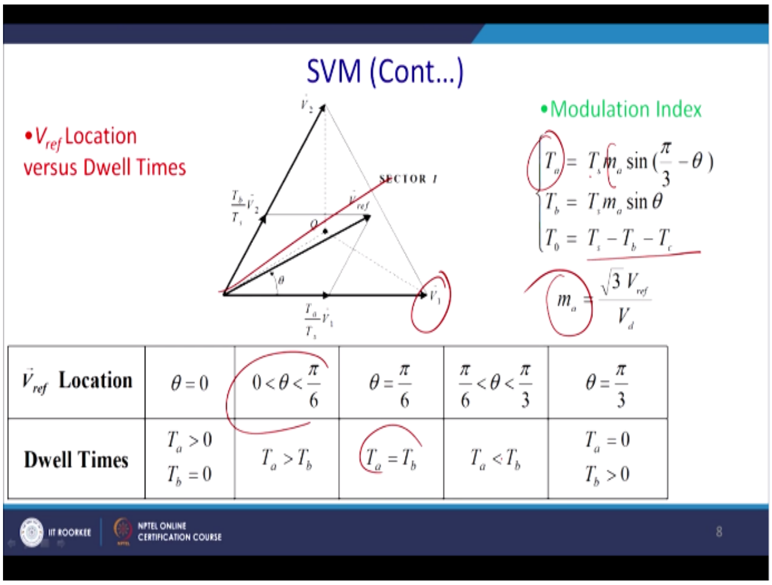


Now you have seen that you know actually Ta=Ts we say actually this one is something like sin angle modulation that is root 3V ref/Vd as a modulation index. So this is actually modulation index of a and this is the modulation index of ma sin theta and this is the basically the value of the T0. So what you can see here you know you can actually split it till 30 degree okay. It is quite clear, so this will be the vector actually will be contributed more till 30 degree.

So Ta will be more and Ta=>0 and Tb=0 for actually if your reference is aligned with the alpha axis. Now till actually till this reference similarly Ta is>Tb. At 30 degree, Ta=Tb because it is the perpendicular bisector so both the vector will have a same value. Then 30 to 45 degree basically Tb is>Ta and at 60 degree definitely all those things will be made by Tb there should not be any component of Ta.

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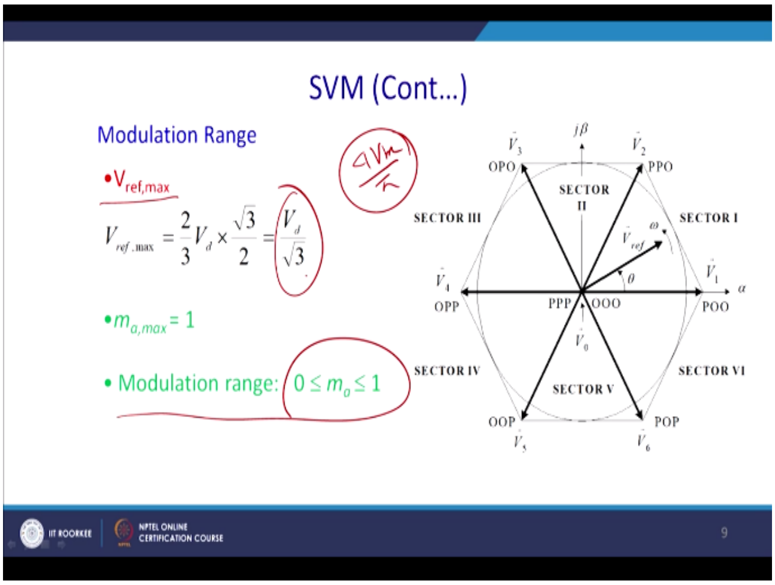


Now modulation index range we have talked about the saturations of this modulation index over modulations because you know that actually over modulation if you have a square wave that is all over modulation and you get the value of 4 Vm/pi and thereafter you can increase this value with injection of the third harmonics and one of the basic advantage I have discussed with this space vector modulation is that it is equivalent to the third harmonic.

But with the less stress across the switches, so what can be the maximum V ref max. So you know that this is basically 2/3 of the receivers voltage*actually root 3/2 so this value can be Vd/root 3 and so modulation index max can be 1 and modulation index can be actually 0 to 1 and effectively you can see that you can have the value of Vd/root 3 as effective V max value. So this is the value you can generate by your space vector modulation.

Very simple thing actually, you have to divide it by 1.732 that is around 60%. So now let us understand what should be the switching sequence and the starting point has a great importance.

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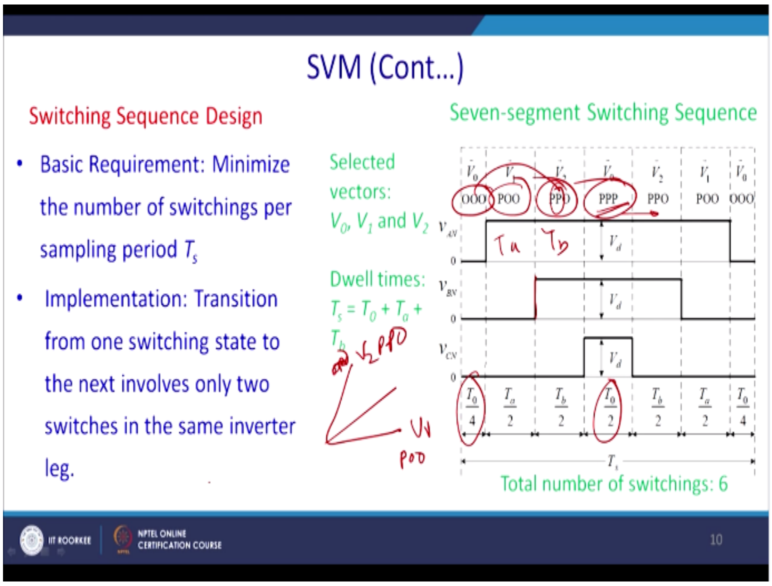


You consider that your starting point was OOO that means all the lower switches are on and you recall that you have actually reference vector this is V1 and this is V2. You will be generating with POO and this you will be generating by OPO. Now see that what will happen, if you go back you see that this voltage is PPO so let us mark it actually PPO, so same voltage vector has been chosen here.

Now actually you have started from the OOO then definitely your one change will be actually POO so you can go here. So thereafter you can have a one-bit change then you will be here so PPO. Then, once this is for Ta and this is for the Tb. Now you have to apply null vector. Of course, if you go to actually OOO there will be a two bit change we will apply PPP. This is also a null vector.

Again, instead of actually starting from V1 this since it is a one bit change you will go for PPO so your computational burden will be reduced. Thereafter, POO thereafter OOO so both the cycle will be combined. Since you are actually operating your switching frequencies at least (()) (20:01) times more than your supply frequency like if you have a 50 hertz it is your supply frequency is 50 hertz that you want to mimic.

And your switching frequency should be around 250 2.5 kilohertz so within the two, three instance you can take that reference as a constant. So similarly for vAN you know actually this phase will be on for this deviations. So once this switch is on second bit or MSB then only this voltage will be on and that continue till that point PPO once this again go to the POO it will go back.

And phase C will come into the picture for those very small duration when actually PPP all the upper switches are on and this is a way so. This is the duration has been splitted you will give the durations T0/4 or 000 and Ta/2 here, Tb/2 here. Thereafter, T0/2 in this duration, thereafter Tb/2, Ta/2 so total will be the total cycle can be generated by this. Now the basic requirement is to minimize the number of the switching per sampling period.

If you actually switch this state to this state what will happen you will have a more switching losses. We required to reduce the switching losses for this reason one which change that you know one switch, one switching transitions if you can achieve that will try to reduce your switching losses. The number of switchings per sampling period is Ts, implementation transition from one switching state to the next switching state involves only two switches in the same inverter leg.

So that if you can ensure the number of switching state is also reduced and switching losses will be also reduced.

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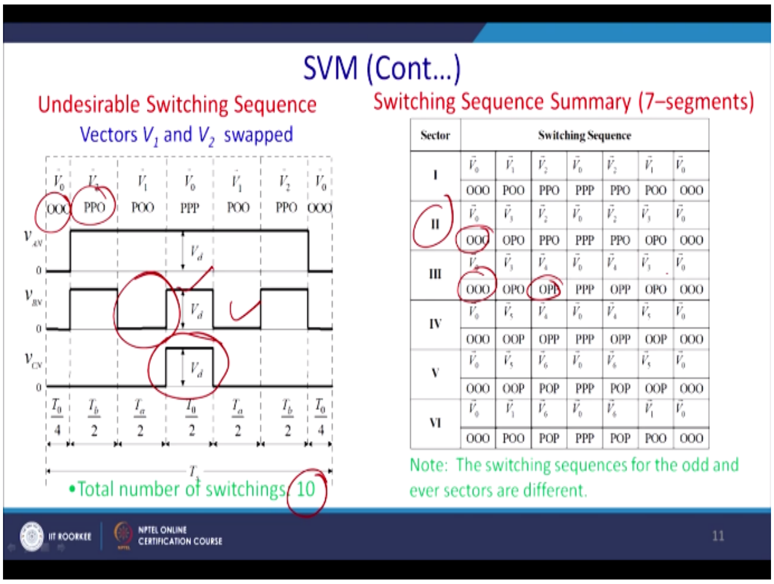


Now see that this is the example of the undesirable switching, if the V1 and V2 are swapped, see there is no change in phase A because it was on for continuous durations so first you have a null vector 000 thereafter it is PPO so vAN will be 1 or high and continue till this time. So again the second will be high for this duration. Again, there is it off, again it is on, again it is unnecessary toggling in between and thus it will give rise to the high switching losses.

And Vd will be actually the phase C will remain same. So total here switching is basically the 10, if you go to the previous slide, total switches are 6 so it is 4 times more switching has been done. So almost 60% more will be the switching losses if you have unreasonable switching. So for this reason, switching sequence has been presented here. So if it is actually 000 you should go to POO and thereafter PPO, thereafter PPP, thereafter it will be again PPO, thereafter POO, thereafter 000. So this will be the sequence.

Similarly, if you start with basically 000 if you are in a sector II switching logic will be OPO, thereafter PPO, thereafter PPP, thereafter PPO, thereafter OPO, thereafter OOO. Similarly, in third sector you start with the same OOO, thereafter OPO that is same but this will change. So Vb theta was PPO then here will be OPP that PPP again the mirror image will be followed.

Similarly, this way all the sequence has been if you are in a particular sector, particular sequence you require to follow to minimizes the switching state. You can achieve with the 6 switching only in a whole cycle.

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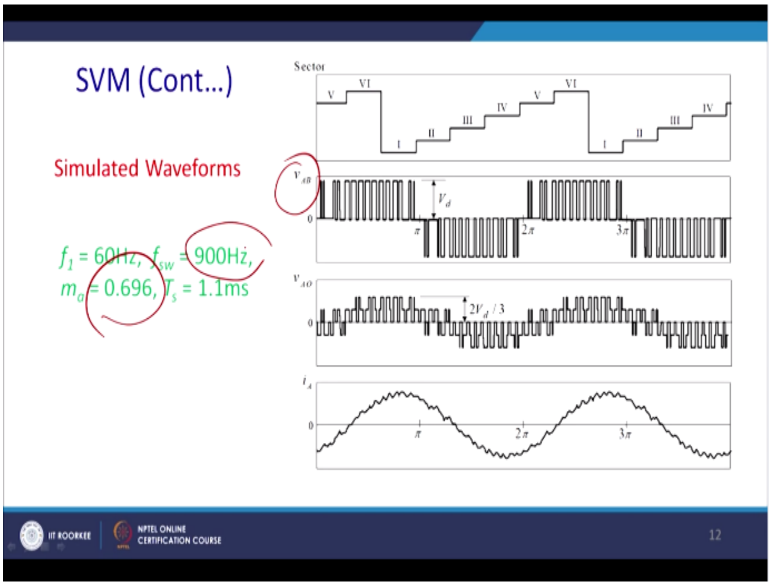


So you see that example, so this is basically the sectors and this is a sector 5, sector 6, thereafter sector 1, sector 2 and so on. This is the way your switching changes and this is the vAB and this is the Vd voltage has actually the DC link voltages and this is the vAO and this will be your actually the line voltages and you can see that modulation index is basically 0.69 around 70% and Ts is 1.1 millisecond and frequency is just close to 1 kilohertz that is 900 hertz, so you will get this kind of results.

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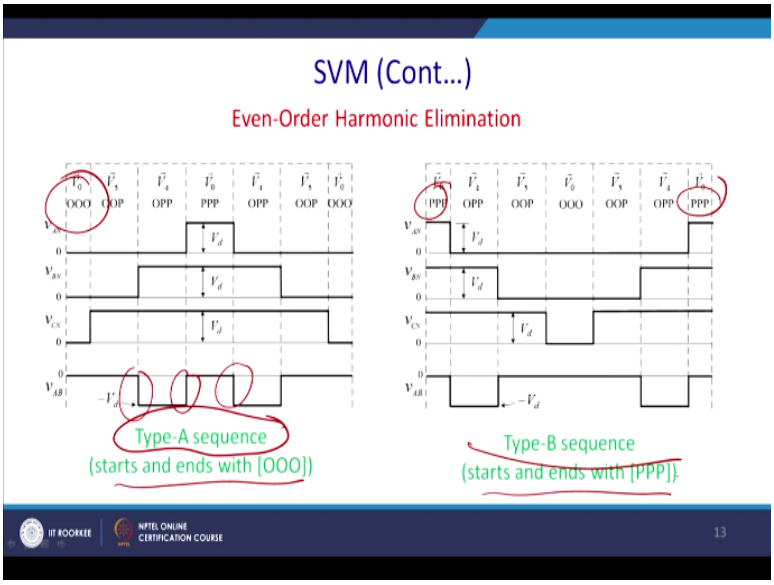


So what will be these, so how can you eliminate this is the question arise, how can you eliminate the even-order harmonics that is generally you have seen that due to the symmetry that does not presents. So you can be actually eliminate in a two way that first take the sequence A, so sequence A, so you have actually you have a logic like you want to generate vAB you start with the 000 that OPP thereafter all the sequence will come.

And you can see that actually this starts and end with basically the 0 and this side also 0 and here there is another sequence that starts with P and ends with the P. So can you infer anything from these two logics? So if you start this pattern, so what are the switching states? So this is the OPP, thereafter this is a BAM, this is the CEN that what you had got in this actual reference case but actually here A phase is actually less content and C phase is the more content.

And thus AB you will get this kind of sequence and it is unnecessarily switching. Same logic you know if you start with this way, PPP and end with the PPP then you will get actually less switching and this starts and end with actually all the positive cycle.

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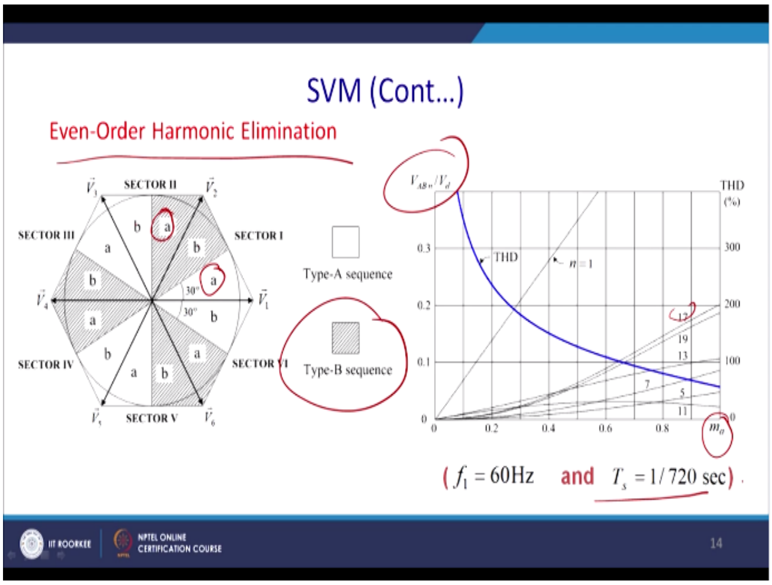


Now even-order harmonic elimination, please go back this is the sequence A, so you start with 000, we say that it is a sequence A and you start with actually PPP or 111 that will say that a sequence 2. Now see that actually this hashed is sequence B and this part is sequence A and you will find that this line this THD line and you have to have combinations or even-order harmonic eliminations by a here then a here.

So b here then b here c here so if this has to be this way combined. So what happen, you require to operate in a sequence a, you cannot mix the sequence A or sequence B then what will happen, you cannot eliminate harmonics, even-order harmonics and you know you can see that how this ratio if it is actually reduced, THD has been actually reduced. So this is the modulation index.

So if you increase the modulation, THD will increase. This is a first fundamental increase linearly and these are actually 75 procedure 3-phase 3-wire system. Then, your harmonic content 6n-1 and you will find that these are the harmonic content. This analysis is done for the 60 hertz and for the sampling frequency of this much. So please note that we required to eliminate the even-order harmonics, so we cannot combine A or B sequence state.

If you wish you can go for the sequence state A or sequence state B so then only you will find to further symmetry you know there is you can go back with the symmetry.

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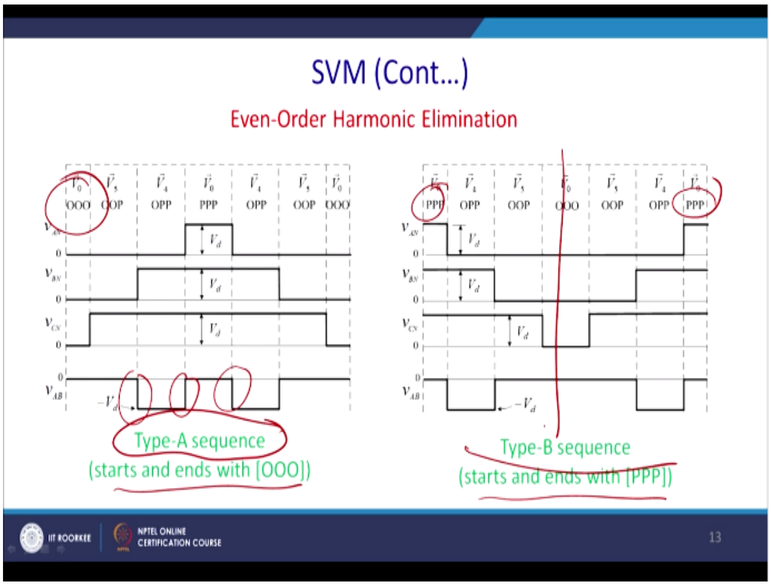


So due to the symmetry you know all this odd harmonic will be or all the even harmonic will be vanished but here you know this symmetry is actually missing, you know if you see this line you know it has a symmetry. So for this reason actually, we will have all the even harmonics present into the system. Thank you for your attention. I shall continue with few part left in the actually space vector modulation technique in our next class. Thank you.