Power Quality Improvement Technique
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Lecture – 24
PWM for Voltage Source Inverter – II

Welcome to our Power Quality Improvement Technique. We will discuss this the PWM techniques for Voltage Source Inverter. This is our second lectures on it. We have discussed the basics of this PWM technique and the third harmonic injections.

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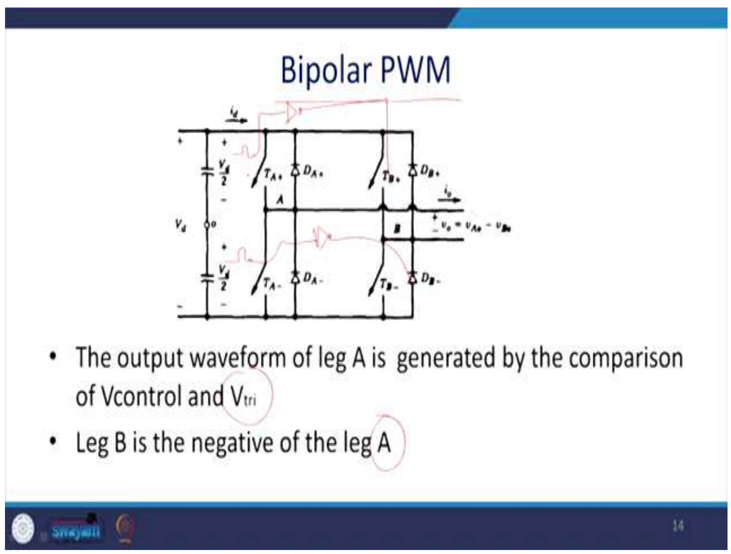

Now, we shall continue with the bipolar PWM. It is a little primitive kind of thing. We generally do not use nowadays. We prefer the unipolar PWM. But, anyway for sake of evolution we shall study these methods also.

Here we have seen that this is a switch and four switches has been employed, for this reason it is a full bridge configuration. In previous configuration or in the previous class it was the half bridge configuration. So, ultimately you know that if modulating wave is more than the triangle, then upper switch T_A and the T_B will be on and otherwise the reverse T_B and minus T_A will be on.

So, in this case the output waveform of leg 'A' is generated by the comparison with the $V_{control}$ and the V_{tri} with the leg B is negative of leg A. That mean, whatever pulses you will feed to a NOT gate, you give it here. That mean if this one is 'on' and this one is 'off', same way whatever pulses you are giving here and you will put a NOT gate and give it here. So, leg B is the negative of the leg A. For this reason, what happens? We will find that the different combinations of the switches. How it will work?

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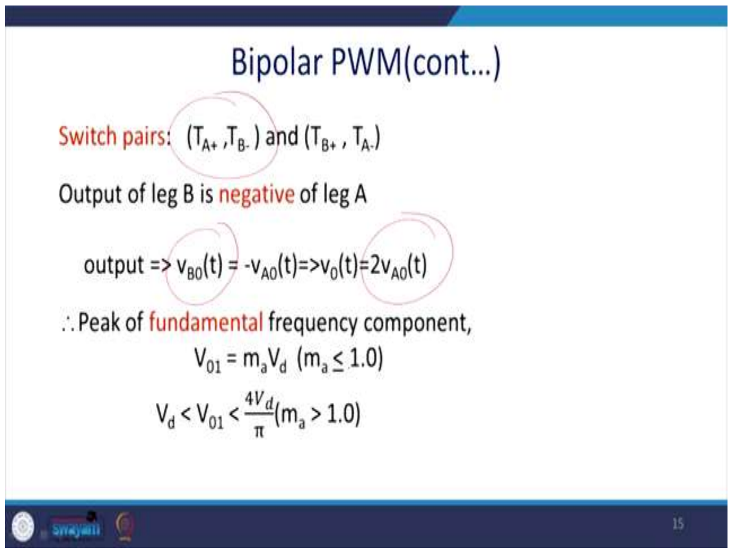

So, there is a pair of the switch which may work is T_{A+} and T_{B-}. So, this is the path of power. For this reason, just reverse that is T_{A-} and T_{B+} and you will get the pluses and the output leg B is negative of leg A. That was a logic we have seen.

So, output voltage will be V_{OB} equal to minus of this logic and thus it will be minus V_{AO} and this output voltage will be $2v_{A0}$(T). It is a full bridge configuration. You will get the double the voltage because you are utilizing the full dc bus.

So, peak of the fundamental will be $m_a \times V_d$ and its maximum value its limited to 1 and you know that. For the square wave operation, it is for $V_m/2\pi$ was for the half bridge and $4V_m/\pi$ will be for the 4 bridge. So, this is your magnitude of the fundamental voltage you can expect.

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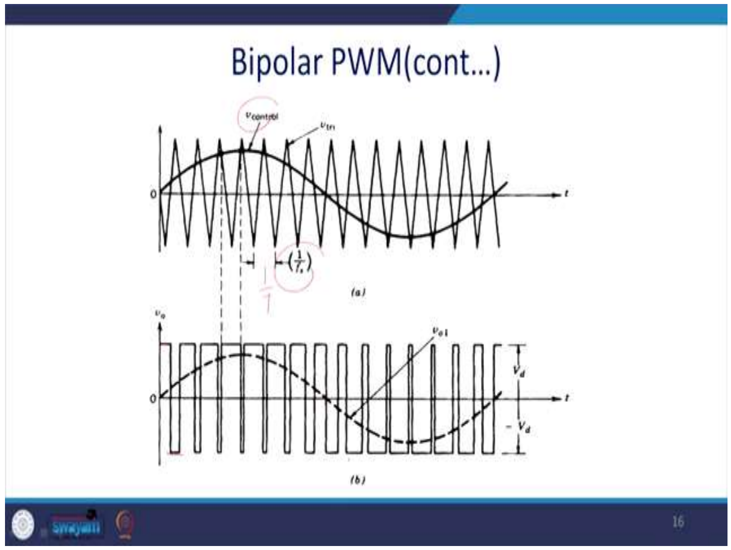

So, how does it work? This is the part of the $1/f$, that is the T. It may be 1 kilo hertz that is 1 millisecond and you have a $V_{control}$ and the V_{tri} you can see that this voltage positive as well as negative. For this reason, we call this as bipolar PWM. So, voltage stress is quite high, because it is switching in half cycle positive to negative. But difference of the voltage will come and that will be effectively positive half of the sine wave.

Here you can see that negative area is more and this will give you the negative part of the sine wave. But problem lie since it is switching over this point to this point, stress of this voltage is quite high. The devices rating is required to be higher.

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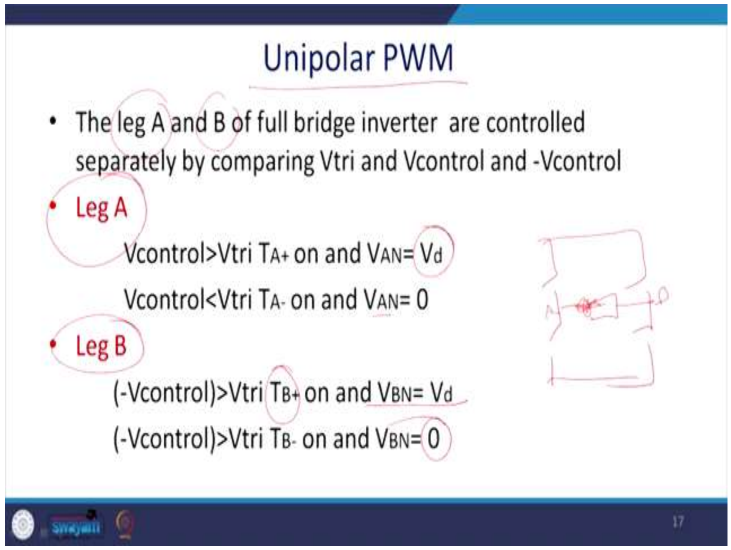

So, let us come to the unipolar PWM. So, logic will be a little different here and we required to generate the sine or the modulating wave and negative of the modulating wave. Not the 'NOT' gate which we have used in case of the bipolar PWM.

The leg A and the leg B of the full bridge inverter are controlled separately. It is not that leg A is a function of leg B. Then What happened? You just complement the leg B and thus you get the voltage which is bipolar and, in this case, then what happened? There is a logic. Leg A: $V_{control}$ is greater than V_{tri} for T_{A+} on and V_{AN} equal to V_d then $V_{control}$ is less than V_{tri} on and that equal to minus V_{AN} equal to 0. Similarly, you can have a 0 logic sometime. It is not that positive V_{dc} or the negative V_{dc}.

So, it can boil down to the '0' voltage sometimes and it will cancel this two-pole voltage. Ultimately you are taking this voltage between these two points. So, this is a load to be connected in between. So, A and B, you are interested to take the voltage. If there is the same voltage, they will cancel.

For leg B: minus $V_{control}$ is greater than 'V_{tri}' then T_{B+} will be on then ultimately you will get the V_{BN} equal to V_d. Similarly, the $V_{control}$ is greater than V_{tri} you will get T_{B-} on and that you will be again this is the value will be equal to V_{BN} equal to 0.

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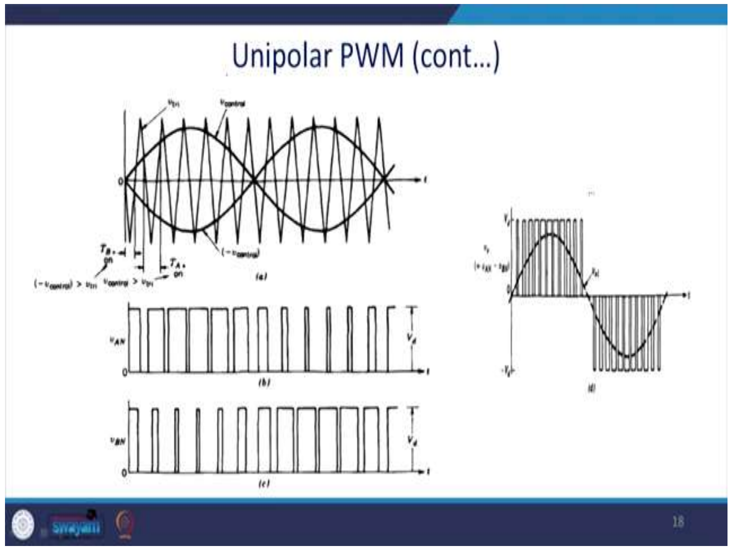

Thus, you require two modulating waveform and one carrier waveform. This is a $V_{control}$ and this is minus $V_{control}$, this is for leg A and this is for leg B. So, this will be the waveform pattern for leg A and this will be a waveform pattern for the leg B. You sum it up. You get this voltage. You can see that there are no negative pulses in positive half cycle.

Similarly, reverse. There are no positive pulses in the negative path part of the sine wave. The stress across the switch is going to be low and also it shifts the harmonics spectrum to quite high.

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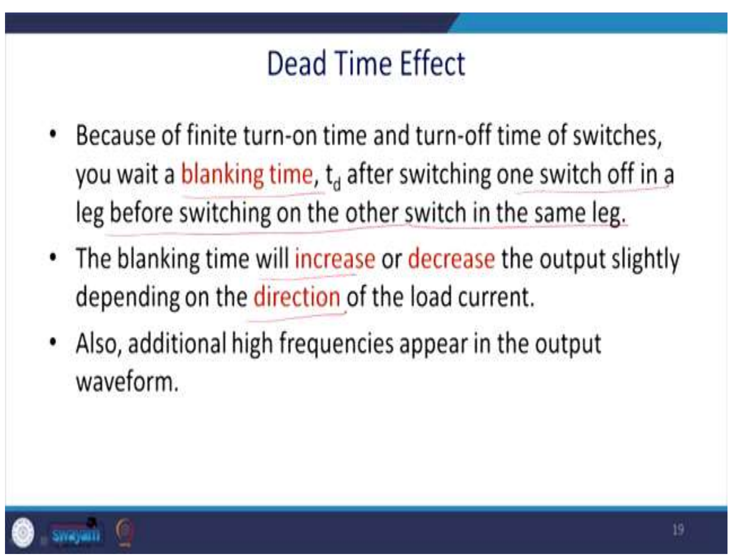

Another important issue we required to discuss is students are required to implement these active rectifier power quality condition as a hardware in master's level or the B Tech level. We required to deal with the switches. Because of the finite turn on and turn off time of the switches you wait for the blanking time.

So, you require to wait. Because unless if you go back since there is a diode you cannot give a flow to the current. If this is a current it is flowing, then ultimately if you turn on this and you cannot instantaneously change the direction of the current. Then first it will go off. Diode will take up, then you can change the direction of the current.

So, you wait for it. That is called the blanking time t_d. After switching one switch off in a leg before the switching of the other switch off the same leg. The blanking time will increase or decrease the output slightly depending on the direction of the load. Sometime if the upper diode is conducting, generally it goes up in a positive half cycle and if it is a same happens in its reverse criteria happens, then negative diode part of the switches has in conducting for the diode. So, it may add up the load current or the subtract load current depending on which devices is conducting. But for the worst case of design we will consider it will add up to the load current.

Also, additional high frequency appears in the output voltage waveform. That is quite important phenomenon. So, you will have a high frequency part. It is coming due to the diode and that is uncontrolled because you are not controlling it. Unless the current directions will change till the current through the diode decays otherwise it will wait. So, that is called a blanking time. So, you have to wait for that time.

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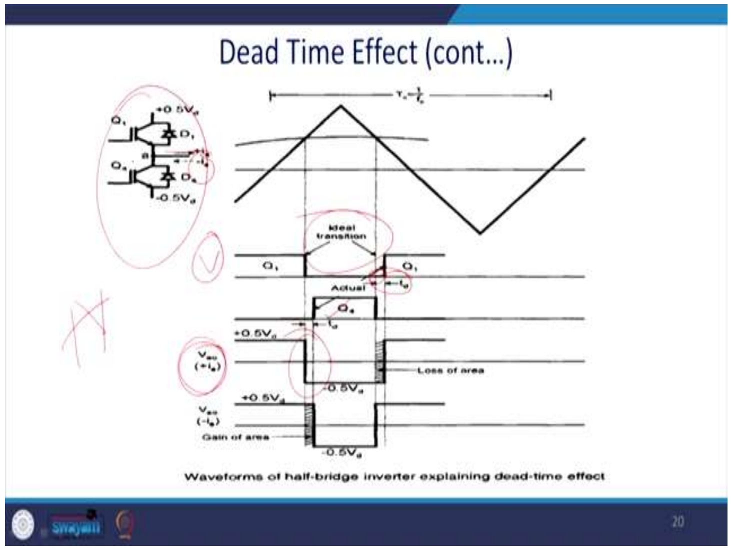

This is some example of this dead time effect and you have to give a little time for the legs so that short does not occurs. You have studied, you know effect of the source inductance in basic power electronics, where, you have essentially overlap angle between the two thyristors that is called 'μ' and in between there is no power being transferred because of the shorting of these thyristors.

But what happened? Since current was low, the shorting was not a problem. But here if the short occurs then your high current will flow and dc bus will sink. So, that is a great challenge itself. For this reason, we generally do not allow this current. We provide a dead time so that no current flows, the legs not being shorted. Except one topology derived on that directions that is called z-source inverter. There we provide the shoot through by shorting the leg.

So, this is the triangular wave and this is the modulating wave, and this is your ideal transition Q_1 was on and Q_1 will go on, conduction mode. So, this is the voltage across it. Your voltage will drop to 0 ideally and after that it is ideal transitions it will take some time again to rebuild its voltage blocking capability and this time is your t_d.

Similarly, let us assume that your lower devices are named as a Q_4. It was conducting and it will get its forward blocking capability after the delay of the t_d. Thus, what happened? If you have the V_{ao} and assuming that current is positive, it is in a positive cycle. If there is a lagging power factor there is a challenge. That will come little later.

Voltage is positive, but since being a lagging power factor current is still in negative half cycles. Assume that this is a case. Current is in is positive. Then what happened? There is no problem here. So ultimately, since current was flowing through this and direction of the current was through this, so automatically when it is put off this will be turn off.

But once these lower devices come into the pictures then once it is regained then there will be a challenge. That will come into the pictures. Current will flow through D_1 and just reverse will happen, if current is actually going out from the neutral point. It is minus a. So, you can see that if you turn it off this devices Q_1, initially it will not go through this path, because it is sinking. Ultimately current will try to flow through the diode, first. Thereafter it will go through the devices. For this reason, you will have a loss area which will be this.

So, depending on the lagging or leading power factor this is basically these devices. For these devices there will be a turn on loss if it is the lagging power factor. If it is a leading power factor you will have a turn off loss. So accordingly, we required to design your dead time so that you can mitigate this loss.

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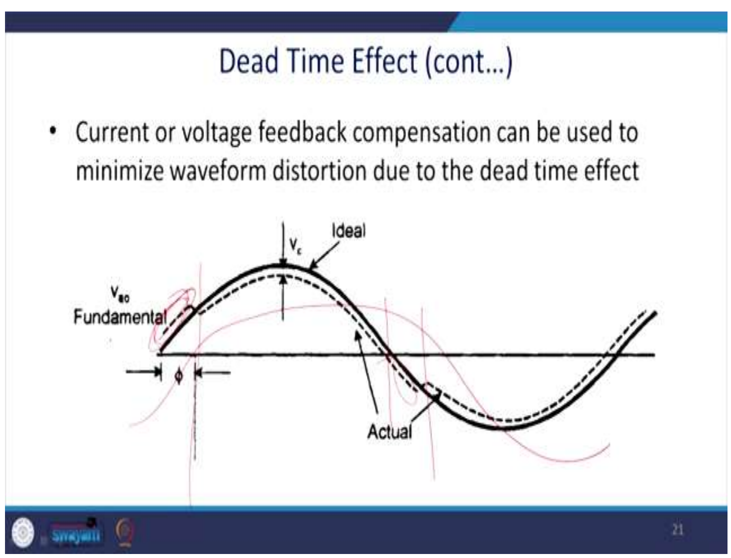

So, what happen actually? So, the current and the voltage feedback compensation. We are talking about. We are not coming into the control system right now. Control system has to mitigate this problem.

Let us assume that voltage and current are been phase lag by 'ϕ'. This is a voltage and ultimately what happened? If till this time when voltage is positive and current is negative, then the once you turn off you will get a little more voltage and ultimately voltage will add up to the loss. Please understand it that this part it is regenerative part. Voltage is positive current is negative.

So, thus what happens? You know it will continue till like that and you also get a benefit from here. You will get a little higher voltage because of the regeneration. You have to feed it back. Basically, you are feeding back here and thus you will generate little more voltage, and after that it will be compassionated.

So, current and voltage feedback compensation generally used to minimize the waveform distortion. Generally, what happened if voltage most of the cases we have an inductive load and thus current is lagging. So, till the lagging portion you will get little more voltage. But fortunately, the advantage is that it occurs at the very beginning of the 0 crossing. So, stress across the machine is not high and ultimately what happen? If this comes due to this blanking, generally voltage will come down little bit and that also good someway, because stress across the switches get reduced.

Here after the 0 crossing again since voltage become negative, current is still positive it will boost up the voltage again in regenerative region. There after again it will be there. So, ultimately this extra energy has to be taken and compensated from this when there is a voltage and current are in a same wave cycle.

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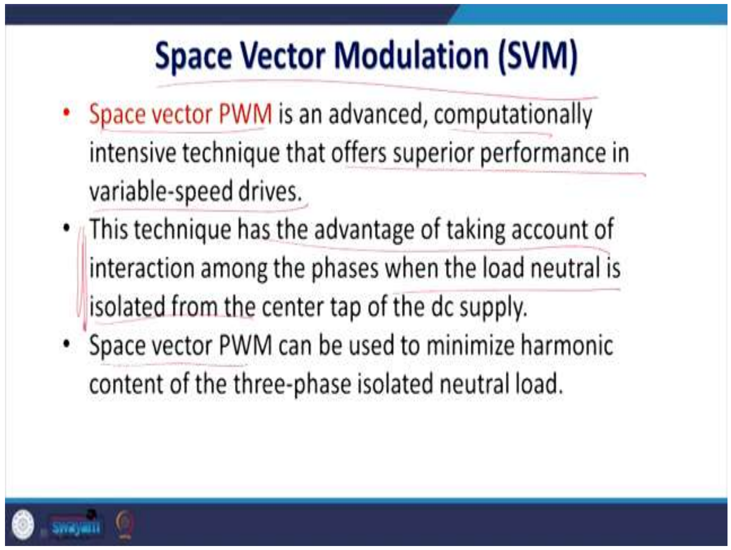

So, now let us talk about very important aspect of this PWM technique. That is called the space vector modulation. This is quite important because mostly most of the drives and as well as the D-STATCOM and your shunt active power filter, all uses now space vector modulation, because of the greater utilization of a dc bus voltage and more attune to the SRF, because we have discussed already the SRF.

That is a synchronous reference frame. It can directly fit to this SRF based volt grid connected inverter or converter as solar inverter or shunt active power filter or D-STATCOM or DVR. For this reason we required to discuss the space vector modulation technique in detail.

The space vector modulation technique is an advance, of course it is more computationally more complex and computationally intensive technique that offers (That is more important why we will go for that performance?), superior performance in variable speed drive as well as a shunt active power filter and DVR, UPQC both. This technique has advantage of taking account of interaction among the phasors, when the load neutral is isolated from the center trap of the dc supply.

Generally, this is the one aspect we required to understand very well. This technique has an advantage of taking account of interactions among the phasors now. That is when load neutral is isolated. Mostly, it is a case we have studied, we have discussed just now. That is for the 3-phase, 3-wire system and if you have a third hormonic injection, and you do not connect the start connected load midpoint to the midpoint of the capacitor then it does not supply.

Some way here, when the load neutral is isolated from the central of the dc supply then there will be a balance of the voltages. Moreover, space vector modulation technique can be used to minimize the harmonic. That is something we required to understand in detail. To minimize the content of the 3-phase isolated neutral loads. That this for the 3-phase, 3-wire system. Generally, you know we have discussed for the grid connected inverter also voltage source converter. That is, we can have 3-phase representations.

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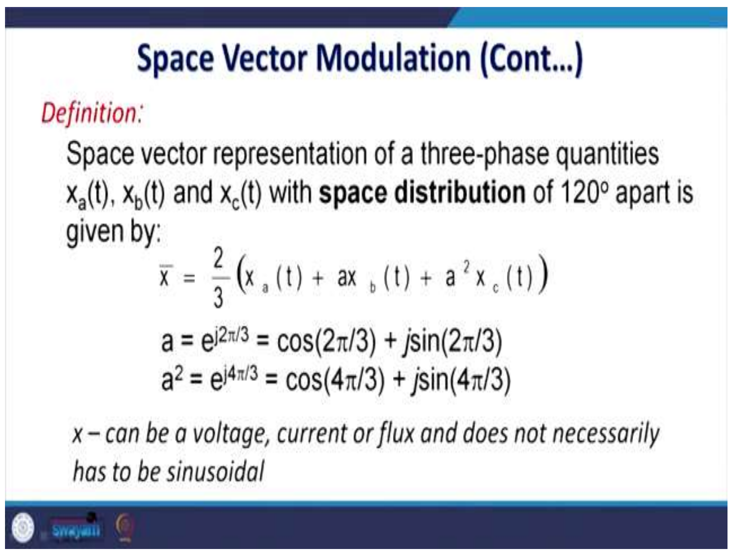

Space vector representations of the 3-phase quantities that is x_a, x_b, x_c. We have already discussed with the space distortion of 120 degrees or the space distribution of the 120. Pardon me. If x can be voltage current or flux also in case of the machines. That is $\bar{x} = \frac{2}{3}(x_a(t) + ax_b(t) + a^2x_c(t))$ where $a = e^{j2\pi/3} = \cos(2\pi/3) + j\sin(2\pi/3)$ and as I have mentioned that, it can be a voltage, it can be current, it can be a flux, or any sinusoidal varying quantity.

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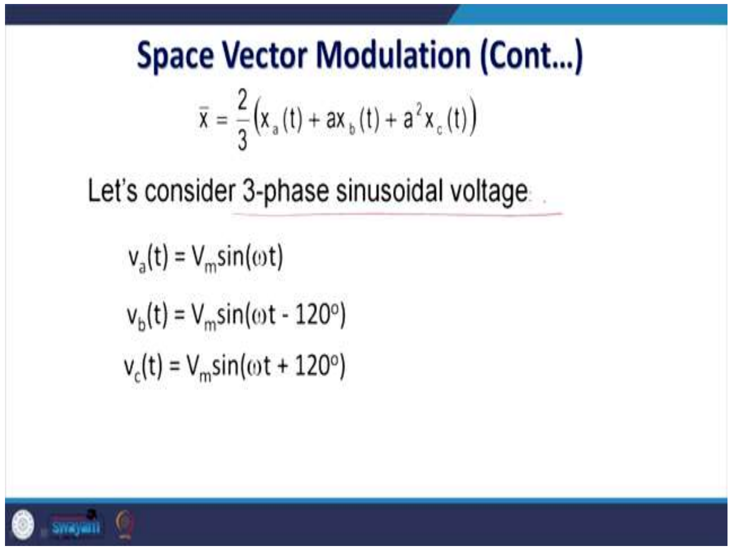

So, thus overall representations in a space vector modulation will be $\frac{2}{3}(x_a(t) + ax_b(t) + a^2x_c(t))$. Now, let us consider that 3-phase sinusoidal voltages. So, there you know that $V_m\sin(\omega t)$, $V_m\sin(\omega t - 120^o)$, $V_m\sin(\omega t + 120^o)$.

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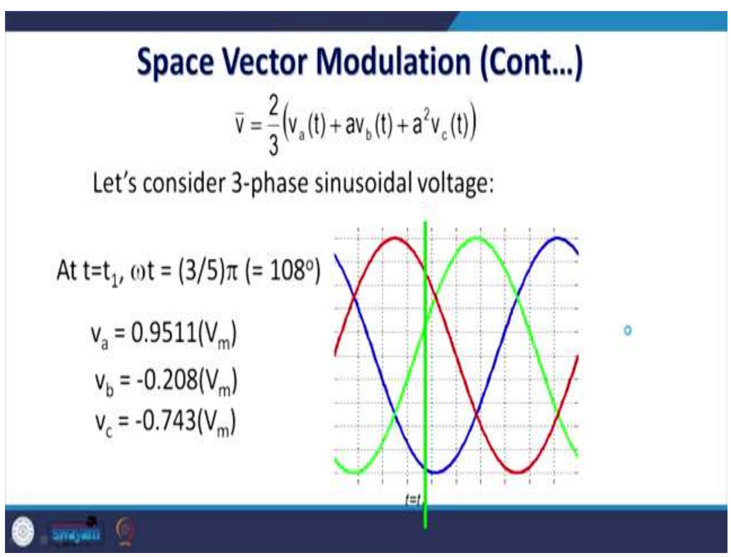

Thus, we required to have this kind of waveform. Required to be generated by the PWM technique. So, let us consider an instantaneous value over the sin wave for all the 3-phases. For let us say that $t=t_1$ and $\omega t = \left(3/5\right)\pi$, that mean add 108 degree. So, somewhere here.

So, v_a will have the 0.95 Vm, v_b will be 0.08 Vm, and v_c is a most active phase here that will be 743 Vm. So ultimately this is the line. Summation is 0. We required to generate this voltage. How we can generate that voltage by inverter?

We can write like this. That is, we know that it can be represented by the voltage current anything. So, $\bar{V} = \frac{2}{3}(V_a(t) + aV_b(t) + a^2V_c(t))$ and let us consider 3-phases of the sinusoidal voltage when a = t_1 and $\omega t = \left(3/_5\right)\pi$ that is 108 degree, that I have told you. Ultimately you got this voltage.

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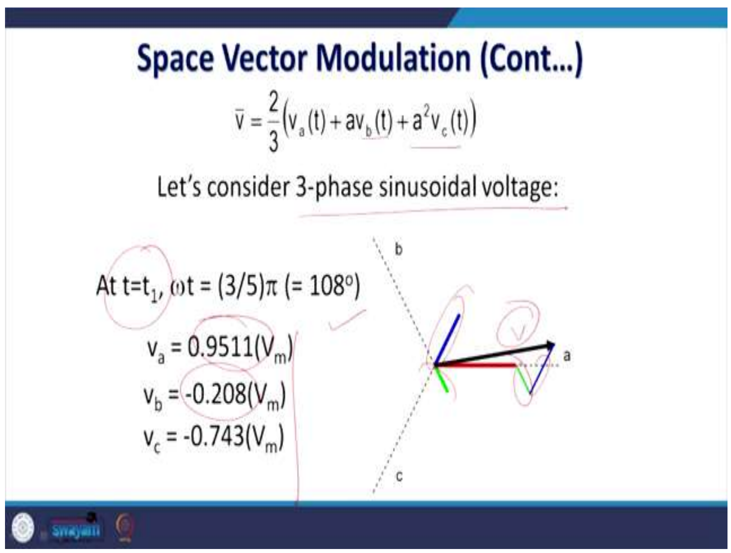

So, let us see. This is the 3-phases 120 degree apart. This value is a v_a that corresponds to 0.95. This corresponds to v_b because it is negative. That corresponds to it because this is a positive v_b. So, this is a negative v_b of 0.208. Similarly, you have 0.743 this value as your 'c'.

Now, you know that. You have studied in eleven. You have studied in mechanics, you have studied in class 9 and 10. So, that is a transpositions of the vector from one point to another. You can take the vector to its line of action any point parallelly. You can shift it and thus you shift this though voltage is not affected. It is just the representation. So, you shift it here.

Similarly, you shift it here and you to draw the phasor and thus this is the resultant voltage of v_a, v_b, v_c. Please understand that if you sum it up algebraically it should be 0. But this is a vector representation so that is not zero. Ok?

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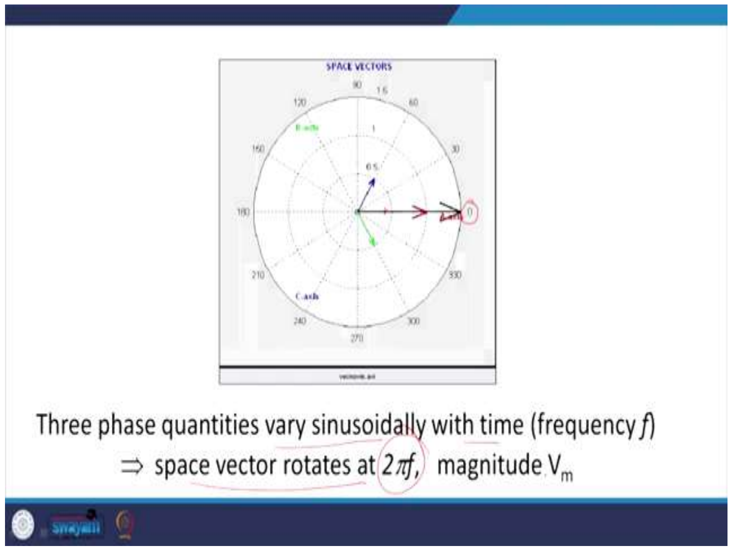

So, this is the way it will rotate. This is a space vector modulation. So, ultimately that this vector and we will calculate. That is all. We will tell this value and theta, and from there every information will be contained. That is a (r, theta) representation. In your question assignments this kind of question will come. For this reason, I am teaching with the emphasis

So, this is considered. This is your 'b' axis, this is your c axis, and this is your 'a' axis and this is a representation instantaneously and ultimately you have to split them because, if you take the resultant this will be this. So, it will add up ultimately. It will make this. So, 3-phase quantity and this will vary in this phase plane.

The 3-phase quantity vary sinusoidally with the time frequency 'f' and space vector rotates at a speed of $\omega = 2\pi f$ and having a magnitude of the modulation index of Vm. I am coming to the magnitude of it.

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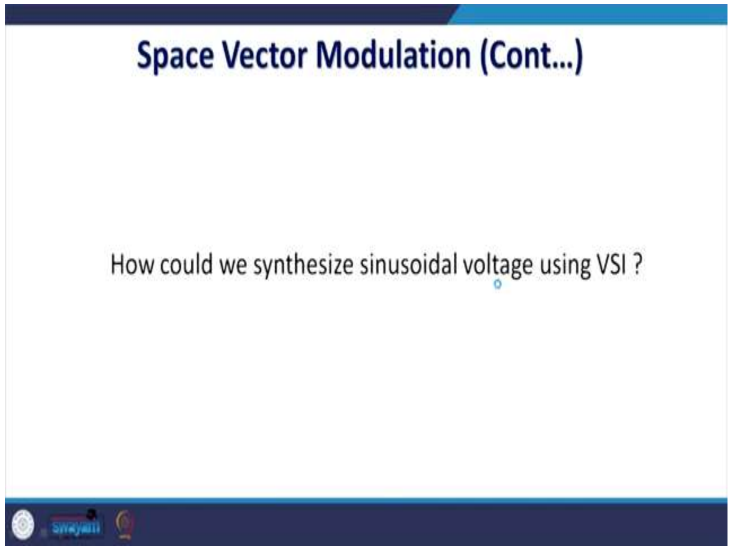

Now, questions arise. How we synthesize the sinusoidal voltages using the VSI?

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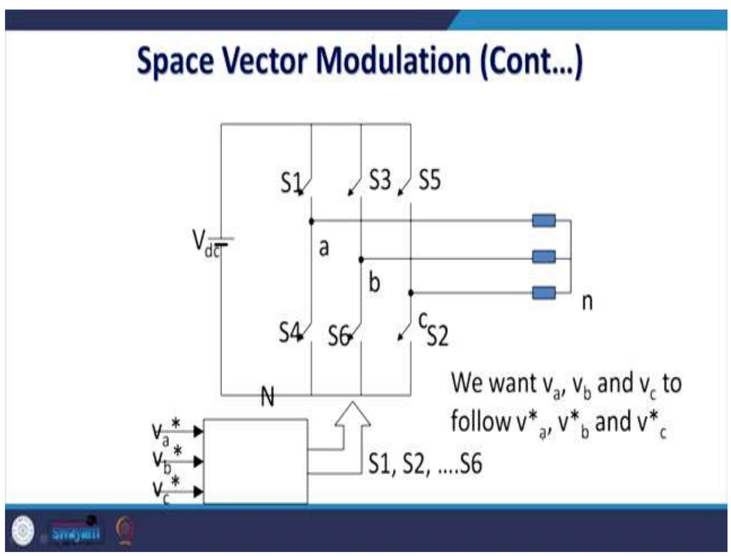

So, this is the representations of VDC, and ultimately, we have drawn the switch. But generally, we have considered a resistive load. Otherwise if it is an inductive load, we have not added the complexity that you required the anti-parallel diode. But, most of the cases that will be the case. So, these are the six-pulse converter something like that. So, how do you work?

So, I will generate the reference v_a, v_b, v_c. That is coming from the modulation technique and that will be switching these six switches. So, let us see we want v_a, v_b, v_c to follow that v_a reference, v_b reference and the v_c reference. How it will work?

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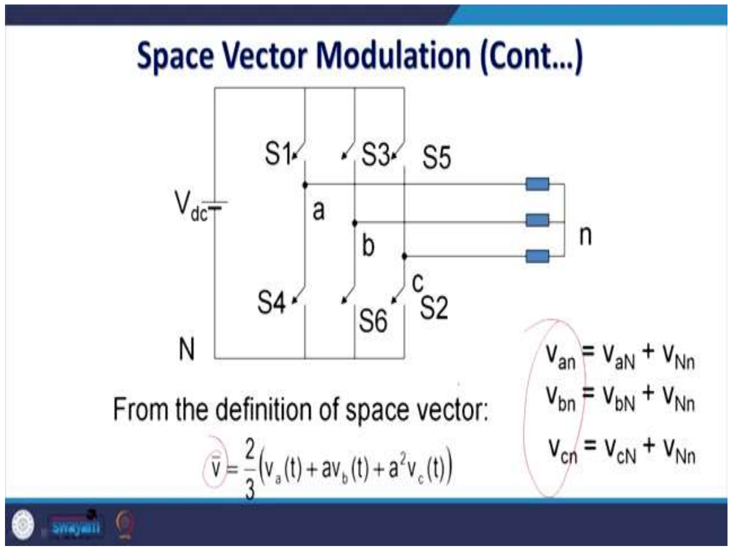

We know that. This we know that this is the angle. So, from there we can calculate the magnitude that is two-third v_a, v_b and v_c multiplying with the 'a' and its square that is just 120 degree phase shift.

So, similarly you have 3 neutral voltages. So, it is $V_{an.}$ Once you switch on with respect to this it is V_{an} plus V_{Nn}. Similarly, you have V_{bn}. This voltage equal to V capital bn and 'Nn' and this is 'V_{cn}' and ultimately this is a common mode voltage. It is called 'V_{Nn}'. Thus, we can cancel once there you add up.

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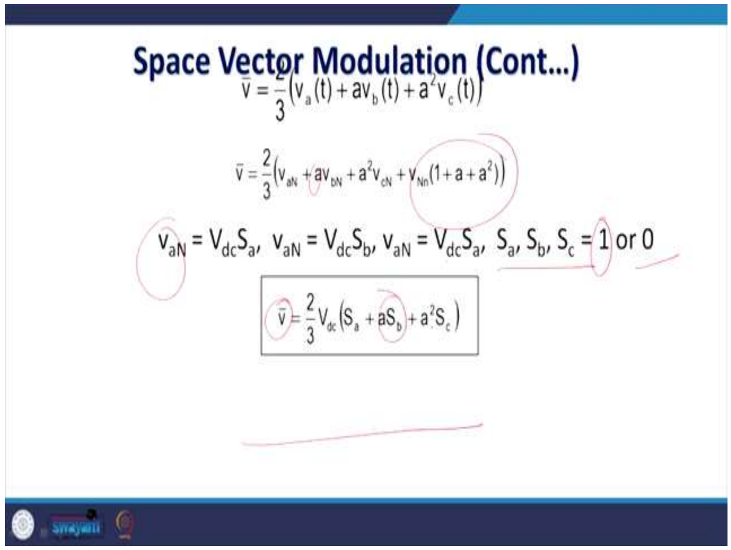

So, this is a representation of this voltage. Next representation will come like this. So, ultimately this summation will give you '0'. You are left with this part of it. That is the beauty of this space vector modulation. You do not bother about the common mode voltages that going to cancel immediately. So, that is $\frac{2}{3}(V_{aN} + a^2V_{cN} + V_{Nn}(1 + s + a^2))$. So, this is term is 0.

Now, you know that $V_{aN} = V_{dc}S_a$ and $V_{aN} = V_{dc}S_b$ and $V_{aN} = V_{dc}S_c$. Ultimately you got the switches. This is a S_a can be that is 'a' leg and representation it can be 1 then upper switch is on. It can be '0' if lower switch is on and thus, we can write in terms of the switching instead of the voltage. So, you can take this dc bus voltage outside. So, this modulate, this magnitude of this voltage will be $\frac{2}{3}V_{dc}(S_a + aS_b + a^2S_c)$.

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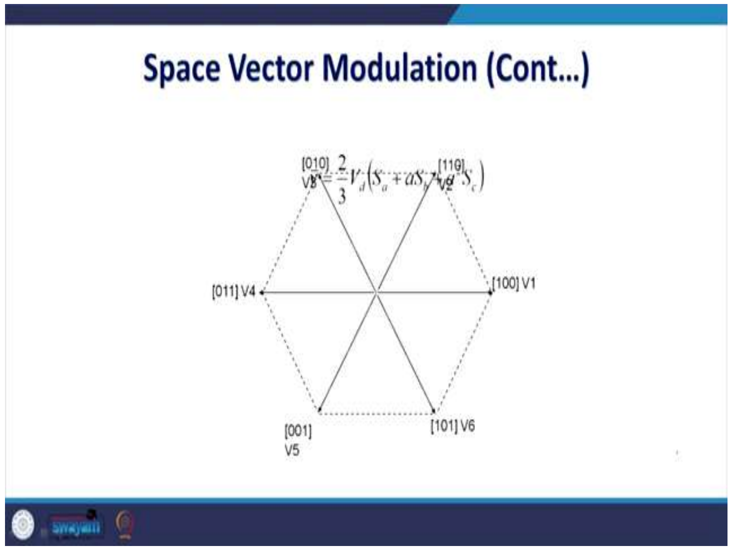

So, this is the representations in terms of the switching. So next, this is a representation of the space vector modulation. Due to lack of time I require to stop here right now. Thank you for your attention. I shall take this discussion from this to our next class.

Thank you so much.