Flexible AC Transmission Systems (FACTS) Devices
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Lecture – 05
PWM – II

Welcome to our 5th lecture. In this lecture we will cover this will be actually in PWM 2 that is basically; we basically try to cover speci vector modulation technique for the 2 level inverter. So, why space vector. So, space vector is an advance computational intensive technique that offers superior performance for the variable speed drive. And same concept has been already taken for the different kind of facts devices that come on all those things.

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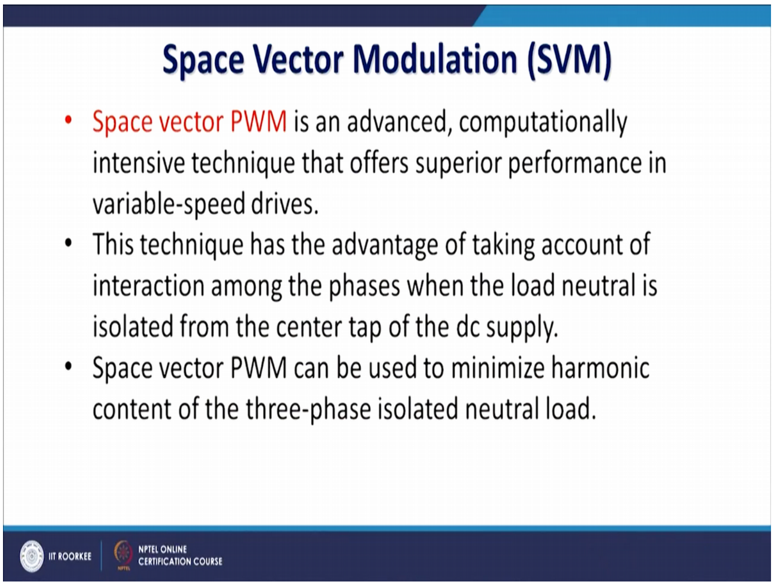

So, for this reason whatever we do in P by M control and vector control that concept is already been used for the facts devices. So, in the facts devices also this PWM this ss special kind of PWM technique, which may say the space vector modulation, is very important.

And, what is the advantage of it this technical advantage of taking account of the interaction of the phases and the neutral load current is isolated from the center of the trap and the DC supply.

So, it will eliminate the common mode noises and signals and space vector can be used to minimize the harmonic let us say every instant you can check, because what happen in the PWM. We have actually seen the very crude PWM that is basically your bipolar PWM, but it has got a very huge content of the harmonic since instantaneous voltage and the applied voltage as huge error.

Thereafter, it has been reduced in case of the unipolar PWM, but in case of this P da in case of this actually space vector. We keep our discussion for a 2 level inverter will be further reduced, and thus we can expect that further reduction of the harmonic that will be present with an end of the table ok.

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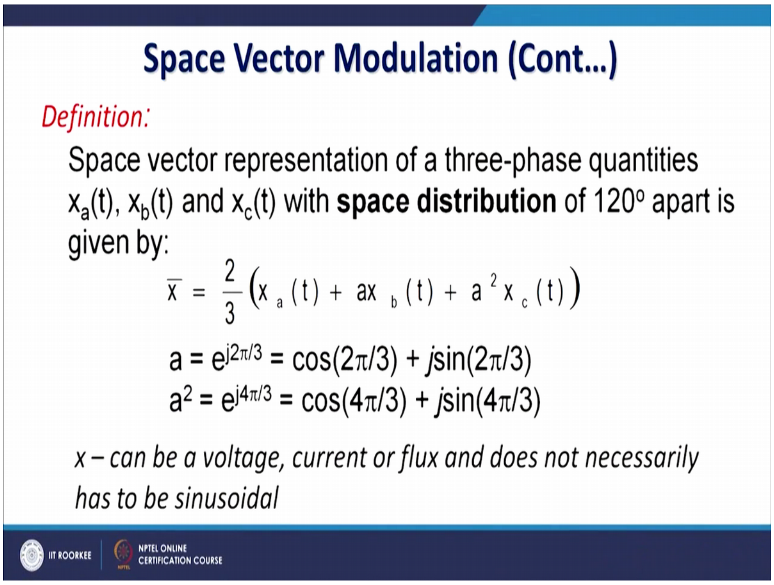

So, what is the definition of it? Space vector essentially represents is a 3 phase quantities, let us consider that current or voltage mostly where it we have represented by the X a X b and X c. And, we can see that actually that X is average is a summation of actually 2 third of X a X b and X c with the suffix a, but a is basically e to the power j 2 by 2 pi by 3. And, thus X can be voltage current flux whatever the electrical can quantity and that can be represented in this fashion. So, this is basically the X and this can be any quantity that is current flux and voltages.

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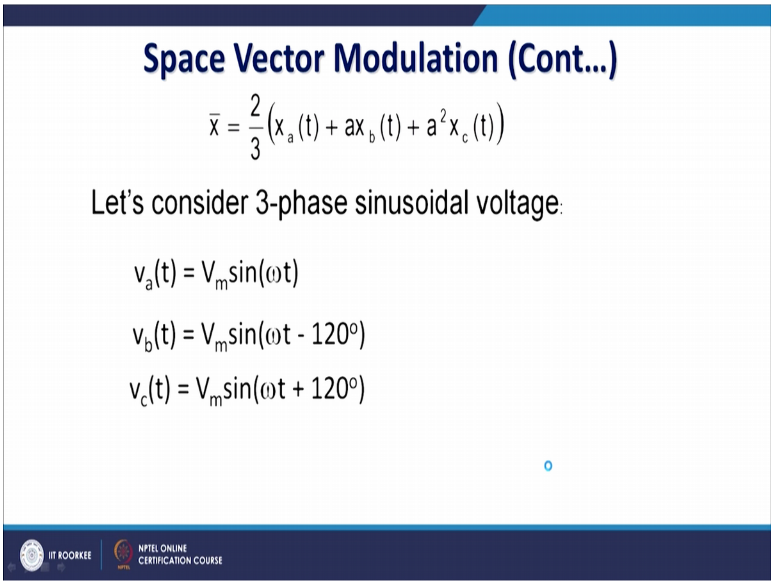

So, essentially the average value of this electrical quantity can be represent by this. So, let us consider a 3 sinusoidal voltages. This is a standard system.

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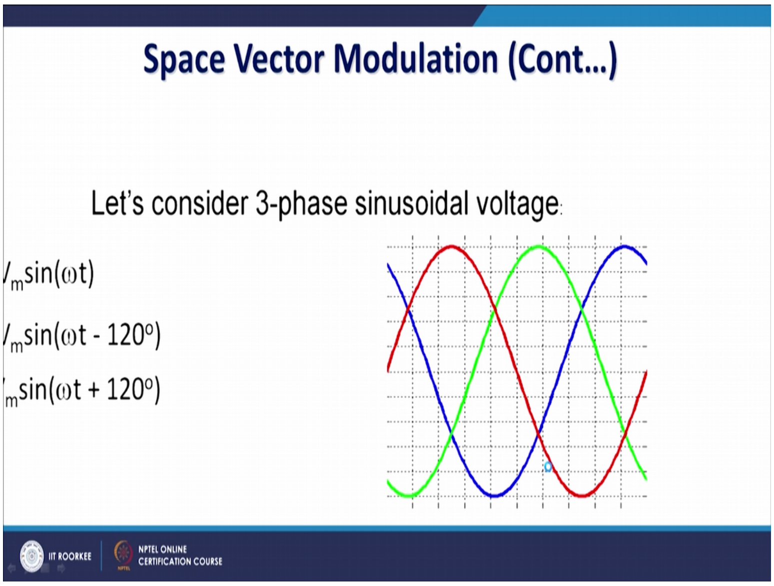

And let us consider this is their graphical representation 3 sin wave 120 degree apart.

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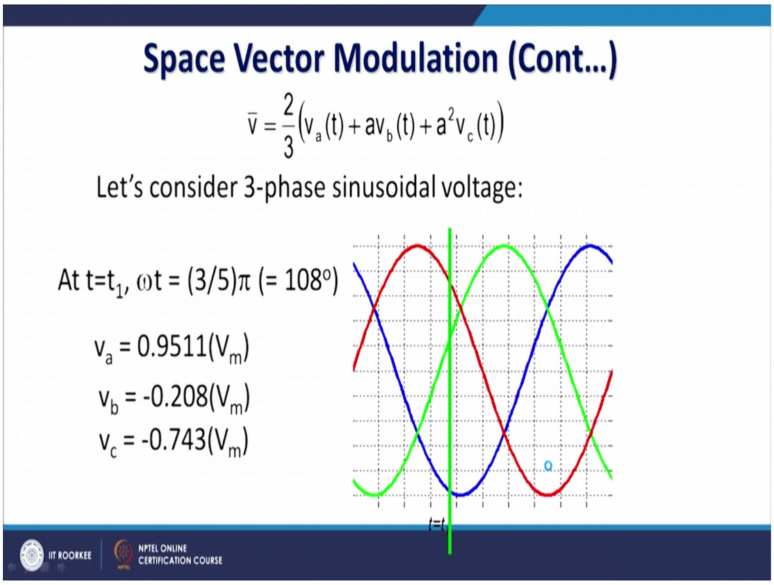

And, then let us take in some instantaneous value assume that an omega T equal to 108. So, what will be the value for V a at that time it is basically 0.95 and will be equal to minus 0.208 and V c equal to 0.78.

But, what happen generally what you do? In case of the PWM you either apply plus V dc or minus VDC. So, let us see that how it is different here?

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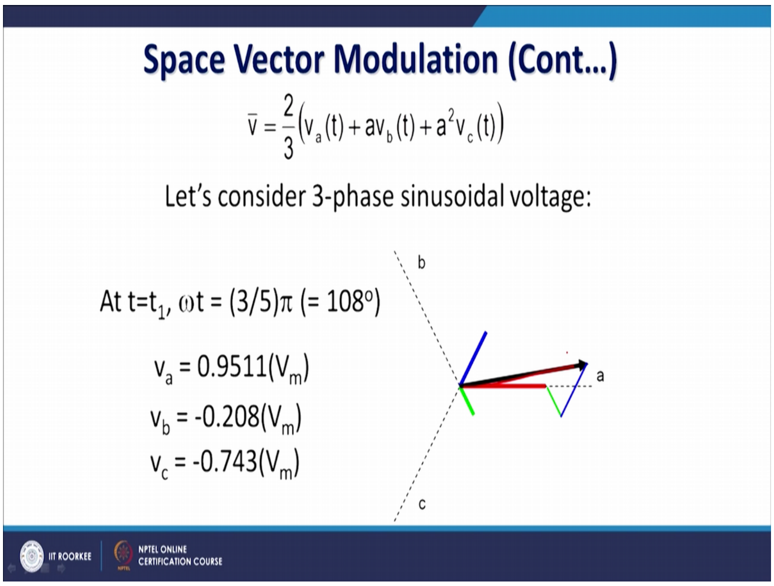

So, this is the phase system we assume that actually the anticlockwise rotation, thereafter this is basically the magnitude of the V a, which magnitude is actually 0.95 thereafter we shall find that magnitude of V b, which is minus 0.2 and this is actually magnitude of the V c, then ultimately this is the resultant of it, this is the average value we will apply.

So, instead of actually generating these 2 voltages these 3 voltages, if we can generate this black line and that will be sufficient to generate that necessary parameter to run the machine or fed into the particular voltage required by the statcom or other devices.

So, let us see that for this reason we have chosen a space vector.

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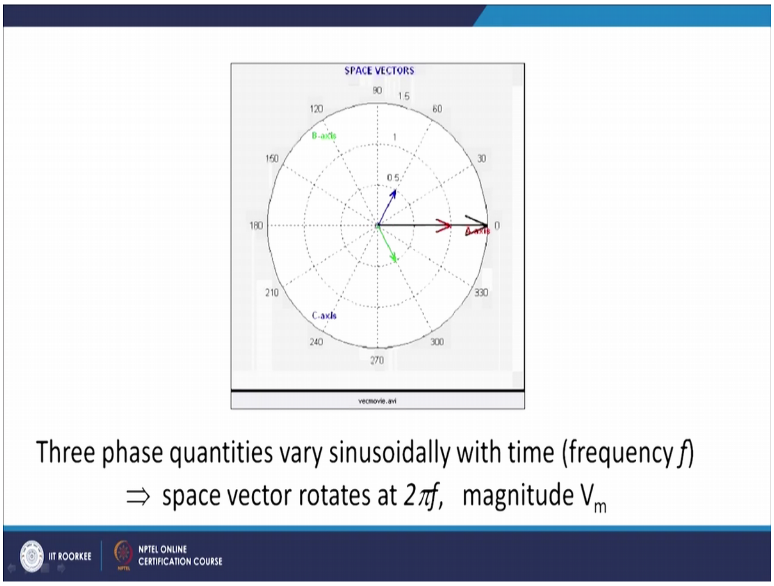

And, where actually this is axis assume that we should actually aligned one of the access with alpha and another axis should be with the beta. We shall use actually the concept of alpha beta frame and or the dq frame dq ds and the qs are stat stationary frame and dr and the q are the rotating frame.

So, here actually, how this actually voltage rotate? Now, in a stationary frame we will be representing this wave form like this. So, actually V a having this magnitude and V b was minus 2 will be given by this magnitude and V c will be actually this magnitude again minus.

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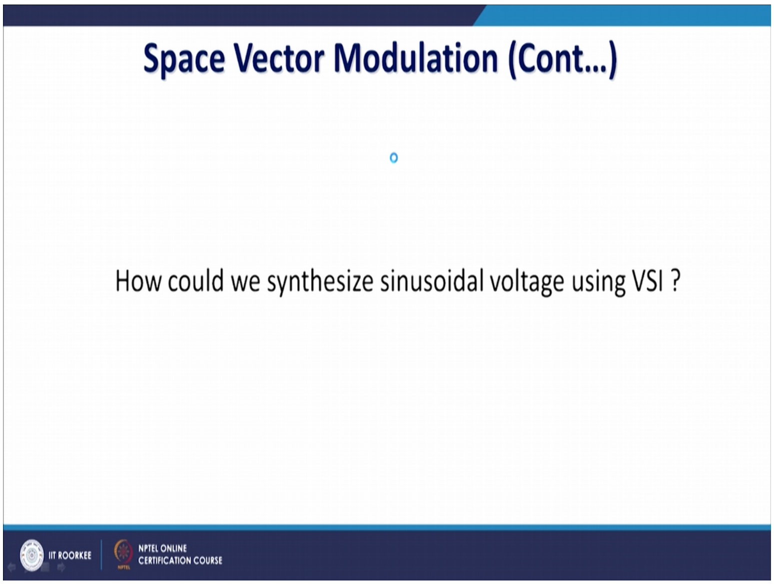

So, how actually you can generate the signals with the help of a voltage source inverter and thus how you can calculate the value? So, let us consider a sa simple 3 level, simple 3 phase 2 level voltage source inverter.

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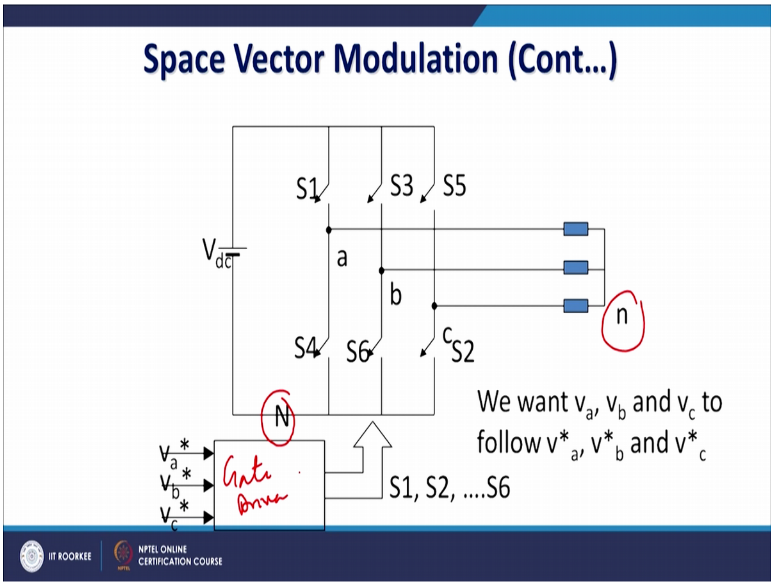

Where this point is a negative of the receivers this is capital N and this is actually the neutral point on the start. And in most of the cases you will have a common mode voltage.

Generally, we will have a reference V a V b V c that will be fed to the this is gate driver and that will be fed to by the gate driver to generate that desired voltages and generally it will be a close loop control. And, what do you want V a V b V c should follow the reference V a start V b star and the V c star.

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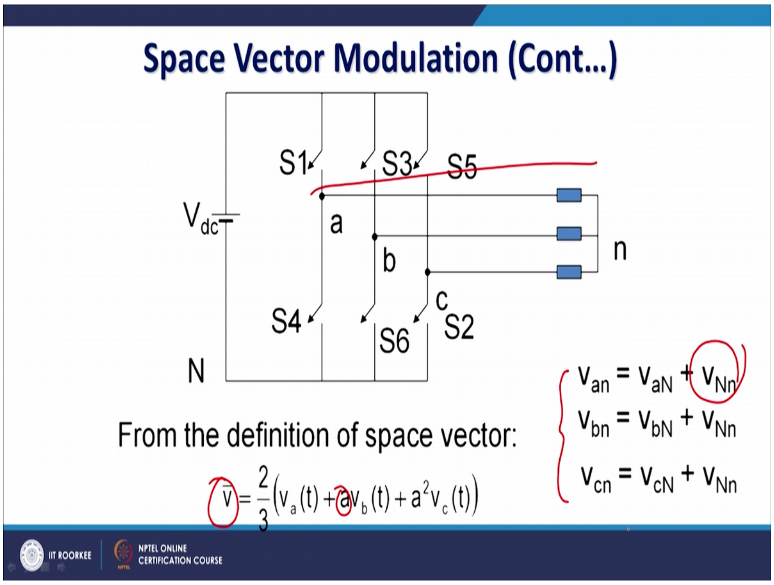

So, we know that actually according to definition on the space vector this average voltage will be actually 2 third of the V dc, that is actually the maximum it is available will be 2 third V a V b V c with the multiplication of the prefix, that is e to the power g omega t.

So, and here you can see that the voltage am is voltage this phase voltage we will have pan van plus actually the common mode con voltage V N n, same way we will have actually V b N plus V c N, that all will content with the common mode voltage, but this common mode voltage in this case will be eliminated in case. So, in case of the line voltage if you subtract.

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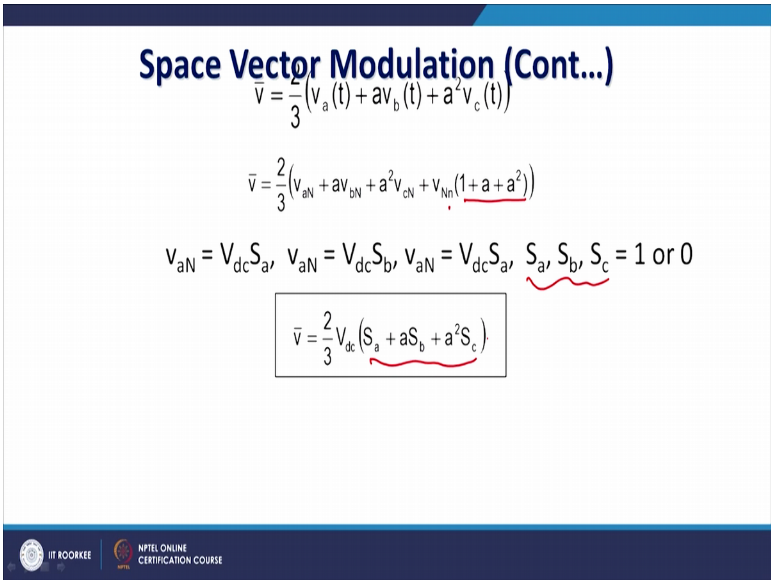

So, this is the average voltage to be fed and you can see that if you add up also. This is basically the summation gives it 0 for this reason your common mode voltage get eliminated. The same concept it been used for the essentially in case of the third harmonic injection and here we can also offer actually the N n voltage or the common mode voltage 0 and thus you know this voltage get eliminated

So, thus we can strictly say that V a N is basically the distilling voltage and the time that the switch up S a is on or off. Similarly, V b N should be similarly V d c into S b and V a m is basically, similarly V c N V a actually can be like that where S a S b S c can be 0 or 1.

Thus, we can write you know the average is 2 third of V d c by the combinations of the voltage and others are shifted by 120 degree in this mode.

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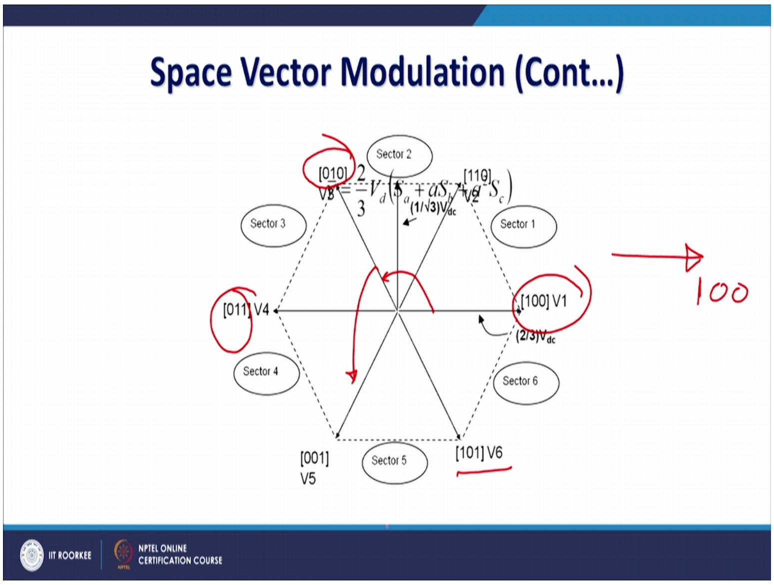

So, we can write V bar equal to 2 third V d c by s into S a a into S b into a square into S c. So, let us represent by this trapizoi about this hexagonal. Since this is the phase a.

And, let us write when it is when it is get a full voltage when actually upper switch of the phase a is on that will be present by the ze 1 and others are 0. So, for this reason you get a voltage V 1. Similarly, actually this will be 120 degree apart and this will be V b and this value will be 0 1 0.

Similarly, this value will be actually 001. Thus, it will be minus a it is 011 and it will be a minus b 101. Similarly, this will be minus c 110. So, these are the 6 voltage vector that will generate all the desired voltage you required to generate by the system. So, we will represent in a different sector task of the controller to identify sector then accordingly it will actually inject the required voltage vector to generate the desired output

So, this value is a maximum length is basically two-third V d c and here. So, you can it is a little geometry. So, this will be 1 by third V d c, thus we require to calculate the different sample time let us take an example we require to let us consider the receivers voltage is 100 volt.

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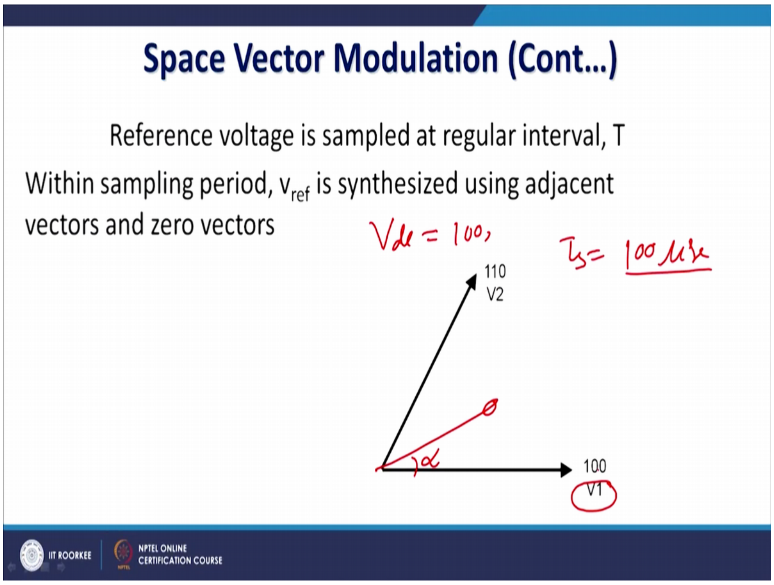

And your T s sampling time is actually 100 millisecond, 100 microsecond, that mean actually you are considering a 10 kilohertz system. So, see that with the sampling period V ref is synthesized using the adjacent so, vector we will see that how it is synthesized. So, see that let us consider that your point is someone here and you are in the first quadrant.

So, this angle alpha will be given to you and the particular magnitude. And, you require to understand wo you require to know what for how much time within the time T. Actually, V 1 voltage to be applied and rest of the time, this actually V 2 voltage to be applied and thus you will find it out and whatever the time will left out we shall apply the null voltage sun. You can go back you know there are actually 6 states and there are another 2 states that is 111 and 000 this means S a S b S c all are connected to the upper pole and this means 000 all are connected to the lower pole these are 2 are called the null vector.

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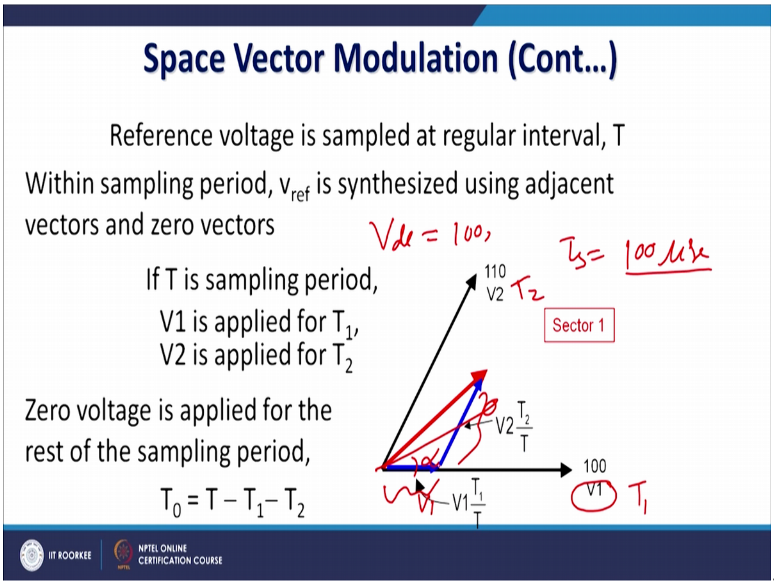

So, in this condition what will happen? You know the time let us say it is V T 1 and corresponding time will be V T 2 and rest of the time will be fed to it by actually the null vector timing, which is be given at a beginning and the end of the cycle then there is a reason behind it and we will discuss it subsequently let us consider that this is vector 1 ok.

And let us see the geometry. So, ultimately you can draw parallel line of b 2. So, ultimately for this much of time, you require to give V 1 and for some amount of time you require to give V 2 to generate this desired voltage

So, T 1 is applied for the for the time to T 1 V 1 is applied same way actually T 2 is applied for the time period of V 2 and 0 is applied rest of the time.

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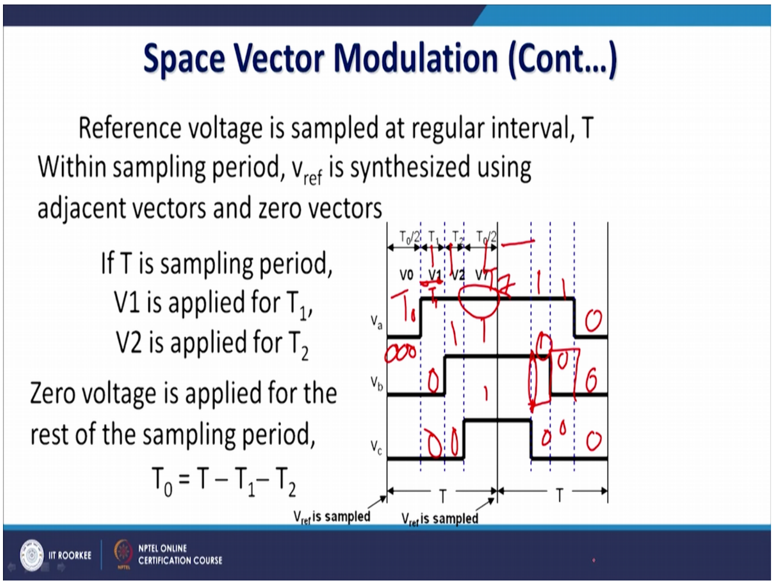

So, let us see what happen? Where V ref is the sample and what are how this actually 3 phase voltage has been applied. Generally we start with 000, then for the period T 1 we apply V 1, that this is the time basically the T 1. And, you apply V 1 and thus actually the upper switch of the phase a will be on essentially it is 1 and this is 0 and this is 0.

After, this time T 1 then we have to apply the voltage V b and what is this bit combination of V b it is 110. So, it is 110. So, rest of the time. So, you have get the result voltage, but you left with some time you have to fill the cavity. And, we want 1 bit change for this is it we apply 111. We, generally what we do actually we say this time as T 7 and we say this time as T 0 it should be splitted half of it at the end and the beginning of the cycle. We want actually less switching for this reason we shall carry out so, see that actually the whatever has been discussed has been written

Now, let us come to the next sample. So, it is past state was because here there is no history. Since, it is past states were 111 and you have to apply the null voltage. Let us apply the same null voltage to reduce the number of switching. So, for the period again it will be applied 111. Thereafter we want 1 bit change it is 111 then you should first go to 110. So, this is actually 110 thereafter we shall go for again 100 and we shall go to 111 it 000.

If, we interchanging then what will happen to some it will be 2 bit change and there will be and necessary actually the State Jam. So, what happen there will be transition loss will increase?

Let us say, it was 1 one 1 if I come to 1 0 0, then there is a 2 bit change that mean it will go low again here it will go high. So, there will be a unnecessary state change of the switches and thus it will incorporate more switching loss. So, 1 bit change actually ensure there is a less switching state and thus reduce switching losses and also implementation of this controller will be easy, because you know that it can be implemented by the synchronous controller and if it is a synchronous controller, if there is a 2 bit change, there can be hazardous and other problems which can be avoided by a by ensuring 1 bit change.

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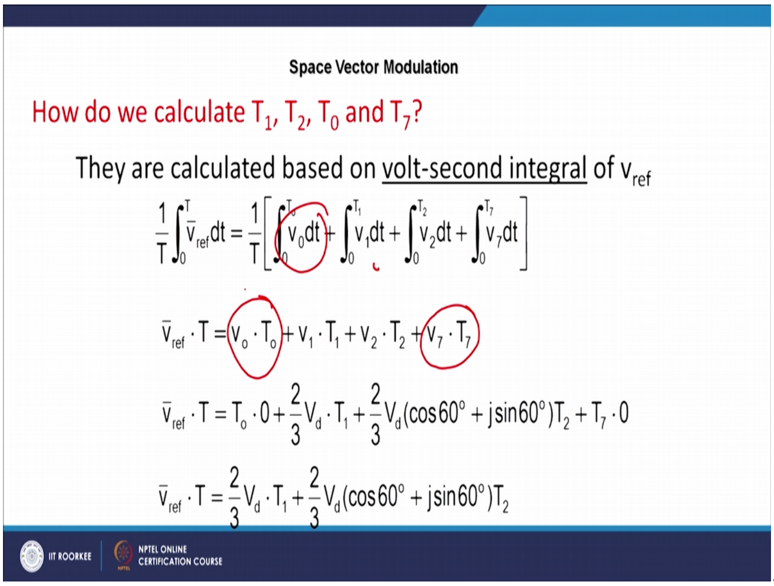

Now, the questions become how to calculate this timing? So, how much time T 1 should be applied, how much time T 2 should be applied? And how much time T 0 and T 7 should be applied. So, let us equate the (Refer Time: 19:29) and the time T. So, V ref it will be integrated 0 to T and that should be equal to actually, V 0 into dt therefore, actually you apply the null voltage here we apply V 1 for the time T 1 and they have the V 2 time T 2 they have to again V 7 time 0. So, these 2 terms are essentially 0 because you applied the null voltage are noncontributory.

So, that is the thing. So, ultimately you come with this equations then just simplification of it and thus.

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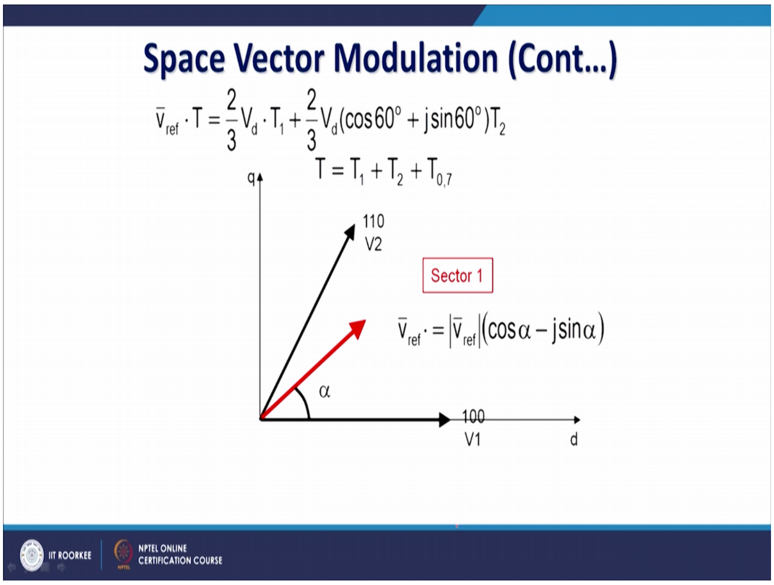

So, V t can be written as 2 third V t into T 1 plus two-third V d into cos 30 plus sin 30 into T 2. So, we require 2 equations to solve this. So, another equation is essentially T 1 plus T 2 plus the null vector timing that 0 you can write 2 T 0 or 2 T 7. So, let us assume that angle between them are alpha. So, V ref equal to essentially mot V ref cos alpha minus j sin alpha. So, from there we can see that actually T into V ref into cos alpha. So, which let us equate the voltage across the X plane ok.

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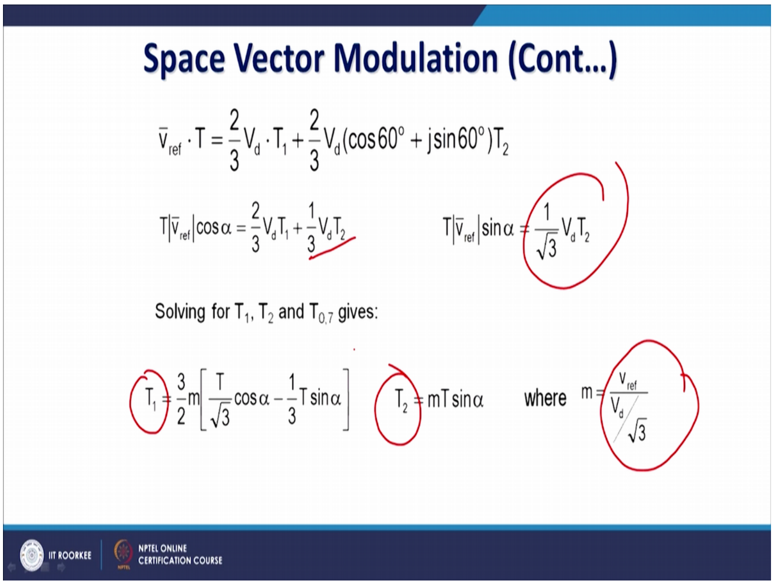

So, from there we can write actually V referred as into cos alpha should be two-third into V d into T 1 plus one-third V d into T 2. Similarly, since there is no component of V 1 in y axis so, y axis it should be actually we refer it as a sin alpha it will be one-third V d into T 2. So, now, we can equate thus we can calculate straight away T 1 equal to two-third, where aim is basically this is a it is in an effectively modulation index of the system that is V reference by V d by root 3.

So, generally what happen in case of the sin triangle PWM it is we call them actually V c be controlled by V triangle here actually it is V reference by V d, but what essentially you get actually this 3 times more than this actually the actual modulating index. So, this is 1 of the advantage you can use the your distilling voltage better than this than this actually normal sin triangle PWM. So, this is the value of T 1 and this is the value of T 2. So, student will be asked to calculate there will be different time will be given and students are required to calculate what are the timing of T 1 T 2.

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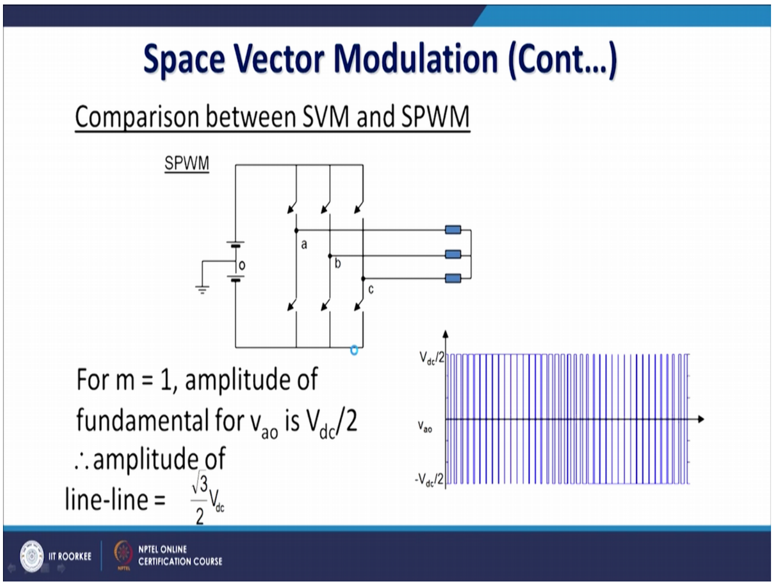

So, let us con compare sin triangle PWM or combination of SVM will SPVM. So, you can have this is the actually the PWM wave form. For modulation index 1 and for the half bridge configurations fundamental voltage is V 1 for V d c by 2 and line to line voltage will be root 3 by 2 V dc as simple as that.

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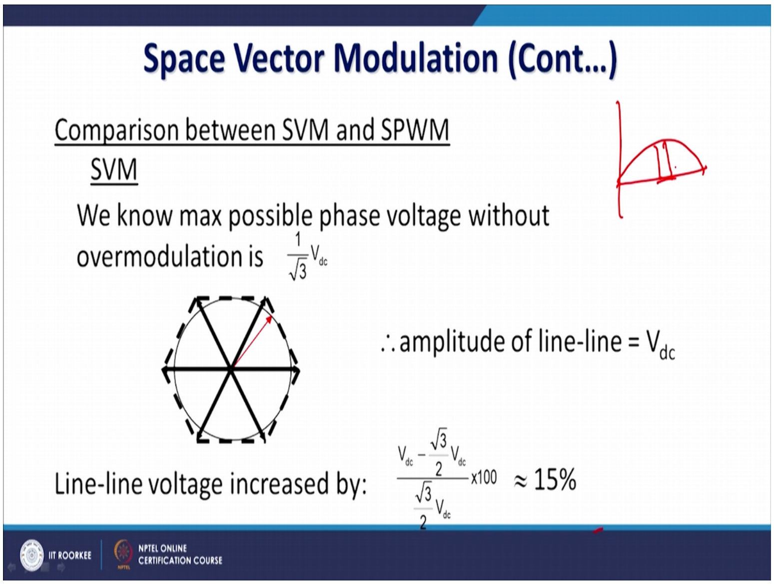

So, and in case of the SPWM what you will get and here we will get the maximum voltage relying with this actually the circle. So, you get one-third V d c as we know that this is a maximum possible filled voltage without over modulation. So, here line to line voltage is V d c and thus you know it straight away we can see that line to line voltage here it is been actually increased by 15 percent. We will almost expect the same kind of entries in case of the third harmonics injection. So, same thing can be achieved by space vector by actually a space vector modulation, it gives actually 15 percent more usage of the distilling voltage and moreover it can instantaneously inject the voltage pretty closer to it.

One of the problem of PWM is that you were here and when it is 0 you are applying this voltage, but any, but here this duration is shortened you just apply for the when you apply null vector, then only this condition arises, but most of the cases you are switching between 1 voltage to another voltage, thus you are applying very close voltages and thus actually harmonic content in this SPWM will be much much lower than the actually bipolar sorry unipolar PWM.

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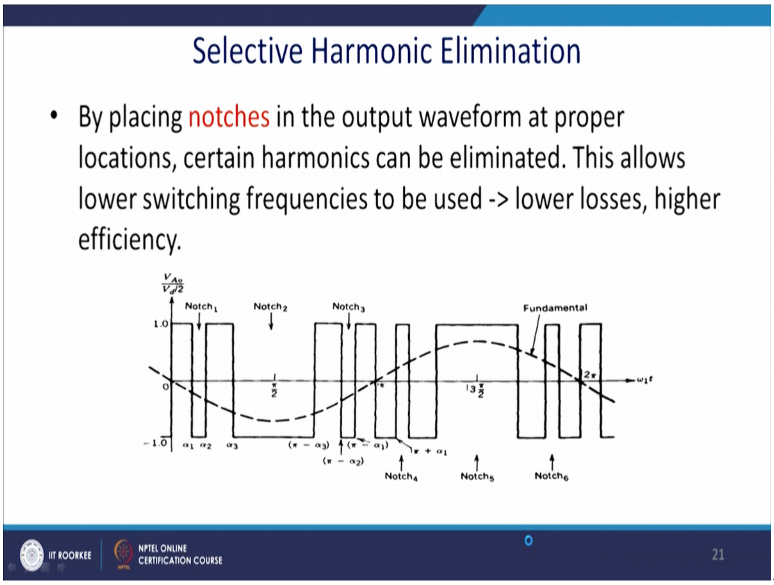

Now, we shall discuss about selective harmonic elimination. First of all we take out this selective harmonic eliminations, by the help of the sin triangle PWM. So, what happen you know we can if we have a this kind of voltages, which is available by the PWM. Why cannot eliminate unnecessary harmonics that will be great help for active filter as well as for the drives application. We know that actually cogging all those issues in the drives. So, fifth harmonic and the 7 th harmonic actually gives a pulsating torque reduction of this actually those harmonics generally it contains actually 6 and plus minus harmonic into the system.

Reduction of this higher order actually lower order high amplitude harmonic will have it is own valid to get better TSD. And this can be achieved by this actually selecting harmonic elimination. So, how I do that, by pressing a notch in the output web form at a proper location certain harmonic can be eliminated. This just like playing a guitar you touch some point of time it will form a node here then that particular harmonic will be eliminated and multiple of it. This allows reverse switching frequency to be used and lower losses and thus we can use you know instead of costly IGBTS we can use may be gto and we can actually eliminate those harmonics and we can get the required TST as teaser.

So, what essentially there is a calculations? So, we require to do the Fourier analysis let us assume, that actually it contains all the harmonics and thus these are the Fourier coefficients, you have studied long time. So, no point of any repetition is required. So, ultimately we require to make a particular voltage for the wave of that water wave symmetry and we shall ensure that actually only odd harmonic had present, even harmonic are absent. So, ultimately you would left with this actually the b n.

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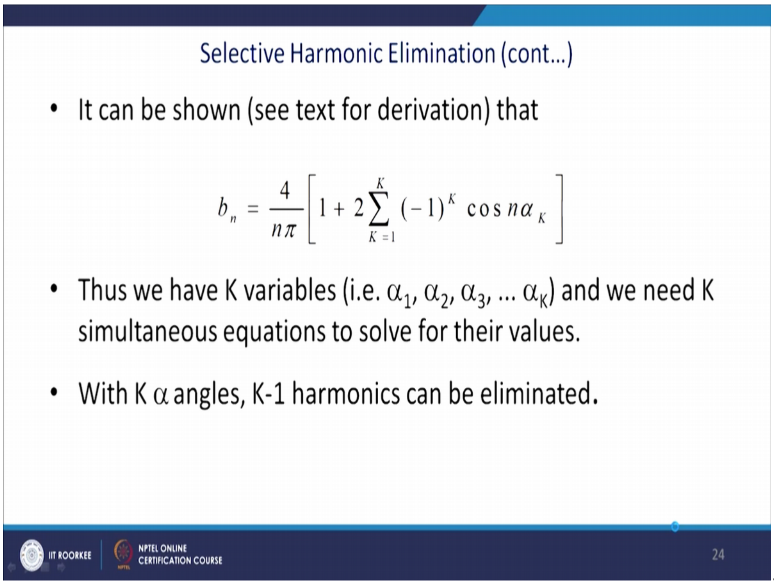

So, within b n we require to actually calculate and were we can eliminate by choosing the value of the K we can eliminate different value of the alpha.

So, we can by choosing a particular value let us say k equal to 1. So, you can choose the particular value of alpha. So, that particular frequency can be eliminated. So, you will have that number of notches if you have 1 notches you can eliminate one particular frequency, if you have 2 notches you can eliminate 2 particular frequency, then 7 you have multiple notches you can eliminate multiple frequencies and with K alpha angle and K 1 harmonics can be eliminated.

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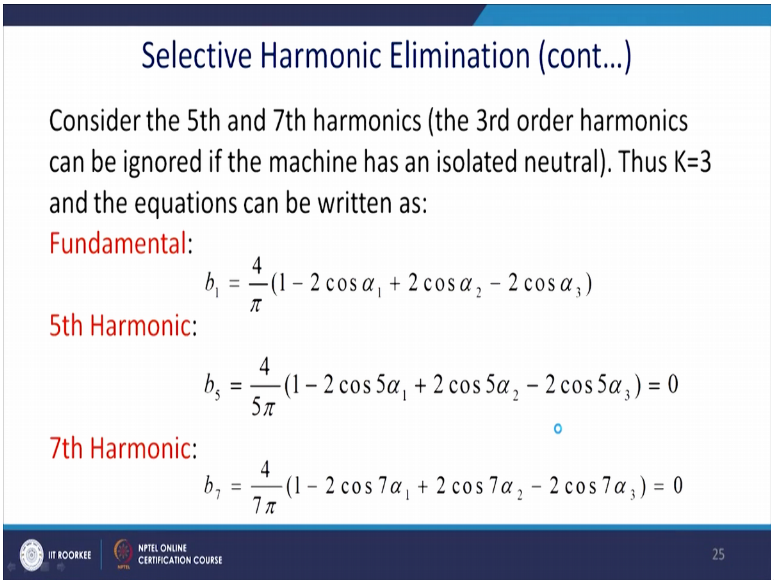

So, this is the calculations and this cannot be require to compute all 9 and you can feed because in space vector modulation mostly it is dynamics you require to feed this in online. So, let us we require to try to actually eliminate fin fundamental should be preserved. So, that is will be the b 1. So, so that value will be given by 1 minus 2 cos alpha plus 2 cos alpha minus 2 cos 3 alpha. And thereafter this 2 sum will be 0 we require to solve the simultaneous equation and find it out a different value of alpha 1, alpha 2, and alpha 3 and thus we can eliminate we can maximize fundamental and we can eliminate fifth and 7 harmonic.

So, by calculation we can find it out you know alpha 1 equal to be 21 degree almost.

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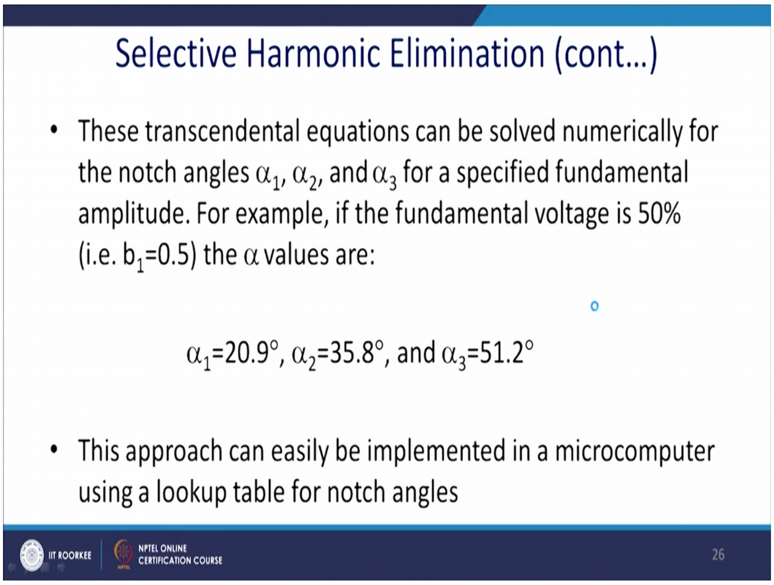

And alpha 2 equal to 35 degree and alpha 3 equal to 51.2 degree. So, and we can said this offline and thus those harmonics will be eliminated

Thank you, we shall continue with our discussions with hysteresis of the carton current board control in our next class.