Power Electronics
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Lecture 22 – SPWM and SVM Technique

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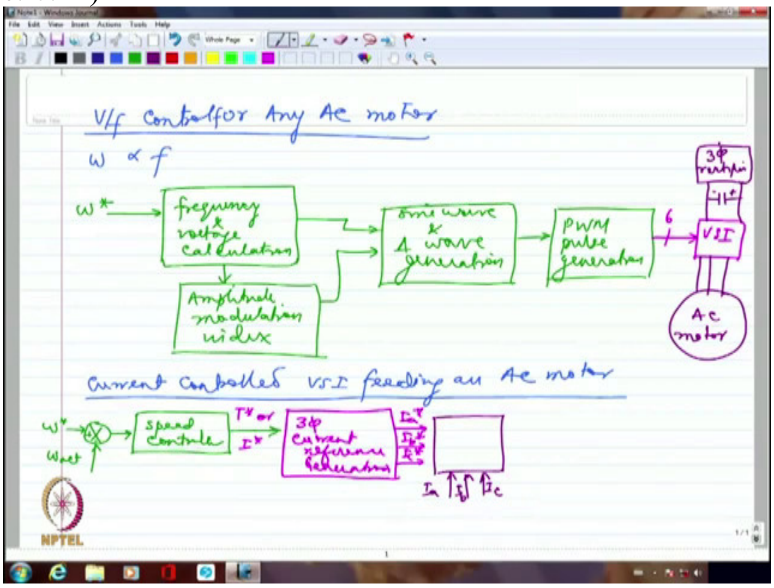

So, I told you that $\frac{V}{f}$ control for any AC motor, may be induction motor, may be synchronous motor, it does not matter, but in general we are going to have $\omega \, \alpha \, f$. Whatever is the speed at which it is going to run is going to be approximately proportional to frequency in the case of an induction machine whereas it is exactly proportional to the frequency in the case of a synchronous machine. So, if I want a particular value of speed to be achieved by the machine and I am implementing $\frac{V}{f}$ control, this could be open loop control. I am not going to really take any feedback.

So I am not talking here about current control VSI, I am directly talking about a PWM based VSI which will allow you to adjust the frequency as per the requirement of the speed but because we want to operate it at constant flux, we said that we are assuming that E by f equal to V by f, that is what we are assuming. So, if I want this particular speed, first of all I will be able to calculate what is the frequency and correspondingly I will be able to calculate the voltage. So, frequency and voltage calculation can be done based on whatever is the speed that I want. So, the moment I calculate the voltage, I will be able to calculate the modulation index, that is the amplitude modulation index directly.

So, I would calculate from here amplitude modulation index. So, the moment I calculate these two that is the frequency and the amplitude modulation index, I should be able to generate the sine wave and the triangular wave if I am talking about an analogue electronics implementation. If it is a digital electronic implementation with DSP or something like that it should be able to calculate the PWM pulses directly. So, I would say this can lead to directly sine wave and triangular wave generation. If I am talking about analogue circuit implementation, then from here this is going to go to the PWM pulse generation circuit. So, sine wave and triangular wave will be compared and then I have to probably give it to a comparator plus and minus and then I will be able to generate the pulses and I have to generate dead band also.

Dead band I am not really giving the details here because we just talked about this very briefly. So, this output will go to PWM pulse generation. So, this is generating the pulses. Now this pulse will be actually 6 in number if I am talking about a 3-phase invertor. So, this is actually going to have six such pulses, 1, 2, 3, 4, 5, 6, all the devices will be fired and then finally I am going to give this to the VSI. So, if this is my VSI, now this will be connected to the AC motor. I am not writing specifically induction motor, it could be induction motor or synchronous motor.

So, whatever I have shown so far is all control electronics but on the other hand I definitely need to have the power here. So, I will have an electrolytic capacitor, I will have a 3-phase rectifier, normally uncontrolled because in VSI as I told you earlier, we are going to use the diode rectifier, generally we do not use the thyristor rectifier. So, this will be an uncontrolled diode rectifier and I am going to have the 3-phase supply here. So, this is 3-phase 50 hertz supply. So, I am starting of 3-phase 50 hertz supply from the grid giving it to a rectifier, rectifying it, filtering it with an electrolytic capacitor.

So, this electrolytic capacitor I may have plus here and minus here, that is why I am showing the polarity because it is not an AC capacitor, it is a DC capacitor. So, plus and minus I have to show. I cannot reverse the polarity. If I try to reverse the polarity, it will blast. So, I am going to have this as the electrolytic capacitor which is filtering out and its output will be given to the VSI and the VSI pulses are generated by the control scheme that I have shown. So, this is completely open loop, we are not checking anything.

If I want really this to be implemented with current control, then I have to go with current controlled VSI feeding an AC motor. So, this will be a close loop control, so let us see how this could be implemented. So, in this case I necessarily need to take the feedback of the AC motor current or VSI is feeding the current to the AC motor, so either VSI's output current or the motor's input current. I have to sense that. So, I would again start with maybe this is going to be my reference speed. And I have to compare this with the actual speed. How do we get the actual speed? Maybe we will use the tachometer, you guys have used but that is read by a human being.

Tachogenerator is what is normally used to sense the speed. Tachogenerator is a small generator which will be coupled to the same shaft. Whatever you have seen in the machines lab, you would see one pole which is indicating the speed in digital quantity. That is essentially a tacho generator from which the signal is going, and it is counting like how many revolutions are happening with the help of the EMF that is generated. So Tachogenerator is a small scale DC generator which will actually generate a small voltage. For 1000 rpm it may generate 2 volts, 3 volts, something like that and that will be directly given to a digital indicator like a voltmeter.

So, now the speeds are compared. Whatever is the speed error, that will go to a speed controller. The speed controller can be a PI controller PID controller, whatever is the kind of controller you want to adopt, you can adopt that. It can be a digital controller, it can be an analogue controller, you can implement the same PID with anything, analogue or digital implementation. It can be advanced controller like ANN or Fuzzy logic, so many types of controller are employed. Now this output is going to tell you whether I should increase the current or decrease the current RMS value or whether I should increase the torque or decrease the torque so that the current the error in the speed is bridged, the gap is bridged.

So, if the speed happens to be higher, then whatever is the reference speed, then I have to probably generate lower torque so that it decelerates. If I am going to have the speed to be lower, then I have to generate a larger torque so that the machine accelerates. So, this is going to decide I would say either the torque reference or current reference. Either way is fine. So, let us say I am looking at electrical quantity, so current reference I can take as the value what I have got. From this I should be able to generate 3-phase current reference.

That is for example if I say that the RMS value what I want is 5 amperes. That 5 amperes can be mapped as $5\sqrt{2}\sin(\omega t)$, $5\sqrt{2}\sin(\omega t-120^0)$, $5\sqrt{2}\sin(\omega t+120^0)$. So, I should be able to map this RMS current value into the 3-phase reference currents. So, this is essentially 3-phase current reference generation. So, it is going to generate 3-phase currents. So, what I get out of this is I_a^*, I_b^* and I_c^*. If I know the torque, I should be able to back calculate the current. So, either I look at the torque reference directly or current reference directly.

I have taken the current reference in this particular case. Now, I have to compare these 3 currents with that of the 3 actual currents. So, this may be I_a, this may be I_b and this may be I_c. All the 3-phase current have to be compared with the 3-phase reference currents.

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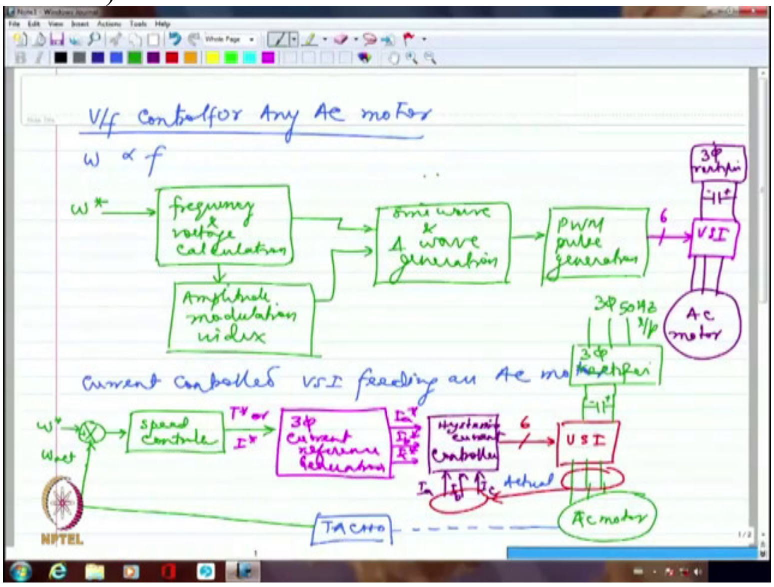

And normally we use a current controller called hysteresis current controller which I would like to explain very briefly, which we will see in detail when we do drives course. In hysteresis current controller normally, what will be done is if let us say this is my reference current value. This is my reference current value, I_a^* is this. I want to adhere to this current as much as possible as I am actually impressing a voltage upon the motor. But, if I try to exactly adhere to this value, I might have to turn on and turn off the devices infinite number of times which is definitely not possible. So, that is the reason why I am going to give a margin like a hysteresis band. So, I am going to essentially give a margin which is on the positive side as well as negative side.

So, what I am going to say is if this is I_a^*, I have to remain within $I_a^* + \Delta I$ or $I_a^* - \Delta I$. I do not want to exceed this margin on either side. So, if I take 5 ampere as my peak current, so $5\sin(\omega t)$ is going to be my current. From that I can probably go 0.5 ampere on the higher side or 0.5 ampere on the lower side. I can fix the margin 10 percent, 15 percent, 20 percent or 2 percent, whatever. So, I am essentially trying to fix the margin. So, if I actually try to turn on, let us say device number 1 because it is A phase I am talking about 2 devices, 1 is 1 and the other one is 4.

Similarly, 3, and I am going to have 6. Then I am going to have 5 and 2. These are the devices in the VSI or voltage source inverter. And I am going to have the DC voltage connected from here. If I turn on 1, the positive terminal is connected to the A phase. If I turn on 4, the negative terminal is connected to A phase. So, if I connect the positive terminal to A phase, the current will start increasing. If I connect the negative terminal to A phase, the current is actually drained, so I am going to have reduction in the current. So, I will look at the present value of current.

Maybe my present value of current is somewhere here right now. It is almost on the brink of the minimum value of current which can be allowed. So, obviously I have to now start increasing the current. So, for increasing the current I will have 1 turned on. If 1 is turned on the current is going to increase. How fast it increases or how slowly it increases depends upon the R and L value what I have connected and also the DC voltage that I have connected. The transient response always depends upon all these things. So, I am going to have increase in the current value like this.

Now, it has almost reached the brink of the maximum value of margin that I have allowed. So, at this point I have to turn off that 1 and turn on 4. So, I would turn on 4 and turn off 1 and during that time the current will now start decreasing. And again, once it hits the minimum value I am going to turn on 1 again. So, it is going to increase decrease, increase decrease, so I am just showing as though this is a kind of current wave form that I am going to get. So, the control of current is essentially done in this manner. In most of the cases, this is what we adopt for controlling the current.

So, we are essentially looking at the present value of current and the reference value of current that we have set and of course it is not going to switch at a constant frequency, because it does not exceed the value, it will not switch. If it does not go below the value also it will not switch. So, I am going to essentially have the current waveform what I get will be like a serrated waveform. It is not exact sinusoid but the smaller the band is I will have it will be the current waveform will be closer to the sinusoid. And the switching will happen very very quickly. So, this is essentially hysteresis current control.

We call it as hysteresis because we give a band that is all, nothing more than that. So, it does not have anything to do with your hysteresis phenomenon in electrical machines or iron losses or anything. So, we call this as hysteresis band current controller or hysteresis current controller. So, this if we are implementing for all the 3 phases, clearly, I am going to get the firing signal either for 1 or 4, 3 or 6 or 2 or 5, that is how I am going to get. So, I am calling this as hysteresis current controller.

Now, what comes out of this will be actually 6 signals because either 1 will be on or 4 will be on. So, both of them have to come out. 1 will be at one stage the other one will be at zero. So, they are NOT of each other in the same leg. So, this is coming out, now this will go to the VSI, right. Now, this is going to the VSI, now I have to show the power side. I have shown so far shown only the control side. So, the power side essentially will look somewhat like this. So, I have to show essentially DC coming up here and here is the capacitor with plus here minus here.

Of course, there will be a 3-phase rectifier. I am taking it as though a large capacity drive. So, I am taking 3-phase input, if it is the small capacity I can go with single phase. Large capacity drive so it is going to have 3-phase, and this is 3-phase 50 hertz input. Now, what is coming out of the VSI, again the power portion will go to the induction motor or AC motor, whatever is your AC motor that you are trying to employ. Now, I have to sense these 3-phase currents. So, I am just showing it like a circle, I have to put a current transformer, maybe some other type of sensor, whatever it is.

So, what I will have is about tens of amperes of current, maybe hundreds of amperes of current, but it has to be stepped down because most of the electronic circuits can handle only milliamperes or millivolts. So, it has to be stepped down and then those 3 currents have to be given here. These are the 3-phase current I have sensed. So, I_a, I_b, I_c what I am talking about are actual currents, these are actual currents. And these are reference currents, reference currents I am showing by star and actual currents I am sensing directly from the motor drive which is connected to the inverter.

Now, only thing that has not been shown is from here I have to put a tacho generator or whatever to sense the speed. So, I am going to sense the speed from here. So, this is a complete closed loop control, how it is normally implemented in an AC motor drive with VSI but of course current is being controlled. So, I am also monitoring the current in this particular case. Please note here we are just not bothered about the current at all. In the previous scheme we have not bothered about current at all. So, by chance if there is a problem, there is no protection.

Whereas here at least I am monitoring the current, so I could send this to your protection circuit and so on and so forth to make sure if there is a problem the motor is at least protected. So, I will be able to do that. So much so for the control of motor using VSI and current control VSI.

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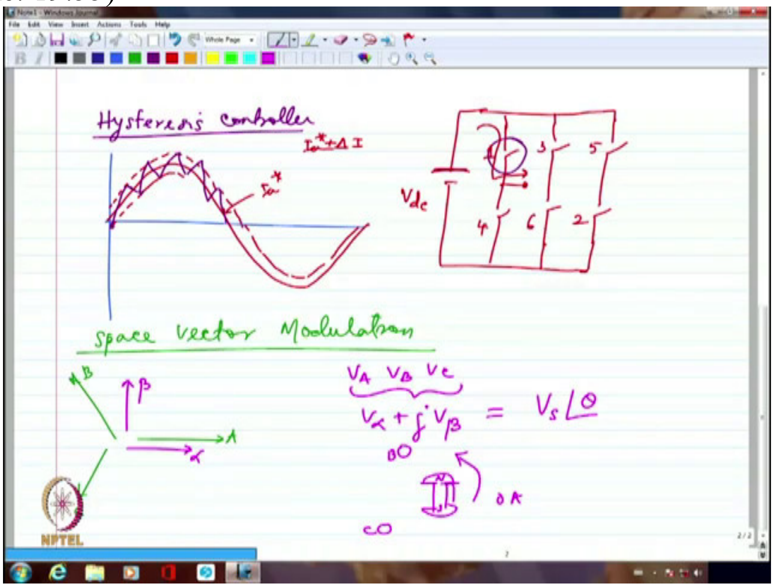

Today will go over to Space Vector Modulation Technique. I gave a small introduction yesterday for this, so continuing from there. In space vector modulation what I told you was we are not going to look at all 3-phase voltages independently; V_a, V_b, V_c, we are not going to look at them independently. And because normally in a 3-phase case $V_a + V_b + V_c$ is equal to zero, we are essentially looking upon them as only 2 independent variables not 3 independent variables. So, we would like to convert them into two form, two variable form rather than 3 variable form.

So, what I told you was if I am going to have A, B and C like this, I am going to rather choose one alpha axis along this, one beta axis along this and then I am going to represent V_a, V_b, V_c together as $V_\alpha + jV_\beta$. So, it is a simple complex number. Single complex number which we actually we are representing all the 3 phase voltages with. So, this I can say as space vector V angle some theta, whatever is the theta. So, this is essentially in polar form, I am representing the entire all 3-phase voltages together. Please note, I have mentioned B as though it is leading A, so I do not know you guys have not noticed this. But we generally take this form only because of one particular reason otherwise we always take B is lagging, we never take B as leading.

This we have taken because if you look at any of the AC motors especially when it is working as a generator, normally we take actually say the magnet is going to rotate in anticlockwise direction. So, if I have A here, it will face A first, then B first then C next. So, I will have when the stator windings are stationary that is what is actually my output voltage that is coming from. I will always have the arrangement in such a way that this is A, this is B and this is C because the other member is rotating. So, I am essentially making this reference to machines where the AC machines will normally have the arrangement somewhat like this.

First you will have A then 120 degrees plus 120 degrees shifted you will have B and another plus 120 degrees shifted you will have C. That is how normally AC machines windings are there because the windings which are actually generating the voltage will be put in stator and the rotor is the one actually having the field system or magnet. So, I have taken essentially A, B, C like this as simple as that. So, if I am going to have A, B, C voltages A, B, C axis like this, I am going to represent V_α and V_β somewhat like this.

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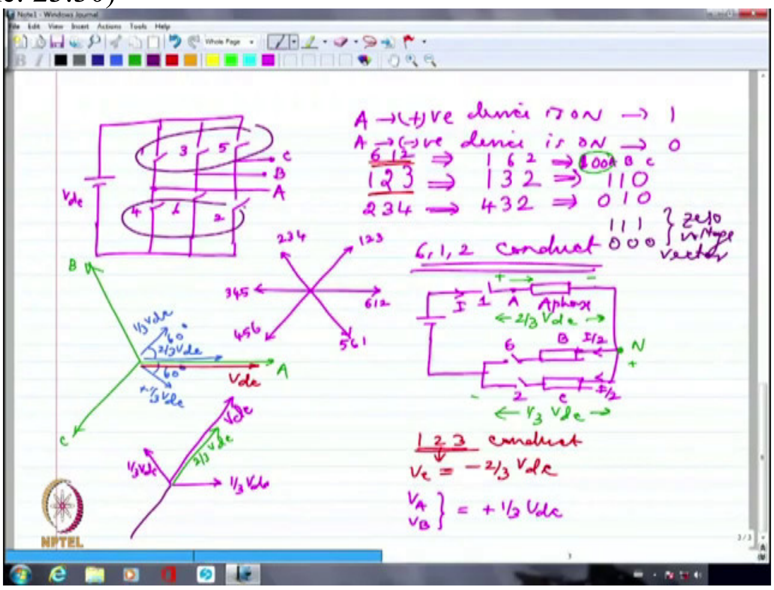

Now, if I look at a normal 3-phase inverter, I am again taking the 3-phase inverter VSI and I am going to have a V_{dc} on this DC link and this is again going to be 1, 4, 3, 6, 5 and 2. So, this is C phase, this is B phase and this is A phase. If I assume that 3 devices conduct at a time in this inverter, I essentially have to have either 1 2 3, 2 3 4, 3 4 5 and so on. That is the way they will conduct in sequence if I try to talk about it in sequence. So, I will always have at least one device from the upper portion and one or two devices from the lower portion.

Again, one or two devices from the upper portion and one or two devices from the lower portion. Obviously both devices in the same leg will not conduct at the same time. So, if I say that A phase is positive device is on, I am going to call that as 1, for A phase if A phase negative device is on, I am going to call that as zero. So, I am going to say either every one of the phases will occupy either one position or zero position depending upon whether the upper device conducts or lower device conducts. Now, if I am talking about for example 1 2 3 as the combination, I want to write A B C, so I better write 1 3 2 because 3 belongs to B phase, 1 belongs to A phase and 2 belongs to C phase.

So, I will write this basically as 1 1 0. A phase positive device 1, B phase positive device which is 3 that will also be indicated by 1 corresponding to B phase and 0 is corresponding to C phase, so I am writing A B C like this. So, similarly let me write for one more 2 3 4, I should write first of all 4 first then 3 will come because 4 belongs to A phase, 3 belongs to B phase, 2 belongs to C phase. I should be able to write 0 1 0. So, like this I should able to write all the 6 combinations. So, if I first of all, the first combination I am going to take out is 6 1 2. So, let me write for that, 6 1 2 will correspond to 1 6 2, so I should be able to write this as 1 0 0.

So, this is this will belong to 1 0 0 this is 1 0 0, A B C will be 1 0 0. Now for each of these combinations, I want to see what the corresponding space vector is. Please recall how we drew A phase, B phase and C phase voltages like this. This is A, this B and this is C. If I take that 6, 1, and 2 conduct at this point in time and starting off with this. If I say 6, 1 and 2 conduct, think about it like what we did in commutation overlap, it is almost similar. So, I have DC voltage, I have 1 is conducting, so this is 1 and I will have A phase load connected here.

This is the A phase terminal. Now, from here I am going to have B phase and C phase because both of them are even devices, even number devices. So, I am going to have B phase and C phase and I am going to have this is corresponding to 6 and this is corresponding to 2. So, I am just closing these two and I am going to have a connection like this. This is an equivalent circuit, then I am talking about only 6 1 2 are conducting. Now, if I try to look at this, all the 3 phase loads are balanced, that is what I am assuming. If it is a motor or any kind of load I connect, generally they will be balanced.

So, if I try to look at this current as I, it will divide itself into $\frac{I}{2}$ and $\frac{I}{2}$ here. Whatever is the current flowing will be $\frac{I}{2}$. So, I will have essentially $\frac{2}{3}V_{dc}$ being the voltage here and $\frac{1}{3}V_{dc}$

being the voltage. Like 180 degree conduction mode, what we did, I am essentially talking about same thing. 3-phase inverter when we talked about 180 degree conduction mode, this is how we wrote. Please note the current is flowing in this direction, so this is plus, and this is minus. I would say this is neutral and this will be plus, and this will be minus as far as these two phases are concerned.

And we always talk about the voltage of A B C terminals with respect to neutral. So, I have to take the direction into consideration. So, if I say during this condition, I am going to have this as maybe $\frac{2}{3}V_{dc}$, this is V a. If I try to look at V_b, V_b is $-\frac{1}{3}V_{dc}$ and V_c is also $-\frac{1}{3}V_{dc}$. So, I have to write this is $-\frac{1}{3}V_{dc}$ which is corresponding to I should say rather this is $\frac{1}{3}V_{dc}$ but it is in the opposite direction of normal B. Similarly, this is again $\frac{1}{3}V_{dc}$ which is corresponding to the opposite of the normal direction of V_c. So I have these 3 voltages now put together and I have to add them to get the space vector finally.

So, when I add them, I will get this will be 60 degrees, this will also be 60 degrees. I hope you understand that. Because half of 120 it will be. So, I will get essentially $\frac{1}{3}V_{dc}$ times cos 60 for B phase. Again 1 by 3 V_{dc} cos 60 for C phase and then $\frac{2}{3}V_{dc}$ which is corresponding to A phase. So, overall the summation will be along this direction itself but it will be V_{dc} because $\frac{2}{3}V_{dc}$ plus $\frac{1}{3}V_{dc}$ multiplied by cos 60 which is half, again $\frac{1}{3}$ cos 60 which is half. So, I will get essentially V_{dc} itself. So, I am going to get this as V_{dc} and it is along the direction of A phase itself.

We will do this for one more combination from which we can infer further results. So, if I try to do it for the next combination which is actually 1 2 3. When 1 2 3 conduct, please note that now on the positive side there will be 2 elements, because 1 and 3 both belong to positive side and 2 is corresponding to the negative side. So, by observation itself I should be able to say that V_c will be $-\frac{2}{3}V_{dc}$ because 2 corresponds to V_c. Whereas I am going to have V_a and V_b, both of them being $\frac{1}{3}V_{dc}$. This is how they are going to be. Is this clear? Because we are talking about only one device in the negative direction and 2 devices in the positive direction. So, I am going to have essentially, this is $\frac{1}{3}V_{dc}$ along this and this is also $\frac{1}{3}V_{dc}$.

Whereas V_c which is in the opposite direction in this way I have to take the opposite. So, I have to take this direction. So, I am going to have $\frac{2}{3}V_{dc}$ corresponding to $-V_c$. Now, I have to add all these 3. So, I will have actually the resultant coming along this direction which will be again V_{dc}. So, when I switch over from 6 1 2 to 1 2 3, I have got the same magnitude of space vector, voltage space vector but it has shifted by 60 degrees ahead. So, obviously if we try to analyze for the next combination which will be 2 3 4 you would see that it is ahead by another 60 degree. 3 4 5 will be another 60 degrees ahead, 4 5 6 will be another 60 degrees ahead.

So, I have 6 combinations, correspondingly I will have 6 space vectors like this. So, I would say this corresponds to 6 1 2, this corresponds to 1 2 3, this will correspond to 2 3 4, this will correspond to 3 4 5, this will correspond to 4 5 6 and this will correspond to 5 6 1. So, I am going to have essentially 6 specific space vectors generated by the 6 combinations of the inverter switches. So, I have only finite voltages that could be generated in the form of space vector. But I may require any other voltage. So, how do I do the generation, how do how is it possible to generate any other voltage which is coming in between?

That is the crux of space vector modulation algorithm basically. So, if I by chance turn on all these 3 together, 1 3 5 which will be a combination which will correspond to 1 1 1. Or if I turn on all these things together which will correspond to 0 0 0, I will get essentially zero voltage. Because I am not going to get any voltage, all the negative terminals connected to all the 3 phases or the positive terminal is connected to all the 3 phases.

So, this will result in zero voltage vector whereas rest of the combinations whatever we have talked about that is 6 1 2, 1 2 3 and so on and so forth, all them of them are going to result in a combination which is a nonzero voltage vector and distinct voltage vector which are occupying 60 degree interval position basically.

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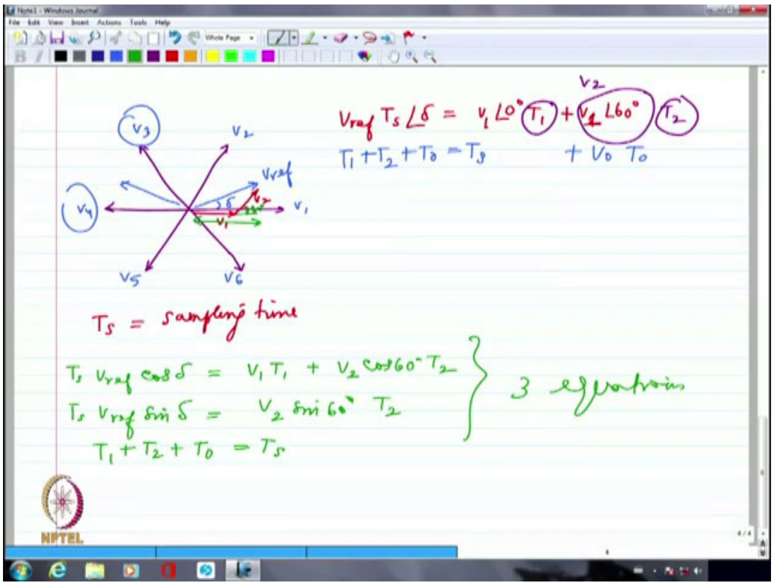

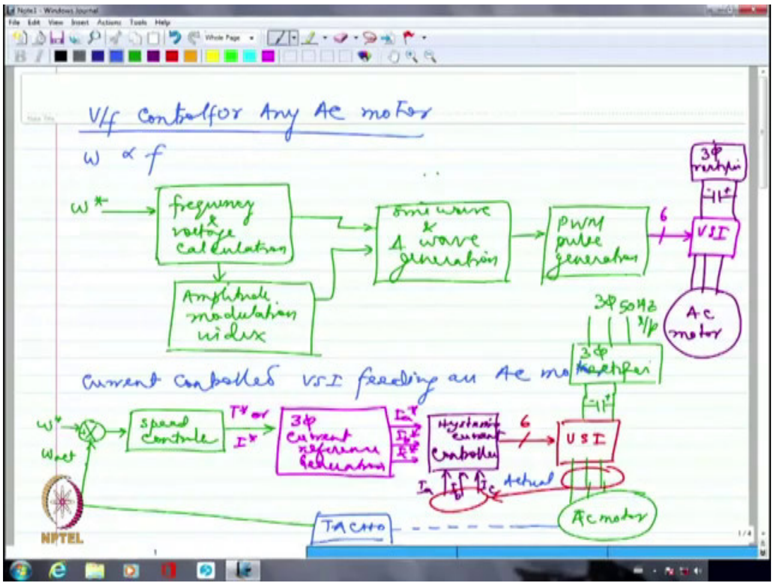

So, if I want, let us say out of these 6 combinations that I have taken. I have got based on the voltage vector, let us say I want the voltage somewhat like this to be generated, maybe V_a is some 15 volts, V_b is some 25 volts, V_c is minus 40 volts, I am just saying. Maybe at this instant I want a voltage which is corresponding to V_a equal to 15 volts, V_b equal to 25 volts and V_c has to be minus 40 because all the 3 of them added together will get zero ultimately. So, if I am going to have a voltage to be generated like this, I call this as the reference value of voltage that I want to generate so that appropriate current flows through the inverter and then probably the motor and then appropriate torque is generated.

So, I will nullify the speed error. That is what I am looking at. So, I would generate a reference value of voltage corresponding to which value the nullification of the speed error will happen. That is what I am trying to look at. So, let us say this happens to some V reference delta. I have calculated what is V_a, V_b, V_c from which I should be able to calculate what is V reference along with its phase angle delta. Once I have calculated this, I have to check how to generate this voltage with this finite composition of V1 , V2, V3, V4, V5 , V6. These are the finite combinations which corresponds to again 6 1 2, 1 2 3 and so on and so forth.

Student: How do we calculate the reference value?

Professor: Reference value you may be able to calculate if you go back to the closed loop control what I have drawn. Here I have said that you will generate the reference current, I_a, I_b, I_c. Those currents if I multiply by the motor impedance. I should be able to generate what is V_a, V_b, V_c. So if I know the motor impedance and maybe the back EMF has to be known also because impedance multiplied by the current plus the back EMF will give me what should be the voltage applied in A phase. Same thing I have to do it for B phase and C phase. So, I should be able to do it at least theoretically. It is the matter of detail how we will really calculate, which we will deal within drive course.

So, we will be able to calculate for sure what is V_a, what is V_b, what is V_c, from which I am actually calculating the V reference along with the angle. Now, I am going to have essentially, if I try to actually apply V1 for some time and V2 for some time, this is V1 along with V1 I have to put a scaling factor clearly because it is V1 vector which is exactly along that direction itself, but the length is smaller. So, I have to put a scaler multiplication clearly, similarly I have V2 which is parallel to my original V2 but I have to put a scalar multiplication. What I want is V reference, but I will not be able to give V reference directly. I have to give it as a linear combination of two available voltages, there is no other option because I have only 6 combinations of voltages possible, nothing more than that.

So, I have to make do with whatever is available with me ultimately to create the voltage reference I wanted finally. Now I will not be able to really calculate exactly what should be the scalar factor unless I bring in the time. So, I am going to actually sense the speed every now and then. If you actually look at the closed loop control once again, I am feeding the speed repeatedly, but the speed error has to be calculated, from that the current has to be calculated, then the hysteresis current controller has to check whether the current has exceeded, or it is less. Then the switches have to be turned on and turned off. So, there will be a finite delay between the time at which the speed is sensed and the actual correction is implemented.

So, there is no point in sensing the speed continuously, I have to definitely say maybe I have sensed the speed now, wait for 100 microseconds to maybe take place all these operations have to take place. After 100 microseconds let me check the speed again. Whether I have reduced the error or not? So, that particular duration is generally known as the sampling duration. I am sampling the speed every now and then. Similarly, I will sample the current every now and then.

There is no point in monitoring it continuously, because even if I monitor it continuously, I have to do all the calculations and all the computations are going to take some time. So, obviously I have to settle for this V reference value at least for that 100 microseconds. I have calculated, let me apply this and see what happens to the motor. That is the way I am looking at it, because I will not be able to calculate it in real time. Every 100 microsecond for example I will calculate this. So, I am calling that duration as the sampling duration.

So, I am going to say Ts is the sampling time corresponding to which I am going to calculate repeatedly what is the voltage to be applied. I have calculated it now, after 100 microsecond I will calculate it again, after 100 microseconds again I will calculate it. So, this V reference will remain as a constant for that 100 microseconds. I will not have any updation within that 100 microseconds. So, I would say I am going to equate the volt second area, $V_{ref} T_s \angle \delta = V_1 \angle 0^0 T_1 + V_1 \angle 60^0 T_2$.

There are several things that are involved here. One is turning on and turning off of the devices. That will take a finite time. Second thing is computation time, the third thing is even the sensors will require some time, it has to sense and then it might be converted from analog value into digital value.

So, A to D converter will have a finite delay, so I will have so many delays and I am accumulating everything and saying that until all these processes are over, I will have the V reference value staying put at that particular. So, I am calling that as the sampling time. So, updation takes place only after sampling time. I am looking at essentially V1 plus V2 equal to V_{ref} in this particular case, but it is not complete V1, it is V1 in the same direction multiplied by a scalar, you get my point?

See V1 is of this length which is corresponding to Vd but what I am using is the smaller length. Maybe 50 percent, maybe 30 percent. I am reducing the amplitude of, I want to reduce the amplitude of V 1, so it is in one sense like a duty ratio. As simple as that, we are using it like a duty ratio, T1 by T s is my duty ratio for V 1, T2 by Ts is my duty ratio for V2. So, we are using the same duty ratio concept here. So, now because of the spatial shift we are not getting the space vector to be zero. It will be zero only in the case of 1 1 1 and 0 0 0. So, coming back to this, I can look at T1 and T2 as the duty ratios corresponding to V1 and V2.

If my V reference had been lying somewhere here then I would choose this two, this and this. Whatever is the closest to space vectors that is what I will choose to create the linear combination so that I ultimately get my V reference. So, this is what we are going to do. So, here because the length is smaller, I may not be able to apply the voltage for so long. So, I might have to resort to applying zero voltage for some time. If V reference happens to be only 40 volts whereas Vdc happens to be 100 volts, there is no way probably I would be able to cover up the entire duration of Ts. So, I can introduce one more variable here saying that V_0 multiplied by T_0 because that is essentially like a buffer.

Whatever is the excess time that is available that will be taken care of by this T_0 and ultimately, I have to necessarily have $T_1 + T_2 + T_0 = T_s$. So, let me try to now equate essentially the cos delta and sine delta portion, that is the real and the imaginary portion. So, I can say this is $V_{ref}\cos(\delta)$, this entire portion is $V_{ref}\cos(\delta)$. So, I can say $T_s V_{ref}\cos(\delta) = V_1 T_1 + V_2\cos(60^0) T_2$.

Second thing I am going to get is $T_s V_{ref}\sin(\delta) = V_2\sin(60^0) T_2$. So, I am going to have $T_1 + T_2 + T_0 = T_s$. So, these are the 3 equations from which I will be able to solve for the duty ratios. I would say corresponding to V1, V2 and V0. And if I am saying I have to apply V1, I know I have to go with the 6 1 2 combination. If I have to apply V2, I have to go with 1 2 3 combination and if I have to apply V0, I have to go with either 0 0 0 or 1 1 1 combination. Should we apply them in the order V1, V2 and V0 or V0, V1, V2 or the way around? We have to follow few conditions.

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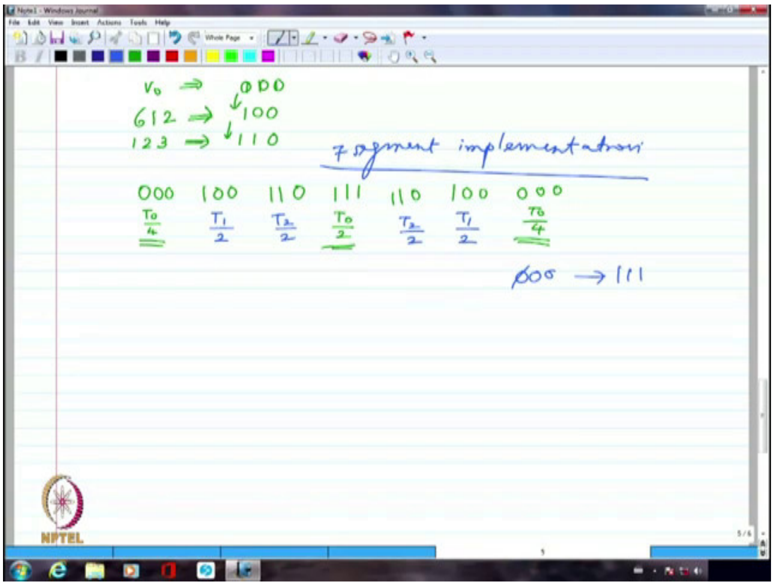

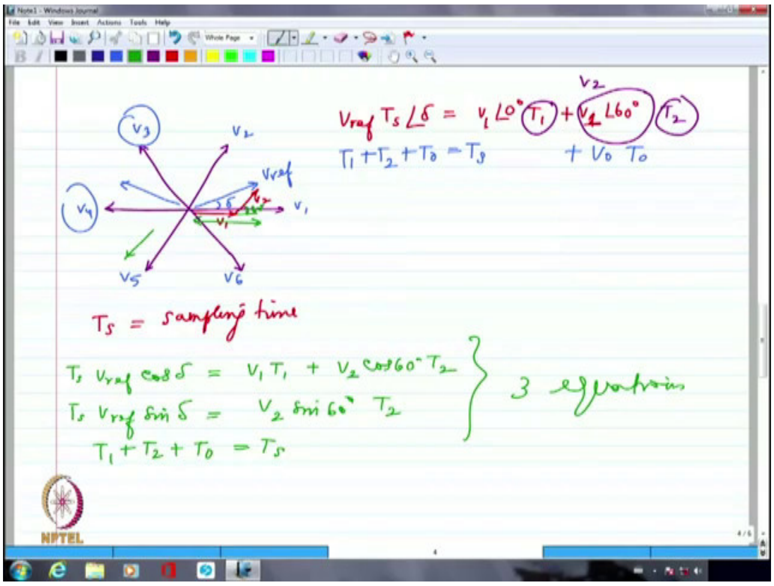

If I am going to have 6 1 2, what is the kind of combination I have? This essentially is 1 and then 0, 0. If I have 123 I am going to have essentially 1 1 0. Between these two there is only one device that is changed, that is only B phase device is changing its status from 0 to 1. If I try to jump to from here I try to apply V naught which is corresponding to 1 1 1 for example, two devices are changing their states. And if two devices are changing the state how much ever I may employ uniform devices, they are all manufactured by the same manufacturer, same batch, everything, still there will be a slight difference in terms of turn on time and turn off time. So, there will be something like a debouncing effect. I do not whether you have heard of this term. Whenever I switch on any mechanical switch it does not go in one go to turn on.

Very often it will actually go through some oscillation before it is stuck in on condition or off condition. That is actually deadly in a semiconductor because you are going to change the voltage very quickly fiercely, that is really not a good thing at all. So, normally what we tend to do is only one switch should change its state at a time, not multiple number of switches. So, I may choose instead 0 0 0, then in that case only one combination, one change occurs, and this is also changing only here. So, normally what we try to do is to go from one combination of switch to the next combination such that only one particular leg changes its state from 0 to 1 or 1 to 0. But after doing this application of this V reference in the next sampling time I do not know really what is going to be my V reference.

It may be completely different, maybe the motor has gained the lot of speed, maybe something has changed drastically. So, the next V reference might lie in a diametrically opposite side. This was my V reference, if suddenly my V reference is lying in a diametrically opposite side, I may have to go from 0 0 0 or 1 1 0 to suddenly 0 1 1 that is deadly. So, that is the reason normally what they tend to do in any of these space vector implementations is they will try to start from 0 0 0, they will go to 1 0 0 then they will implement 1 1 0, then they may give 1 1 1, again 1 1 0.

So, what you have as T 1, T 2, and T 0, they will try divide it into 7 segments. So, what we try to do is let us say this may be $\frac{T_0}{4}$, this may be $\frac{T_0}{2}$, then again from 1 1 0 I will go to 1 0 0 then 0 0 0, let us say. So, this will be again $\frac{T_0}{4}$. So, these 3 add up together to T_0. Now, similarly 1 0 0 and 1 0 0, so let us say 1 0 0 corresponds to this 6 1 2 so I will be able to call this as $\frac{T_1}{2}$, this is also $\frac{T_1}{2}$.

Then this will be $\frac{T_2}{2}$, this will be $\frac{T_2}{2}$. So, you start from 0 0 0 and end in 0 0 0. So, the next one if it happens to be completely 1 1 1, we will not try to adopt 1 1 1, instead we will try to adopt 0 0 0 itself for 0 voltage vector. See this is helping because of the fact that you are not switching more than one leg at a time. If you choose from 0 0 0 and try to go to 1 1 1, let it go what is the problem, both are 0 vectors but if I try to switch from 0 0 0 to 1 1 1 in the process this is switching properly but the other two phases are maybe taking some more time. Then I will get essentially 1 0 0 as an in-between stage which is a nonzero voltage vector which is deadly. Because I did not mean to apply that, but I am applying that.

So, generally we will never ever have a combination which will allow me to switch more than one phase at a time. I would like to switch only one phases state at a time, 0 to 1 or 1 to 0. I will transfer only in one particular phase. So, this generally we call as 7 segment implementations. So, there may be other types of implementation that might have been there but I have seen in some of the books and research papers this kind of implementation. So, I just told you one type of method, there may be definitely other types of implementations that are possible. Thank You.