CHARGING INFRASTRUCTURE

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Week-05

Lecture-22

Lec 22: Pulse Width Modulation

Hello everyone, welcome to lecture number 22 of this NPTEL lecture series on charging infrastructure. In this lecture, we will see the concept of pulse width modulation and how it will help in implementing a three-phase AC to DC converter. We will study in this particular lecture. Now, before starting that, let us recap some of the concepts we have studied in previous lectures. We have seen in detail about the boost converter-based PFC converters, where we have seen its operation, design, and different design aspects. We have seen the small signal modeling. We have also seen the closed-loop control of this converter, in which the control objectives were to maintain or regulate the output voltage while achieving unity power factor current drawn from the AC source.

Then, we have seen its CCM operation and DCM operation, how these two operations different, why they are used, and how the controls change. We have seen this in detail in some previous lectures. We have also seen how the PFC converter can be obtained using a flyback-based converter, which is again derived from a buck-boost converter, or you can say it has the same concept as the buck-boost-based converter. So, we have also seen buck-boost-based PFC converters, their operation, and particularly the DCM operation, because during DCM operation, it acts as a voltage follower mode, or the effective input impedance of this converter is purely resistive, thus drawing unity power factor current from the AC voltage source. Now, having understood single-phase AC to DC converters, we now move our focus to three-phase AC to DC converters.

These single-phase AC to DC converters are used for low-power applications, going up to 7 kilowatts. But beyond that power level, one needs a three-phase AC to DC power converter.

Now, before starting the discussion on three-phase AC to DC converters. Let us first understand the basic principle concept of pulse width modulation, which is one of the modulation methods by which one achieves AC to DC conversion for three-phase systems, maintaining constant voltage at the output and having unity power factor current drawn from the source. So, let us understand the concept of PWM.

And before understanding the concept of PWM, we know that mostly we are dealing with voltage source converters. And in voltage source converters, it's the half-bridge configuration, which is the fundamental building block, which can be used as that half-bridge. One can actually build the buck converter, boost converter, buck-boost converter, single-phase AC-DC converter, Three-phase AC-DC converter, single-phase DC-AC converter, and three-phase DC-AC converter. It comprises two switches, S1 and S2, and these are connected in a—I mean, I have shown it in this manner.

Now, these switches, as we have seen, both S1 and S2 block the voltage of one polarity and allows the current to flow through them in either direction. So, this S1 and S2 block voltage of single polarity and allow current in either direction. So, any switch which can support this kind of functionality can be used to realize this S1 and S2. It could be a MOSFET with a body diode, or it could be an IGBT with a freewheeling diode, or it could be a BJT with a freewheeling diode, but mostly it is done using MOSFETs and IGBTs with freewheeling diodes.

Now, if you see its operation, it has two states: State One and State Two, or State A and State B. Let us call them State A and State B. In State A, my S1 switch is on—that's when you will see the S1 switch is on and the S2 switch is off. Now, since my S1 switch is on and the S2 switch is off, what happens is that this entire— We will see—it will come across this point. So, as two blocks, we receive voltage. When the S1 is on, it carries the current depending upon the load. I mean, if the load is having current in this direction, it will draw current in this direction. If the load is having current in this direction, the S1 has to allow current to flow in this direction. Now, if you look very carefully here, we have a resistive load and a large inductor is kept at the pole of the half-bridge, which is the standard configuration one can have in any voltage source converter, whether it is AC to DC, DC to AC, or DC to DC converter, where the inductor is placed at the pole of the half-bridge. Now, this half-bridge configuration, irrespective of the direction of load current, can impose voltage at its pole having the same magnitude as that of the

voltage source. So, in this case, when the S1 is on and the S2 is off, what happens is that the voltage across VAO—the voltage across VAO—is nothing but Vdc/2, and this—you can say—this point or this midpoint of these two switches is also called a pole.

of the of the half bridge and the voltage vao is actually called as the pole voltage that means the voltage which is appearing at VA to o that is the pole voltage now the pole voltage is Vdc/2 and if we see the VANwhere n is the negative terminal of the DC link is nothing but V an is nothing but Vdc and it actually appears across switch S2. Now, if we take the next stage, if we just see the next stage, in next stage, let me write this one on here, pole of the bridge. Now, if we see the next stage, in next state, state B, what we are doing is we are turning off this switch S1 and we are allowing the switch S2, I mean and we are turning on this switch S2. Now, when you turn on this switch S2, you are actually applying the pole voltage which is the voltage between VAO, nothing but - Vdc/2.

So, in state A, we were applying Vdc/2. In state B, we are applying - Vdc/2. And if you look very carefully, since my S2 switch is on, the voltage between A and N is actually 0 and that particular voltage is appearing across the S1. So, S1 blocks the voltage of Vdc in with this polarity because always the Vdc will be of this polarity. So, S1 always blocks the voltage of this polarity. However depending upon the load let's say the switch has to be is the MOSFET current is going from source to drain or from drain to source depending upon the load or the magnitude of the you know inductance and resistance , so there could be possibility that there could be negative i mean current going in this direction or in this direction in some portion of the line cycle so irrespective of the load current both S1 and S2 is blocking the voltage Vdc and it can allow current in either direction it has to be realized in such a manner that both the switches can allow the current to flow in either directions. Now, if you look very carefully from the pole voltage that means VAO we are applying Vdc/2 for some time whenever my S1 is on and we are applying - Vdc/2 for some time when my S2 is on. So, we can actually vary the duration of this turn on time of S1 and S2 and that is when we can get the average pole voltage variation varying somewhere between - Vdc/2 to +Vdc/2 and that is how we can get from the DC we can get the AC output or AC at its output or let us say if we have the AC at the output we can actually generate the DC accordingly vice versa in either direction.

So, let us see how this half-bridge configuration—I mean, we can vary this average pole voltage variation. Now, to do that, a very commonly used modulation technique—which is called pulse width modulation—is being used, where the output voltage of the inverter (which is nothing but the pole voltage) is controlled by changing the width of the pole voltage VAO. So, if you see VAO, VAO for some time is varying at Vdc/2, and for some time, it is at - Vdc/2. Now, if we vary the pulse width, that means we are not changing the magnitude; we are just changing the duration for which Vdc/2 is applied and -Vdc/2 is applied.

That means we are just changing the width of the pulses, which vary between Vdc/2 and -Vdc/2. So, If we can change the timing or the duration of those switching pulses between Vdc/2 and - Vdc/2—that means if we change the width of the pole voltage VAO—then we can say that we are actually changing the pulse width, and that is why it is called pulse width modulation. Now, the simplest way of doing it is by using a high-frequency carrier signal. A high-frequency carrier signal could be a triangle or a ramp.

Let us take a simple triangle signal, which goes from +Vc to minus Vc and then from - Vc to + Vc in one carrier cycle. So, if we see this carrier cycle, this pulse actually repeats itself—going from here, like this, and then from here, like this. It repeats itself: in one carrier cycle, it goes from plus Vc to minus Vc and then from - Vc to + Vc. Now, if we see, we have one high-frequency carrier—we are taking a high-frequency carrier, which means The variation of this modulating signal—or the frequency of variation of this modulating signal—is very small compared to the frequency of this carrier signal.

That means the time period during which the modulation signal changes is very much larger compared to the value Tc. So, now if this modulating signal, since the variation of this modulating signal is very slow, or you can say the time after which that variation or the change in the modulating signal will take place is very large compared to Tc. So, in one Tc or in one carrier cycle, you can see that this modulating signal is kind of a constant. Now, this high-frequency carrier is compared with the low-frequency modulating signal.

The modulating signal is sometimes also called a reference signal. And the low-frequency modulating signal—I mean, that low-frequency modulating signal could be DC, where the frequency is equal to 0, or sinusoidal with a frequency very much less than the carrier frequency,

which is the case, you know, we have done—we have seen in the case of boost PFC, where we were doing the switching frequency very much larger than the line frequency. So, if we can ensure that this modulating signal is varying sinusoidally and has a frequency very much less than the carrier frequency, then we can try to implement this pulse-width modulation. So, let us see how this can be implemented.

Now, for example, here we see that we have a carrier which is varying between Vc to - Vc, having a time period Tc, which is nothing but given by $\frac{1}{f_c}$, where f_c is nothing but the carrier frequency, and this frequency is very much greater than the modulating signal frequency. And this modulating signal could be DC or could be a low-frequency AC, which, since it is a low-frequency signal or low-frequency AC, has a constant magnitude or constant value over one carrier cycle Tc. Now, if we see very carefully, in the half-bridge configuration, we can do a simple logic. Since we are comparing this modulating signal with this carrier signal, what can we do? We can apply one logic where—I mean, again, you can also apply the logic in a different manner.

In this particular method, we are saying the logic, the switching logic could be, if my modulating wave, which is this modulating wave, Modulating wave or modulating signal. If my modulating signal is greater than the carrier signal, which is this carrier signal. If my modulating wave is greater than the carrier, then I will turn on this top switch S1, which is here top switch S1. And when the top switch S1 is on, we are applying Vdc/ 2.

across the load or you can say the pole voltage of this half bridge is nothing but Vdc/2. Otherwise, that means when the modulation wave is less than carrier wave, my S2 switch is on and then we are applying - Vdc/2 voltage across the load or you can say the pole voltage of this half bridge. Now, because of that, we see that if you see this particular part, only this particular part, in this particular part from the carrier is going from A to C, While my modulating wave or modulating signal is kept at constant at point B. So, at that point from A to C point what is happening is that my triangle signal or my carrier is greater than the modulating signal and that is when my S2 switch is on and that is when I am applying minus - Vdc/2 across VAO. So, you can see here it is minus - Vdc/2 it is being applied from C to E from C to E we can say that our modulating signal which is maintained at constant value at Vm at this point my modulating wave is greater than the carrier wave and that's when my S1 switch is on and I am applying Vdc/2 across VAO. Then again at that point we see that at during this point we see that the value of the

carrier wave is greater than the value of the modulating signal that's when the second condition holds true and then you are turning on the S2 switch and that's when you are applying - Vdc/2. So, now if we see very carefully, if we try to apply the slope of line AC, if we see the slope of line AC, I mean line going from A to C, We can say that the slope we can write down nothing but this is at Vm and this is at Vc is nothing but $(V_c - V_m)$. Now, if we look very carefully, this is Tc / 2 period and this period is nothing but Tc / 2 minus t on. So, we can write down this part from here to here. If this is t equal to 0, then this point is at Tc / 2 - Ton. So, we can write this is at Vc and this is at this one. So, we can say that the slope of this line is nothing but $(V_c - V_m)$, and this Vc was at 0, or we can say minus of (Tc / 2 -Ton), which we can write.

$$\text{slope of line } AC = \frac{(V_c - V_m)}{\frac{T_c}{2} - t_{on}}$$

Similarly,

$$\text{slope of line } AE = \frac{V_c - (-V_c)}{\frac{T_c}{2}}$$

$$slope\ of\ line\ AC = slope\ of\ line\ AE$$

$$\frac{(V_c - V_m)}{\frac{T_c}{2} - t_{on}} = \frac{2V_c}{\frac{T_c}{2}}$$

$$\frac{V_m}{2V_c} + \frac{1}{2} = \frac{t_{on}}{T_c}$$

$$\frac{V_c - V_m}{2V_c} = \frac{\frac{T_c}{2} - t_{on}}{\frac{T_c}{2}}$$

$$\frac{1}{2} - \frac{V_m}{2V_c} = 1 - \frac{t_{on}}{\frac{T_c}{2}}$$

and this we can rearrange this particular part so we can bring this side and this we can take this side. So this is Vm and 1 − ½ which is 1/2, so we will get t on by Tc / 2, and this we can say this Vm/2 Vc +1 /2 = ton + Tc / 2 is nothing but equal to D,

$$\frac{V_m}{2V_c} + \frac{1}{2} = \frac{t_{on}}{T_c} = D \qquad\qquad (1)$$

which is nothing but the We define a term called duty ratio because it is the portion of Tc/2 where your S1 switch is on. So, we can say this is nothing but a term called duty ratio. Now, let us define this as equation number 1 because we will be using this equation to derive the average pole voltage variation.

Now, then we can do a simple thing. Average pole voltage variation over a carrier cycle. So, this is my carrier cycle. TC is the carrier cycle. We can say that we are applying -Vdc/2 for Tc/2 - ton period and we are applying Vdc/2.

I mean, if we do only for Tc/2 because the other part is also repeating itself. It has a half-wave symmetry around Tc/2. If you look from Tc/2, this side and this side both have the same variation, so we can say that it has half-wave symmetry. So, we can write for Tc/2 period. We can do the averaging up to Tc/2 period, and that average will be the same as when we do the averaging up to Tc period. So, we will do

$$V_{AO} = \frac{-\frac{V_{dc}}{2}\left(\frac{T_c}{2} - t_{on}\right) + \frac{V_{dc}}{2}t_{on}}{\frac{T_c}{2}} = -\frac{V_{dc}}{2} + \frac{V_{dc}}{\frac{T_c}{2}}t_{on}$$

$$V_{AO} = -\frac{V_{dc}}{2} + V_{dc}D$$

Substitute value of $\frac{V_m}{2V_c} + \frac{1}{2} = \frac{t_{on}}{T_c} = D$ from eq.1

$$V_{AO} = -\frac{V_{dc}}{2} + V_{dc}\left(\frac{V_m}{2V_c} + \frac{1}{2}\right)$$

$$V_{AO} = \frac{V_m}{2V_c}V_{dc}$$

Vdc is the DC link which you are applying, and Vm is the amplitude of your modulating signal. How far your modulating signal is from this zero line, and your Vc is nothing but the value up to which your carrier goes on one side, or you can say the amplitude of your carrier signal. So, this is what we get. So, we can say that the average variation of pole voltage over a carrier cycle is proportional to the amplitude of the modulating signal sampled during the carrier cycle. We can confidently say that if I sample this modulating signal, which is varying slowly with respect to the

carrier cycle, we can say that the average pole voltage variation over the carrier cycle is proportional to the amplitude of the modulating signal. Now, here we have taken two things: one, we assume that the modulating signal is constant in one carrier cycle, and if we look very carefully at my switches—if we say switches here—my switch S1 is on, and here my switch S1 is off. So, we can say that here S1 is on and here S1 is off.

Similarly, at this point, my S2 is off, and here again, S2 is on. So, in one carrier cycle, my switches change their state, and that's when we can say that the carrier cycle in this particular scenario. When we are doing this in this particular scenario, when we have this kind of carrier, we can say that the carrier cycle is nothing but equal to the switching cycle—the switching cycle—and we can also say that the carrier frequency is nothing but equal to the switching frequency in this particular way of doing modulation.

So, we have seen that the average pole voltage variation over the carrier cycle, which is also a switching cycle or switching period, we can say is proportional to the amplitude of the modulating signal, which is a constant value over that particular switching cycle, carrier cycle, or switching period. Now, if I can vary—if you see this one—the amplitude of this modulating signal, if I can ensure that the amplitude varies sinusoidally, we can ensure that the average pole voltage variation over the switching cycle also varies sinusoidally. And thus, this kind of modulation is called sinusoidal pulse width modulation. We can also see that this is the average pole voltage variation, but instantaneously, the pole voltage has pulses which vary sinusoidally over the line cycle. So, if the amplitude of this modulating wave varies sinusoidally, we can ensure that the width of the pole voltage pulses or the width of the pole voltage will also vary sinusoidally and switches between Vdc/2 and -Vdc/2. This is why it is called sinusoidal pulse width modulation, because the width of the pole voltage pulses varies sinusoidally.

And it is one of the commonly used high frequency pulse width modulation used in inverters to generate an AC voltage from a DC bus or vice versa from AC voltage to a DC voltage which is a very commonly used. We will study that as we go along. So here again the same concept we have done. Here whenever the modulating signal is greater than carrier signal my S2 switch is on and that's when it is applying plus Vdc/2 and when my carrier is greater than the modulating signal my S2 switch is on and that's when it is applying - Vdc/2. Now here if you look very

carefully, here we have taken the voltage with respect to the point O. Generally this point O does not exist.

This is the fictitious reference point we have assumed and this is also called as the fictitious midpoint. However, in actual scenario, we have the point between A and N and that is when if we see the variation which goes between A and N with this Vdc/2 added constant dc added, we will see that it varies between 0 and Vdc. So, if we see the VAN voltage, V A capital N voltage, it is going between 0 and V dc voltage. Here, it is going between Vdc/2 and - Vdc/2.

And again here if we see if this modulating signal has the let's say frequency fm and this carrier signal has the frequency fc here we ensure that fc >>fm , this is the main criteria for this because if we maintain that then in each carrier cycle we ensure that the modulating signal is constant. Here you can see that there is variation but just for the visual representation we have represented in this manner but generally this carrier cycle is very very much smaller that is when we can ensure that we have the constant amplitude of the modulating signal.

So, we have already seen that if my

$$V_m(t) = \sin \sin \omega t$$

where $\omega = 2\pi f_m$ and where f_m is nothing but frequency of the modulating signal this is also called as the fundamental frequency because this is a fundamental frequency with which the pulses of the pole voltages are varying. So, that is why we call this modulating signal frequency as the fundamental frequency.

And if we substitute this $V_m(t)$ in $V_{AO}(av)$ which is

$$V_{AO}(av) = \frac{V_m}{2V_c}V_{dc}$$

we will get that V_{AO} which is again varying with time which is nothing but I mean that is varying with time and this is $V_{AO}(av)$, this is $V_{AO}(av)$ over the carrier cycle is

$$V_{AO}(av) = \frac{\sin \sin \omega t}{2V_c}V_{dc}$$

So, thus we can ensure that if we vary our modulating signal by sinusoidally we can also ensure that the average pole voltage variation over the carrier cycle also vary with that with the frequency same as that of the modulating signal. So if you look very carefully this particular expression we will define one term called as a modulation index which is nothing but the ratio of peak of modulating signal which is Vm to the peak of the carrier signal which is Vc if is we have seen that it goes between - Vc to + Vc peak is Vc and Vm is going i mean is maximum going up to Vm value as we have taken it is nothing but sin $sin\ \omega t$, so that will actually gives you if we substitute this m value we will get the average pole voltage variation over the carrier cycle or switching cycle is

$$V_{AO}(av) = \frac{mV_{dc}}{2}\sin\ sin\ \omega t$$

and this if we see this pole voltage variation shows that we have the fundamental component which is having the frequency nothing but at fm, and along with this, it will also generate harmonics because if you look very carefully, this is the actual pole voltage we are getting, V_{AO}. The average of this pole voltage is nothing but, I mean the average of this pole voltage over the switching cycle is nothing but varying sinusoidally. But actually the voltage pulses or the voltages are varying between Vdc/2 and - Vdc/2. So, along with that fundamental frequency, we also have other harmonics which are also generated as there is an error between the instantaneous applied voltage at the pole and the switching cycle averaged pole voltage. So if we look very carefully when we have the sinusoidal pulse with variation the output of that half bridge will have the fundamental component and modulating signal frequency which is fm and the amplitude of that fundamental component is nothing but mVdc/2 and it depends upon the modulation index.

That means, if we keep the peak of our modulating signal smaller, then we will get smaller fundamental component and if we keep the peak of the modulating signal higher, maximum up to Vc, we will get the higher fundamental component. That means, the amplitude of the average pole voltage variation will be more as compared to when we have the smaller amplitude of the modulating signal. Along with this fundamental component, it also generates the harmonics. Now, again to calculate, to quantify these harmonics, we require again the derivation of double Fourier series which we will avoid to do in this particular lecture series. One can easily go

through the literatures to obtain that mathematical formulation of that particular harmonic at what frequency those harmonics are present.

So, however, But we will take the inference of that particular mathematical expression, which says that along with this fundamental component, which is mVdc/2, we also have harmonics at a carrier frequency and its sidebands, which is given by IMF plus minus J, where MF is nothing but the ratio of fc/fm, where fc is the carrier frequency. And fm is the modulating wave frequency or modulating signal frequency. Now, it says that if I is odd, then J has to be even, and if I is even, then J has to be odd. That means if my I equals 1, J should be 0, 2, 4, 6, and if my I equals 2, J should be 1, 3, 5. These are the harmonic numbers around which your harmonic lies.

So, for example, if I take my modulating signal frequency to be equal to the line frequency, equal to 50 Hz, and I take MF equal to 21, that means my carrier frequency fc is nothing but 21 times 50 Hz, which is somewhere around 1050 Hz. Then we will have the frequency component at the fundamental at the fundamental frequency, and we have H equal to 1. I mean, this is at the fm frequency, same as the modulating signal frequency. That means we have the fundamental component, and along with that, we have the frequency component at the sidebands of the carrier frequency, which is I equal to 1 and J equal to 0, so that means H equal to 21. So we have H equal to 21. Then we will keep I equal to 1 and J equal to 2. So we will have 21 $\pm$2.

So 21 $\pm$2 means 23 and 19. And then when we keep I equal to 1, which is again 21, and $\pm$4. So when we keep $\pm$4, it is 25 and 17. So this is at I equal to 1, J equal to 0. I equal to 1, J equal to 0; this is at I equal to 1, J equal to 2; this is at I equal to 1, J equal to - 2; this is at I equal to 1, J equal to 4; this is at I equal to 1, J equal to -4.

Similarly, after this, we will keep i equal to 2. When we keep i equal to 2, 2 into 21, 42 and j we will keep 1. So, $\pm$1. So, it is 43 and 41. So, here it is i equal to 2, j equal to 1, i equal to 2, j equal to minus 1, and then we have I equal to 2 and j $\pm$j equal to 3, so $\pm$3 so it is i equal to 2 j equal to 3 and then we also have our 39 which is i equal to 2 j equal to minus 3 and this is i equal to 2 j equal to 5. So, accordingly we will get the sidebands of carrier frequency components along with the fundamental component which is at modulating signal frequency. So, let us take an example where we have taken Vdc = 400 volt. We have taken our modulation

index 0.9 where modulation index is nothing but Vm /Vc and our mf which is fc /fm is equals to 21. And we again take our fm = 50 Hz.

When we take that, our fc is nothing but 1050 Hz. So, taking this value, we have done the simulation in MATLAB and the output is shown over here. And this is the actual your VAO look like. vao voltage so if we see the vao voltage it has the pulse width modulated pulses which actually varies sinusoidally and if we see the frequency components we have at fundamental component which is at 50 Hz and that value we will get nothing but equal to 180 so how we can get 180 we have kept modulation index 0.9. So, 0.9 times 400 /2 we will get that 180 volt and which we have also seen over here so this component is nothing but 180 here we have plotted with magnitude percent as a percentage of frequency

Similarly, we will see the next harmonic exists at this is 21. This is at 19. This is at 23 because this is the mf and this is ±J , ±2. So 19, 23. This is your 17, this is our 25.

So, what we see is that this variation first of all we will see that from this the fundamental the other harmonic content is actually falling or decreases as the harmonic order increases approximately with a value 1 divided by harmonic order and here between this and this also the magnitude decreases in this manner as shown here. However, one can get the exact variation or the harmonic content by doing the double Fourier transformations and this one is at if we do this one this is 41 this is 43 then we have 39 here we have at 45 so then 47 and this is 37 so this is the pole voltage variation which we see across the vao where o is the fictitious midpoint and this VAO will have this frequency component now if you look very carefully we have frequency component at fundamental frequency which is at 50Hz and then we have the frequency in the side bands of the carrier frequency and that carrier frequency is very very much larger than the fundamental frequency, so if we keep our our carrier frequency much higher here we have shown with 21, let's take if we keep our carrier frequency to let's take a very high value in case of low power converters we can keep that into you know more than 100 or more than 200 number so when we keep that such a higher value so we are pushing the harmonics after the fundamental see we want only fundamental component we want to convert dc to ac or ac to dc. So, we are only bothered about fundamental component but along with fundamental we are also introducing harmonics but this harmonic we can push it to very larger frequencies and thus we can design the smaller filters to filter out those harmonics at a very high frequency and we can

easily design the filter a low pass filter which allows only the fundamental component to go while filtering out those harmonic which exist at a very far away from the fundamental component if we take this mf much higher then we will have the harmonics existed across i mean at that higher frequencies if we keep our carrier frequencies to be very high or we can say we keep our switching frequencies to be very high we are pushing the harmonics to a very high frequency And that's when we can design a smaller filter to filter out those high frequency harmonics and only let the fundamental component to go through it. Now here we have discussed DC to AC operation.

Similarly, the same thing will happen when we are converting from AC to DC operation. So, in AC to DC operation, we are actually applying a fundamental component of AC, and we want a DC. The same concept applies, but we have to see it from the other side, and we can easily implement this concept in AC to DC converters. In this, we have understood the concept of pulse width modulation, where the pulse width of the pole voltage varies, and that is what is called pulse width modulation. We can vary them proportionally to the amplitude of the modulating signal, and that is when we can get any average pole voltage variation. That pole voltage variation could also vary sinusoidally or with different frequencies. However, one condition is that we must ensure the frequency of the modulating signal is very much smaller than the carrier signal frequency. Now, we will use this concept and stabilize the concepts related to three-phase AC to DC power conversion, relying on the same concept of pulse width modulation, which we will study in the next lecture.

Thank you very much for patiently listening to this lecture.