Advance Power Electronics and Control
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Lecture – 10
Single Phase Converter - II

Welcome to our NPTEL classes on advanced power electronics and control. We were discussing with the single phase converter. This will be your second lecture on it. Till now we have discussed half bridge configuration. Now let us go for the full bridge configuration. Half bridge configuration is actually not at all practicable because conversion rate is very low. For this, we have single phase central tap full bridge configuration.

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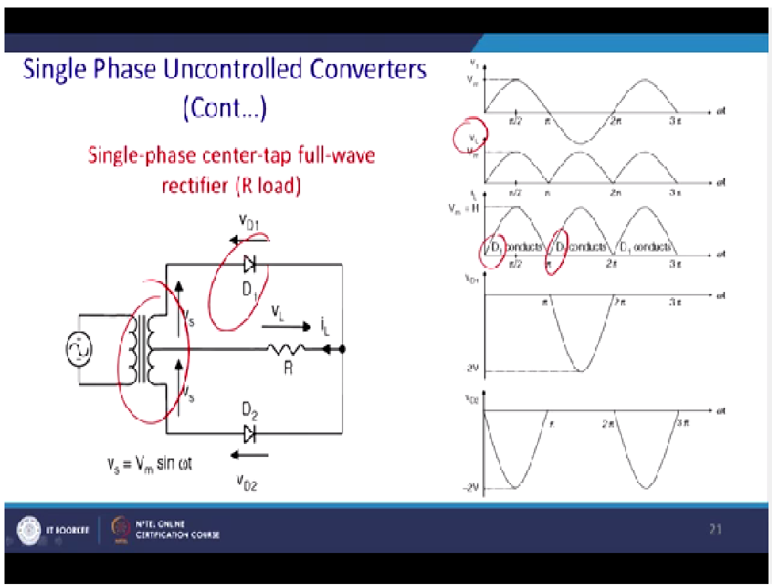

However, availability of the central tap transformer for the little higher power rating is definitely difficult to get for, this is an applications is less. However, it has some utility because the semiconductor component count is less. So this is actually the supply voltage. And ultimately this is the voltage coming across load and you get full rectifications.

And this is the point where D1 conducts or the forwards half cycle and this is the D2 conducts and so on. Or one of the biggest disadvantage of it that is the peak inverse voltage of this diode D1 or any diode or D2, is the double of the supply voltage. So it has to block huge amount of the voltage.

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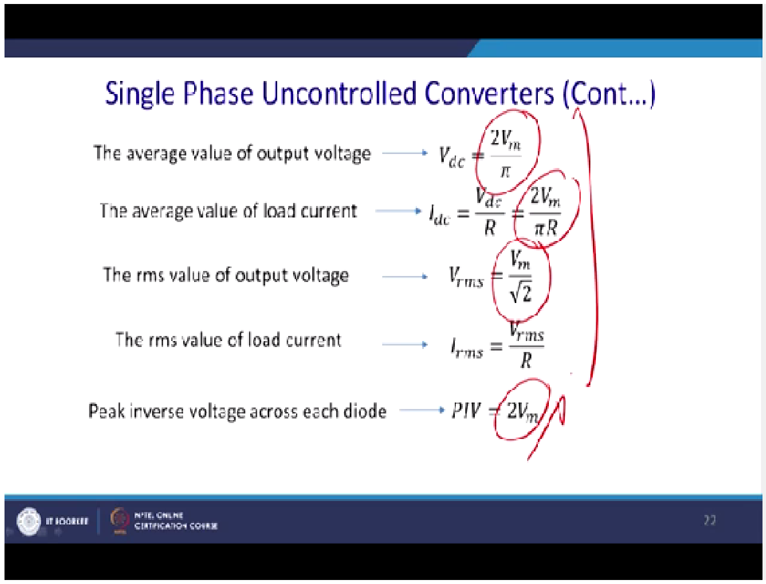

But there is the big advantage of it compared to the single phase diode. The average value of the output voltage has been doubled. It was Vm/pi. Here it is 2Vm/pi. And the load current similarly, it will be more. So it is power handling capability is straightaway is actually quite high. The rms value is basically, it was Vm/2, yes. Here it is Vm/root 2 and it is divided by R and peak inverse voltage of the diode, this is actually one of disadvantage of it.

Otherwise, these are high and thus it is used for the higher power application, that is 2Vm. Another configuration definitely is the bridge configuration because we get rid of the bulky transformer and where you can directly convert but it is the popular usage that consists of the 4 diodes.

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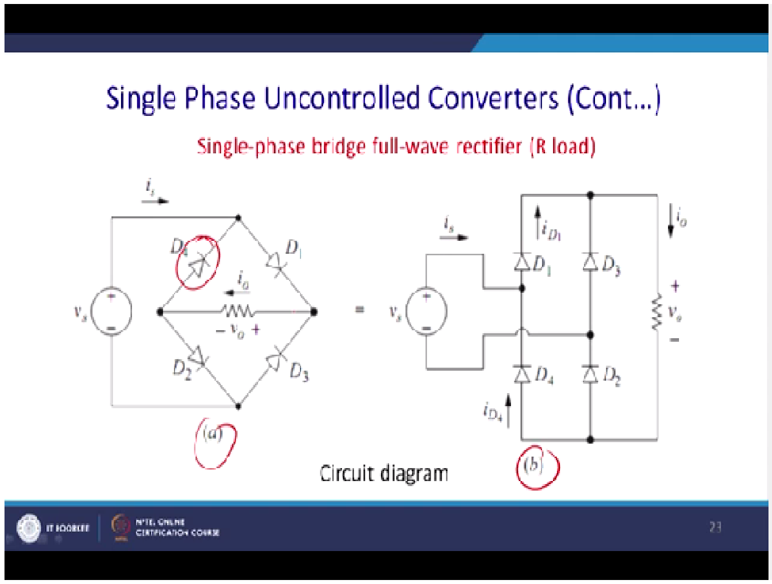

However, it will be loss because you know you have to incorporate though while starting, we have said that we assume that this conducting device while turn on are lossless, but it is not so. So you have a diode of across it, so while lecturely current flows, transfer of the power takes place through 3 diode devices and thus you have a little more losses. So this is one configuration and this is another configuration.

It is almost same kind of configuration. It is just the way you actually put it. Here load is actually put inside the bridge configuration and it is just taking away and put it in a different configuration.

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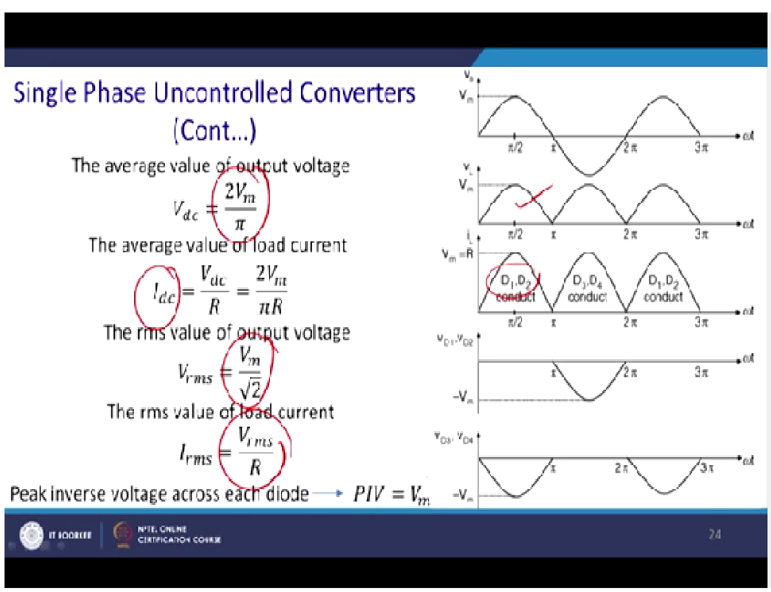

Now here what happens? It is same as this actually central tap. Amount of the Vdc is at 2Vm/pi. And this is the input voltage and this is actually the output voltage. This is actually the conductions of Vm. So D1D2 conducts or D3D4 conducts and so on. And PIV is basically Vm across each of the devices and thus, you have actually not much voltage stress but here component count is more and another issue is that actually has to flow, power loss across each power diode if it is little more than 0.7.

Say is 1 volt and 1 volt, 2 volt is lost. But in the case of this, the diode, it has been lost by 1 volt. So this is the Idc. Idc is given by 2Vm/pi R. Similarly, rms is this. Rms will be given by Vrms/R. P inverse voltage across the diode is actually the Vm.

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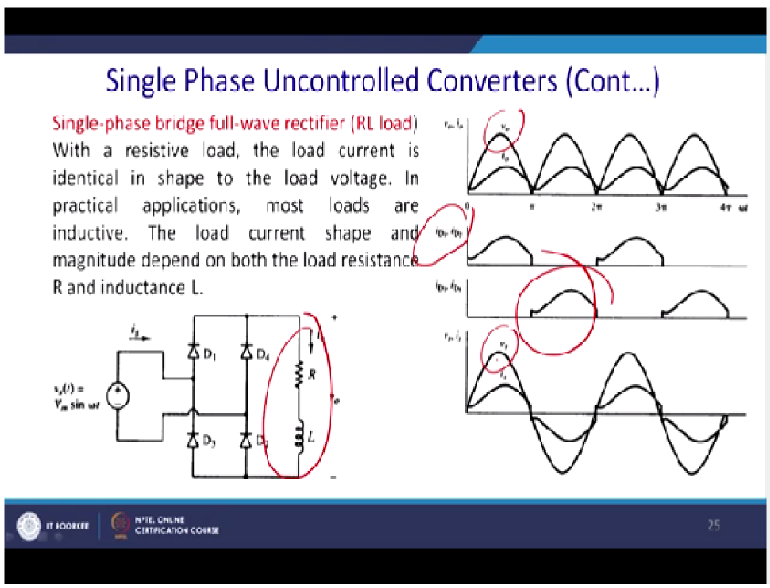

Single phase full wave rectifier with the RL load, let us say. With the resistive load, the current is identical to the shape of the voltages. In the practical applications, most of the loads are inductive. Why? Because mostly this fits to the DC motor drive. DC motor drive actually has a huge value of the field because it has a huge inductance when placed in series of shunt. And thus to incorporate it, we can model, it is a DC motor as a higher load.

So for this reason, the load current shape and the magnitude depends on both the load resistance and the load inductance. And let us consider that. This is the configuration of RL load. So we assume that this is a continuous conduction mode and we have a huge load current also. So for this reason, this is the output voltage and output current. And this is the current through D1D2 and this is the current through D3D4.

And ultimately, this is the overall voltage and the current in the single phase diode based rectifier feeding an RL load. See that actually even though voltage is sinusoidal, but output voltage has got a non-linear change. Thus it is contaminated with the harmonics. So when actually this value of the inductive load is quite high. In most of the cases, you know actually omega L/R, if it is more than 10, so this is the case, then we can assume that there is a constant load current.

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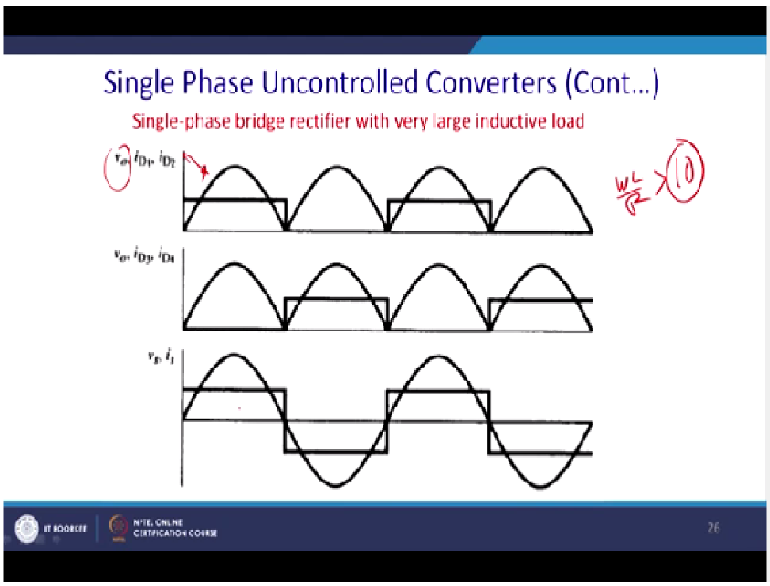

In that case, you will have, this is a voltage and this is actually the current. This is a voltage and D1D2 is the current. Then after current will flow through D3D4 and so on. And thus this is the voltage and current profile where current will be the square wave. We prefer this kind of thing because you know it is very easier to analyze.

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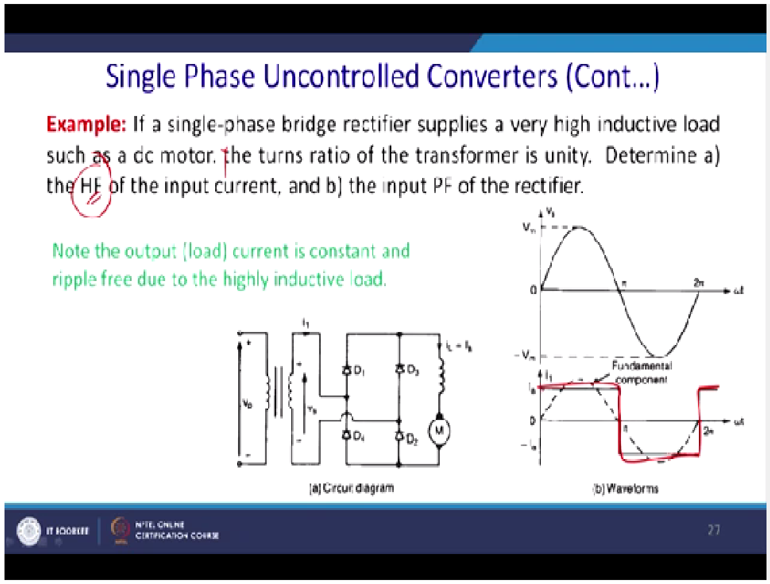

Example, single phase uncontrolled converter that is feeding a DC motor. In a single phase bridge rectifier, supplies are very highly inductive load such as DC motor. The turn ratio of the transformer is assumed to be unity. Determine the HF, that is THD of the input current; b, the input power factor. So since it is a very high current, so we can have by ly inductance, we can assume, we can find that an input current can be like this, the square wave. And this is just fundamental and this is just supply voltage where you got to find it out HF and the rectifier.

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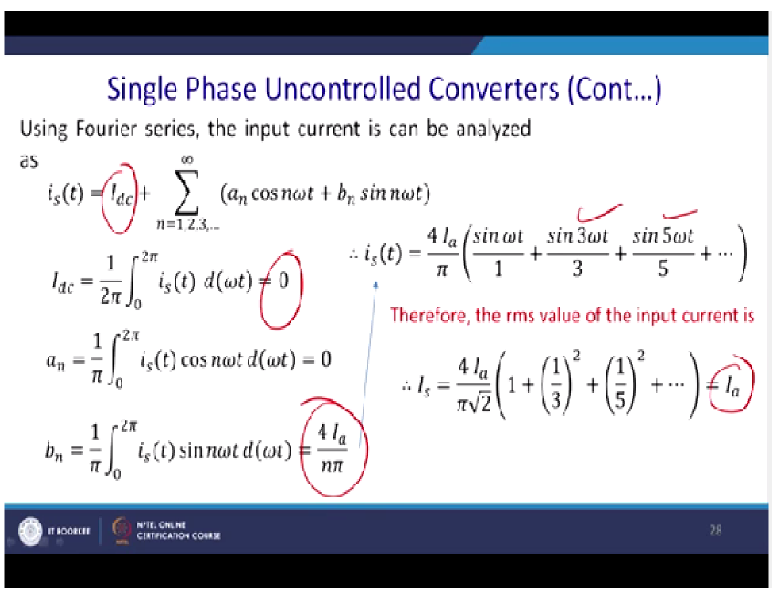

So we can split it. So iS=idc+the harmonic part of it since we have actually no DC, average value will be 0. So it is a properly AC current. So this value will be actually 0 and we have to calculate the an and bn. So from the order of symmetry, we can find that cos part will be 0 and we find that basically that part component will be present and this value will be 4Ia/n pi, where n is actually any odd number.

So iS will be given by 4Ia/pi 1 sin omega t, this is basically the fundamental. Thereafter third, fifth, so on. On or harmonics. Therefore, the rms values will be given by, you can actually calculate, that value will be basically Ia.

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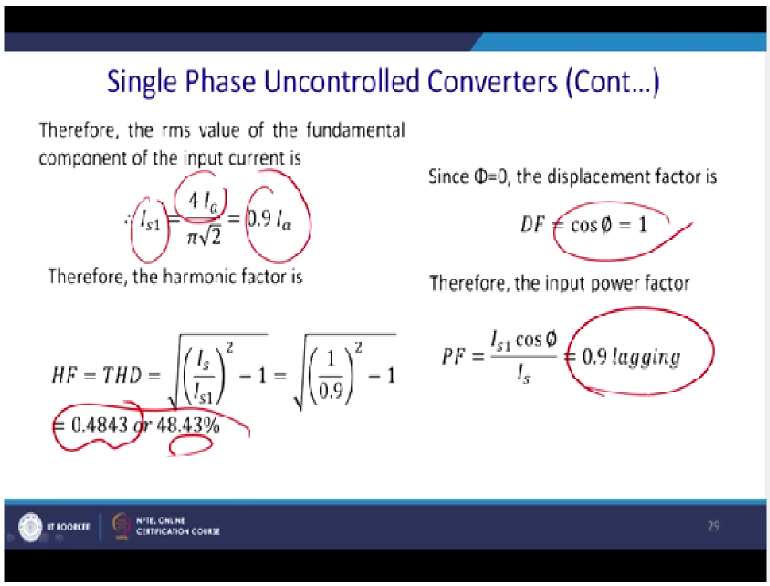

So therefore, rms value of the fundamental of the component of the current Is1 is 4Ia/root 2 pi, that leads to actually 0.9Ia. Therefore, the harmonic factor is basically or the THD will be Is/Is square-1 is 1/0.9 square-1. So you get the value of around 48.43%, that is quite high. We want, basically the harmonic content in the system is around 5, that is this prescribed by IEEE 519 standard in any power quality problems.

So you know, so what does it do? Because when you are feeding a rectifier, when you are actually feeding an RL load to a rectifier, mostly you do this experiment in your actually, undergraduate B.Tech levels, so you would see that what kind of harm you are doing to the power system. So since phi=0 in this case because it is uncontrolled and displacement power factor is actually 1, so ultimately you got a lagging power factor of 0.9. So this is the actually some analysis of highly inductive RL load. Similarly, if you replace it, same thing, one by one by a controlled manner.

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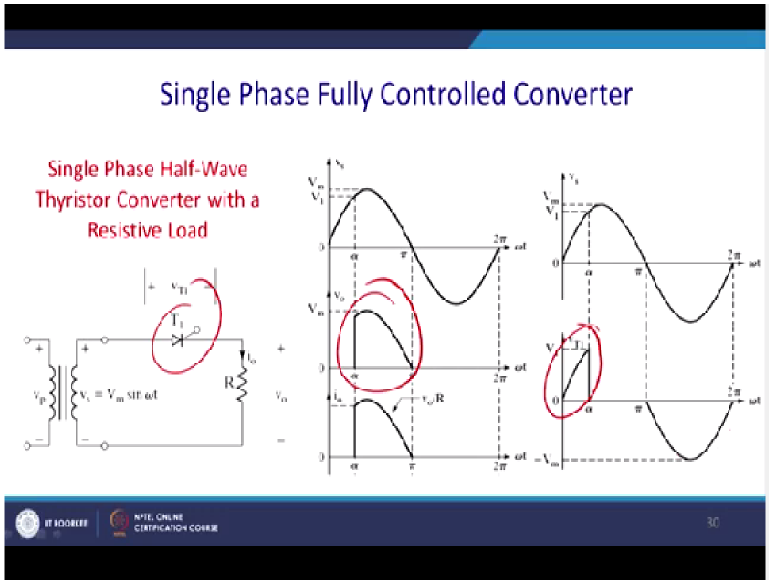

Instead of the diode if you put a thyristor, then you can change the angle alpha and thus wave will take the load, voltage will take this pattern and the current will take this pattern. And so ultimately this is actually the voltage blocking capability of the thyristor. So this has then blocked the voltage after it is triggered. Thereafter actually we have almost 0 conduction drop and thereafter again it will block the voltage, the value of Vm.

Now same calculation what we have done in the case of a diode, we require to do that. Ultimately we will see that actually this value will change little bit because you to speed the limit, 0 to alpha and alpha to pi.

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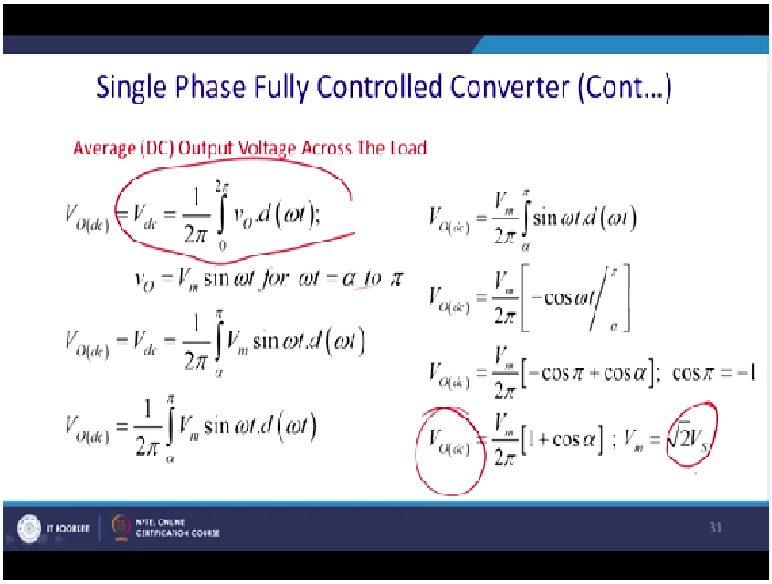

And thus we get the results, you know, actually, some different value that is root 2 Vs. So V0 from this actually 0 to alpha. Similarly, we can calculate and we can find it out what is the alpha. So ultimately the output voltage we get here, it is Vm/2pi 1+cos alpha where actually Vm is under root 2Vs.

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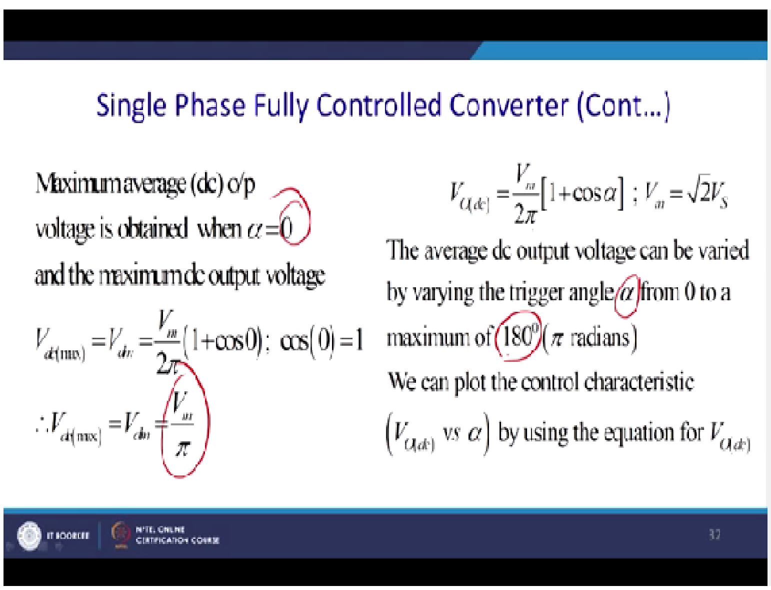

Similarly, maximum output voltage of the DC can be obtained when alpha=0 and the maximum DC output voltage is the same as that we have seen in the case of the diode. It is Vm/pi. So V0dc actually basically similarly Vm/2pi 1+cos alpha that is basically, you know, this value. The average output voltage can be varied by varying the triggering angle alpha from 0 to a maximum of 180 degree and which can plot the characteristics alpha versus actually the output voltage.

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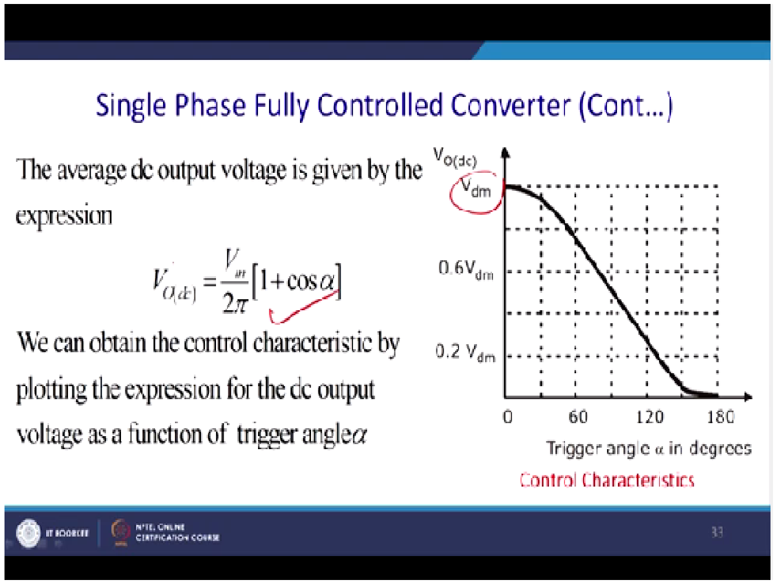

You can see that the maximum output voltage you get for alpha=0 and now it is almost linearly drop and these values will be given by Vm/2pi 1+cos alpha till 90. Basically it is adding up. Thereafter actually cos becomes negative and thus actually gradually it will drop and it will drop to 0. So we can obtain the control characteristics by plotting the expression. So by controlling the alpha, we can control the amount of the DC voltage come across the load.

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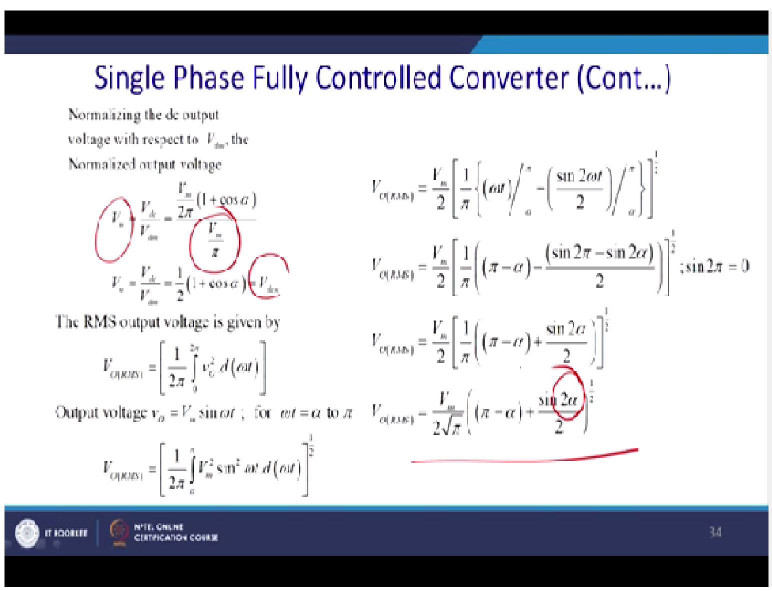

Now let us come to the single phase full controlled converter and some parameter analysis. So the output normalized using that DC output voltage with respect to Vdm, so Vn, the normalized output voltage will be the ratio of Vdc/Vdm, that is the maximum peak value. So it is Vm/2pi

1+cos alpha/Vm/pi. Ultimately, you get basically 1/2 1+cos alpha. So it depends on cos alpha. The term we will say that Vcn.

Similarly, rms value you can get it 0 to pi, you have to split the limit. Since 0 to alpha, there was no current into the system, so 0 to alpha you can get it. So rms value will be given by Vm/2 root pi pi-alpha+sin 2alpha/2. So you can understand that in case of the rms, you will have a component of the double frequency. So it will be a 2 pulse converter. So you have a double frequency ripple followed by a DC part.

If you see that, you know, this part is DC. And this part is essentially AC. So DC superimposed on to a double frequency oscillation, okay. And thus it is a 2 pulse. More the number of pulses, you know, actually what happens? You will, actually you will get a high frequency and thus filter will be actually a smaller and you will find much (()) (14:17) to actually remove those components. And for this instant, we are looking for the high pulse converter.

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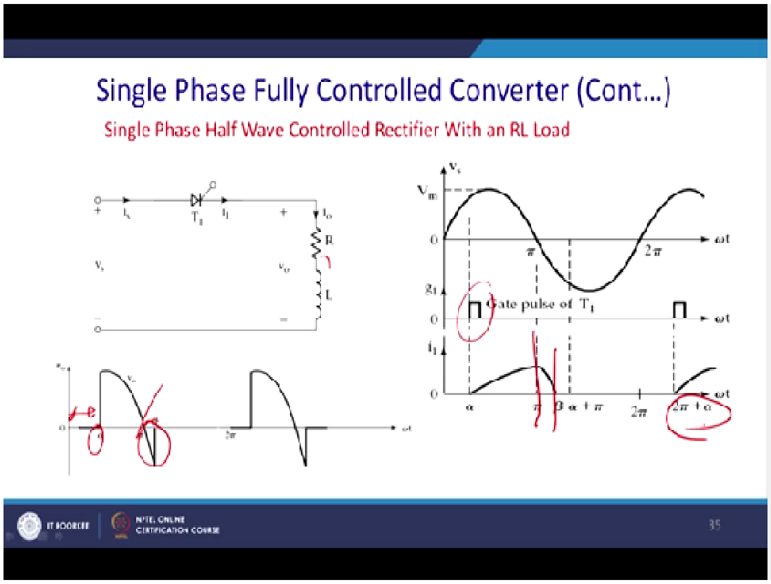

Now let us consider the case of the single phase half wave full controlled rectifier with the RL load. And we assume that inductive value is not quite high. Otherwise, you would have taken a different kind of current shape. So till alpha, it has been triggered. So after that it has been triggered, actually the output voltage will take this shape and it will continue to conduct after pi because this thyristor is a current control device.

So ultimately it will go on conducting on it and due to that, you know, this is basically your, the voltage profile. This is the gate pulse and this is the current profile. It will conduct till angle beta. And again, it will be same because there will be a huge lagging because of the half bridge. Sorry it is half controlled converter. So again it will start conduction after 2pi+alpha.

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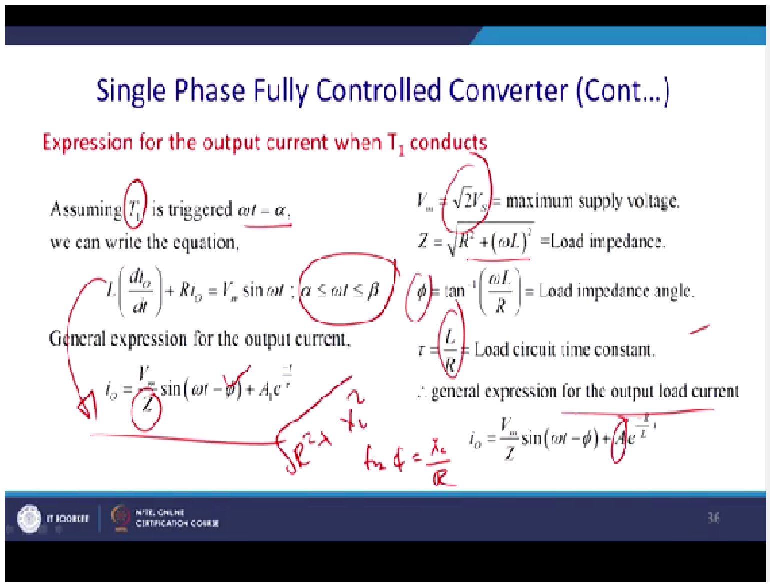

So for analyzing it, we require to take the help of the differential equations assuming that it has been triggered at T1 and at an angle alpha. We can write this equation basically Ldi dt+Ri0=Vm for this zone of conduction from alpha to beta. So an i0, we can actually if you solve it, this equation, ultimately you get i0=Vm/impedance that is basically nothing but under root R square+xL square.

So we can calculate. Sin omega t-phi, where tan phi will be equal to basically XL/R. So from there, we can get this result. So where maximum supply voltage is root 2*of the supply voltage and this is the load impedance which I have just referred. So phi=tan inverse of omega L/R, the load impedance angle. So this is load impedance angle and this is basically the time constant L/R that is tau and general expressions can be written as Vm/Z sin omega t-phi+, this term.

Now we require to have a one unknown to be left out in the previous slide that is the A1. We require to calculate A1 from the initial conditions.

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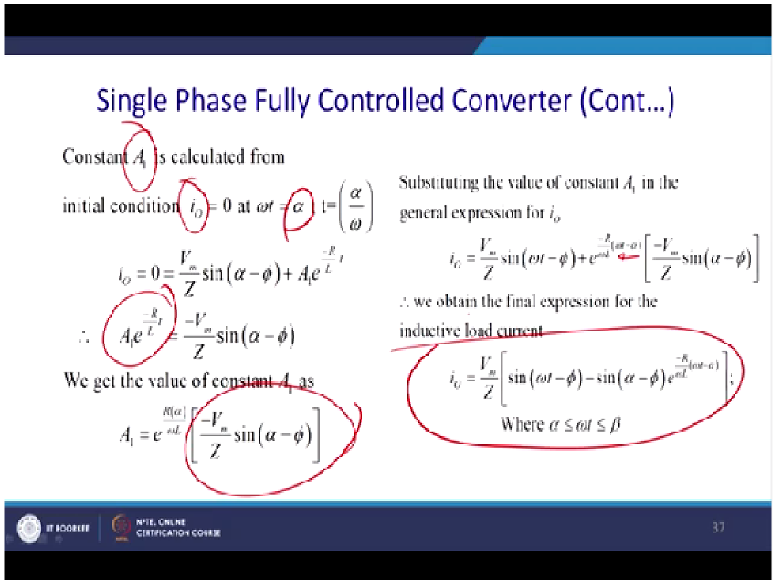

So condition is when load current was 0, it was either beta or alpha. So omega t=alpha, so t=, definitely alpha/omega. So you substitute these results. Ultimately you get A1e to the power RLt=-Vm/Z sin alpha-phi. So this term can be 0 if alpha=phi or A1=this value. So total equations of the i0, thus will be Vm/Z sin omega t-phi+e to the power -R/omega L omega t-alpha-Vm/Z sin alpha-phi.

So this will be the final expressions of the load current, so, in a known form. So if you know the alpha, if you know the phi, you can calculate. And if you tell the instant, you can, of course, you can calculate the load current. So this analysis is a little complex than your actually the diode based rectifier. Students are required to practice it. Assignment will be given on it and especially all the competitive exam will get a problem on different kind of actually load current calculations, mostly in chopper.

So they can have this kind of thing. But chopper is, essentially there is a difference. That is not AC to DC application. That is basically DC to DC application. It is basically AC to DC application. But treatment has lot of similarity.

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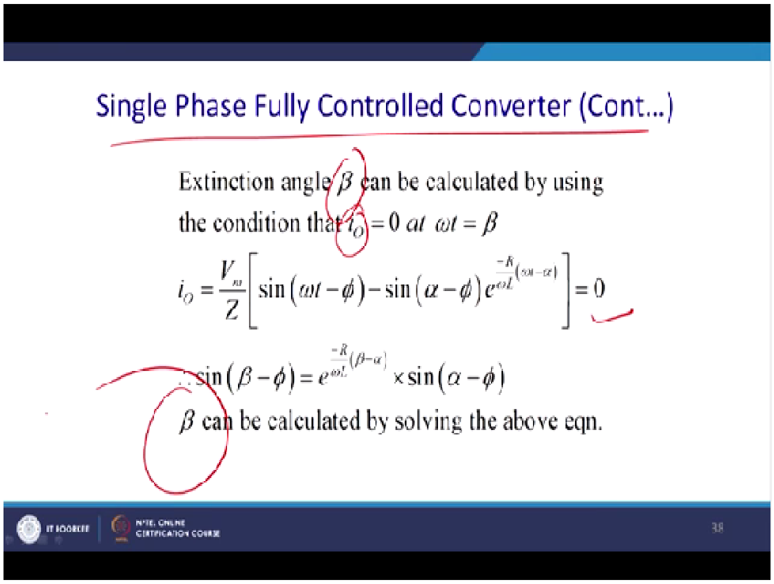

Now let us come to the single phase fully controlled converter. So your extinction angle beta can be calculated by using i0=0 again at the beta, not only at alpha. So you can write in terms of the beta also but that is quite complicated. But generally we prefer to write in terms of alpha. Anyway, Vm/Z sin omega t-phi-sin alpha-phi e to the power -R/omega L omega t-alpha=0. From there, actually beta can be calculated. So this is the way we can calculate the extinction angle of this half controlled converter. Now other parameters.

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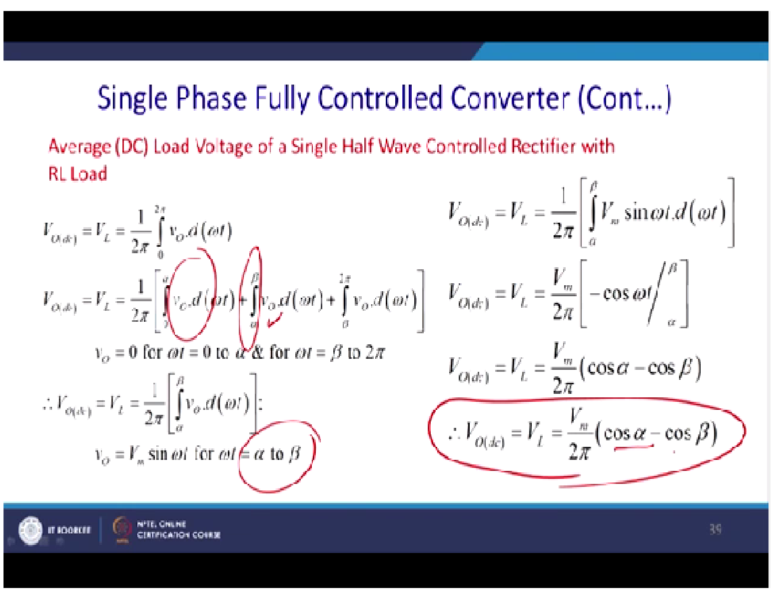

The average DC load for the single half wave controlled rectifier for RL load, that is the same load. So you can integrate over it, 0 to 2pi and here you have to split it, the limits. So first part is 0 till 0 to alpha. Alpha to beta, you will get a voltage V0. Thereafter again it is basically 0. So you have to check it. So ultimately you get VL=1/2pi alpha to beta and you can calculate the extinction angle which I have shown in the previous slide.

So you get alpha to beta and thus Vdc=VL=1/2pi alpha to beta Vm sin omega tdt. From there actually you get a calculation. This is the value of the Vdc output voltage that is Vm/2pi cos alpha-cos beta. Mind it actually beta is mostly more than 90 degree and thus actually value of the cos beta is generally negative. Thus you basically add some.

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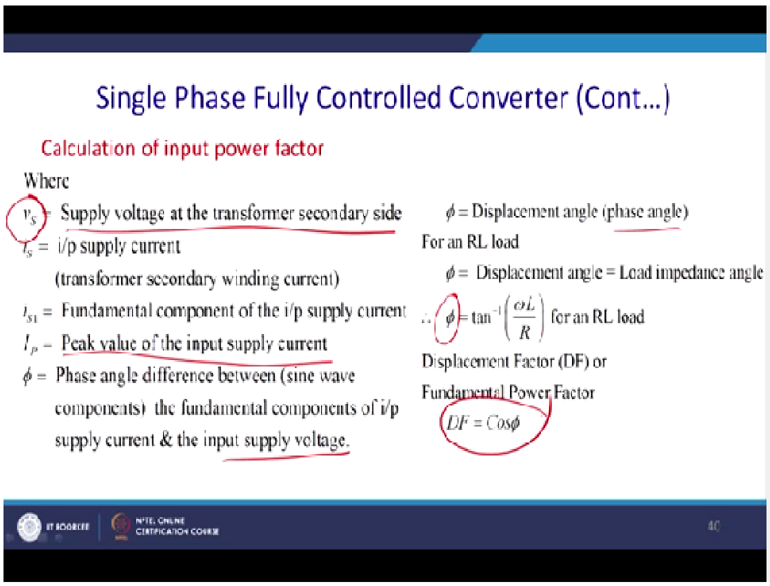

So another parameter we require to calculate. So these are single phase fully controlled converter. Now where we have to assume, we have taken some distinction to it. Supply voltage at the transformer side is taken as Vs. is=input supply current, transformer second winding current, is1 is the fundamental component of the input supply current and Ip is the peak value of the input current.

Phi is the phase angle difference between the sine wave components, the fundamental component of input supply current and the input supply voltage. phi=displacement angle, phase angle for an RL load, phi is the displacement angle, load impedance angle and phi=tan inverse omega L/R for an RL load, displacement factor DF or the fundamental factor=cos phi.

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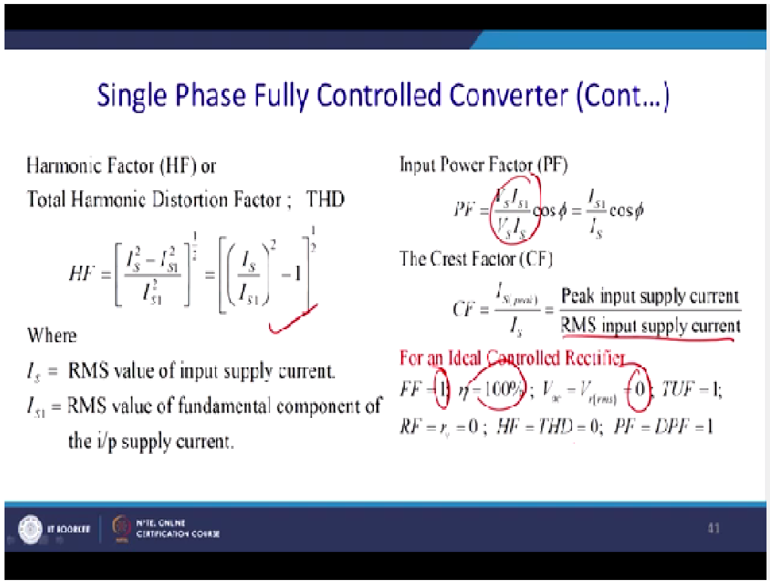

Now let us calculate the THD or the harmonic factor, total harmonic distortion, that in Is square-Is1 square/Is1 square. So that is basically this term where rms value of the input current is Is. Is1 is the rms of the fundamental component. So this is basically VsIs1/VsIs cos phi=Is1/Is cos phi. And Crest factor CF, Is peak/Is, peak input supply current/rms input current. For an ideal controlled rectifier, what happens you know, form factor is generally 1, efficiency required is equal to be 1 and there should not be any part of the AC component.

For this reason, this required to be 0. So total utility factor is 1 and ripple factor should be 0 because it does not contain any AC. THD should be 0 and power factor or the displacement power factor also should be 1. Now let us see we have seen the, actually, single phase half wave controlled rectifier with RL load, now we will feed, we will put a freewheel diode.

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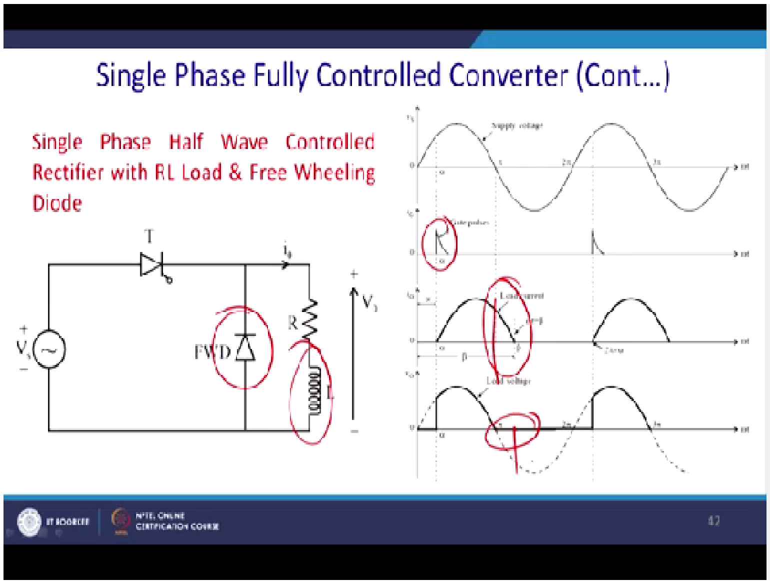

We have seen in case of the diode, diode actually, freewheel diode increases the amount of the DC into the load by reducing the magnetic energy stored into the inductor. Now let us see that what happens in case of the half wave single phase controlled rectifier. There is a, so many actually, prefix added to it. So it has been delayed by an angle alpha. This is the supply voltage and this is the gate currents. And ultimately current will take, I assume that it will take this kind of profile.

If it is a square, then it will take a different profile because if this inductor value is quite high. Now this will be a sinusoidal in nature. And output voltage come across it, will have basically triggered here. Thereafter, what will happen? You know, once actually negative voltage comes into the picture, then this diode actually forward biased and it starts conducting. And thus, you know, in load current basically, will continue to flow but you will get actually the 0 voltage across the load.

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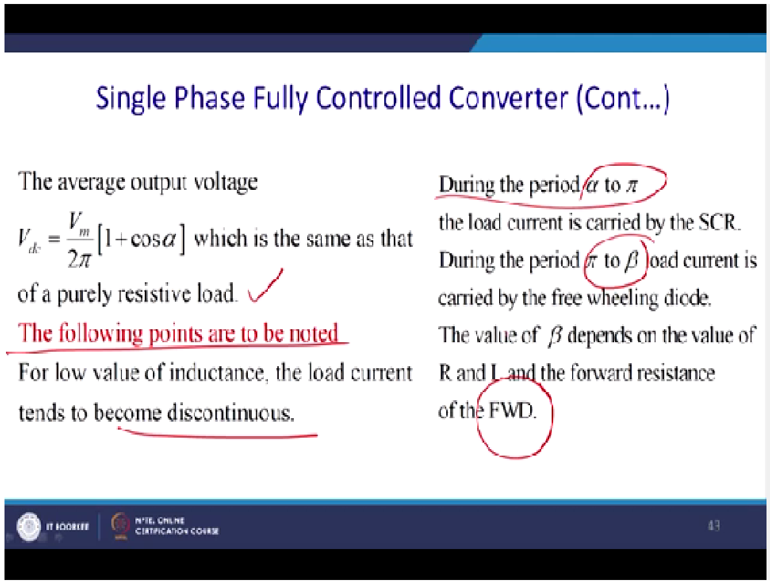

And due to that, you will have actually no power being supplied across during this time. Because you can see that load voltage is 0. Previously what used to happen, you know, without diode, there will be a negative portion of it. And ultimately, you know, positive current and the negative voltage will lead through the AC component of it, increasing the AC component of it.

So you can reduce the AC component since basically you will not get any load voltage due to this actually, since it will short, basically the current, little current i will flow but load voltage is going to be 0 after pi. The average value definitely will change. So it will change to Vm/2pi 1+cos alpha. So which is the same that of the purely resistive load. So what happens, while freewheel, it will leads to the same value and you get more amount of DC.

So following points to be noted. For low value of the inductance, the load current become discontinuous. Mostly this is the case in case of the half wave circuits. During the period alpha to pi, the load current actually flows through or carried by the SCR and during the period pi to beta, the load current carried by the freewheel diode. The value of the beta depends on the value of the RL load and the freewheel diode.

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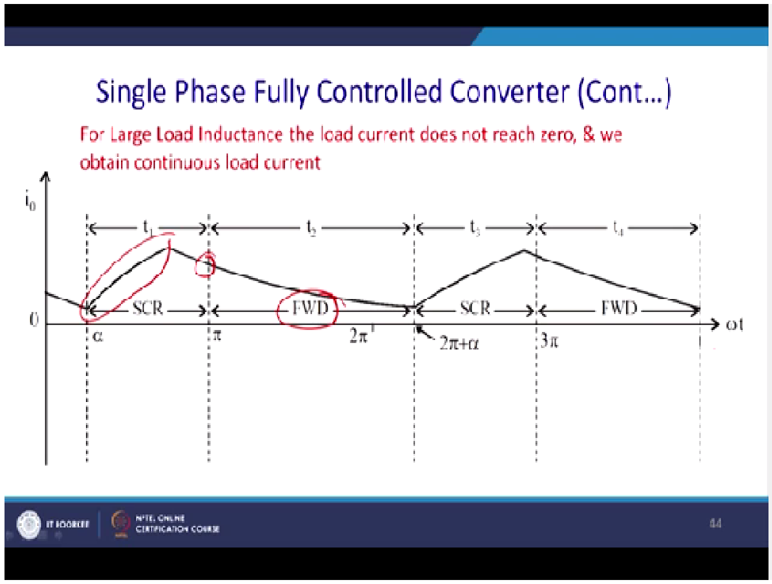

So this is the case, so you know, this is actually the alpha current. So then actually current will drop because it has a sinusoidal pattern of the voltage. So thereafter, at this point become pi. So then forward conduction mode start for continuous conduction mode. So diode will be actually, this freewheel diode will carry the power and thus load will not get any voltages. And then again after 2pi+alpha, it has been triggered and been followed. So this is the case of the single phase fully controlled converter.

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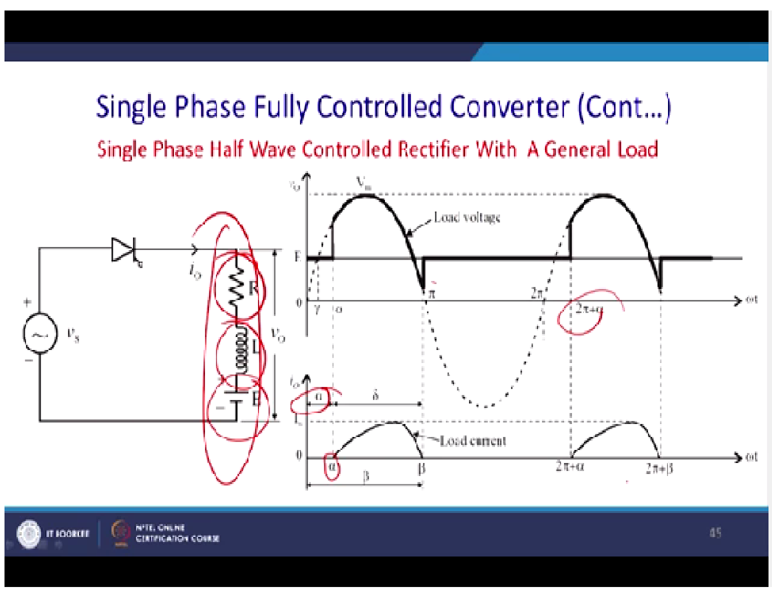

Now next definitely another entrant to the scheme is that actually an RLE load. Generally, this is the typical model of DC machines because you got a resistance and this is a combined sandwich resistance and the mechanical conversion part of it. And thereafter you have the inductance that leads to the losses across the fields, either it is a shunt or series. And then you have a back EMF mostly of the motor.

Because due to the inertia of the motor, the speed of the motor does not change instantaneously. So essentially when you talk about the RLE, we take care of DC motor. So this is the supply, Vm. Ultimately value of this E will have some value. So that value have to be, V should be equal to some value of the V sine omega t1. Now you have triggered an angle alpha and it will continue to conduct the load current. And it will go to the negative but it will not go to that point because of that.

Basically, you know, this of angle E, because this is the back EMF part comes into the consideration. It will continue to conduct till this value. Since this is a half wave, there will be a long pause, again it will conduct till this point. And here also, you can find that actually it will continue to conduct from alpha to beta and same way, it will conduct. Now this is something we require to analyze. We shall continue our discussion in the next class with the single phase half wave converter feeding the RLE load. Thank you so much.