Advance Power Electronics and Control
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Lecture – 09
Single Phase Converter

Welcome to the advanced power electronic and control courses. We shall discuss today single phase converter. Single phase converter finds its applications, wide application because previously we had a DC supply and thus we had a DC loads. Once the supply has been changed to the AC, then we require genuine purpose to rectify this. For example, actually in older household in Calcutta, we already had a DC supply.

We required to rectify it to put it to the actually DC fans in other applications. So now we refer to the process of conversion to the AC to DC as rectifications. So rectification refer to the process of converting an AC voltage and current to the DC voltage and current. And rectifications specially refer to the power electronic converter where the power flows from AC side to the DC side and not in a generative way.

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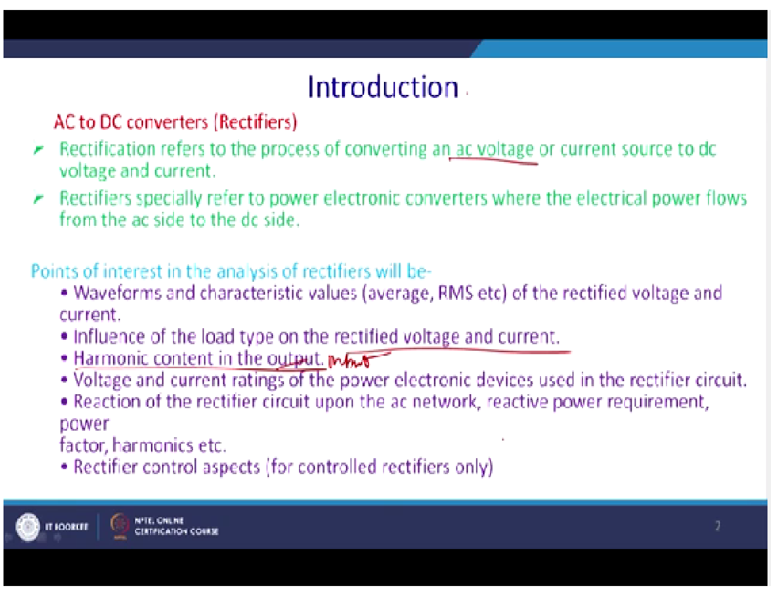

Mostly load is, mostly AC will be the source and load will be the DC and mostly these are DC motors. Now point of interest of the analysis of the rectifier will be actually we require to analysis the waveform of the, while AC to DC conversion, so while various things. Where the inputs side, when you talk about the waveforms and characteristics values, when you talk about DC value after rectification, we will have an average value.

And when the RMS value becomes my ripple DC, not a constant DC with the rectified voltage have the current. Then due to rectification, there the influence of the load and the rectified voltage and the current will change according to the type of load, whether it is RL, RLE, different kind of load will give rise to a different kind of waveform.

Harmonic content in the input. So you are feeding AC, so since it is a non-linear conversions, AC to DC conversion, then leads to the harmonic contamination in the source side. So you will see that what is the problem or what is all of the arising the harmonics in the input. Voltage and current ratings of the power electronic device used for the rectifier operation, that also will be analyzed.

So what should be the proper rating for the particular wattage of the load. Reactions of the rectifier circuit upon the AC networks reactive power equipments and the power factor harmonics, these will be the actually characteristics of this actually the rectifications and rectifier controlled aspects for controlled rectifier, generally it has been achieved by the thyristors.

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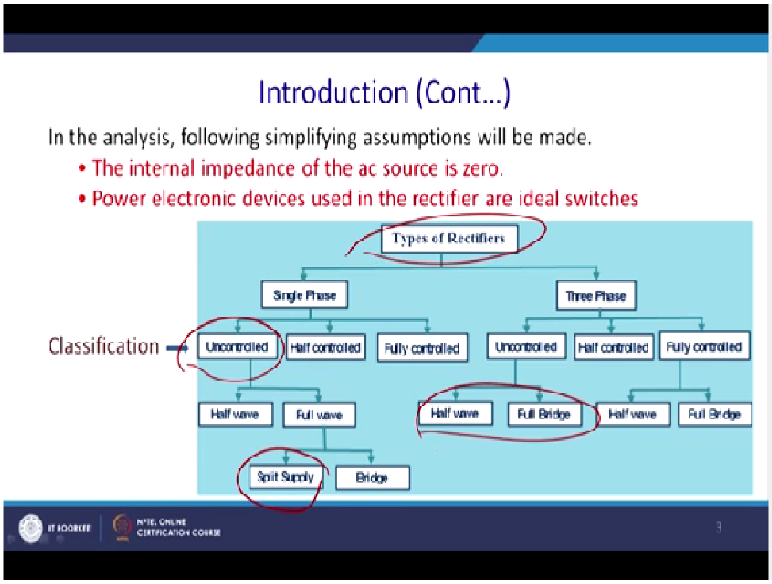

Now in the analysis following simplifying assumptions will be made. Internal impedance of the

AC source is 0 if otherwise not mentioned or taken into the consideration. Power electronic device used in rectifications are the ideal switches. So types of the rectifies. We have a single phase and the 3 phase. Today, we shall consider a single phase. And definitely, we have uncontrolled fitted by the diode rectifier.

You have a half controlled fitted by the combinations of the thyristors and the diode. That of full controlled, it is fed through actually the thyristors. Then we may have a half wave where we require to buck down a voltage a lot. Then we have a full wave where you require to have a total cycle. Then we have a different kind of supply, whether you have a, actually the midpoint of the transformer is available or not, that is also a matter of questions.

If it is available, then we will go for the split supply. And otherwise, we have a bridge kind of configurations. And same way, in 3 phase also we have uncontrolled fitted by a diode with rectifier. We have a half controlled and the full controlled. If uncontrolled, we have a half wave as well as a full bridge. And same way, you have a full control, we have a half wave and full bridge. So all those topology will be discussed.

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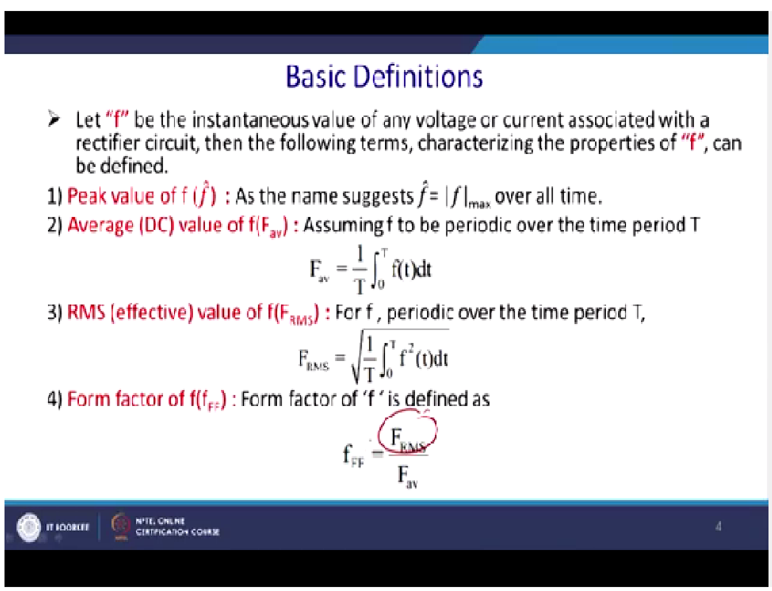

First we will take out actually the single phase. So let f be the instantaneous value of any voltage and current associated with the rectifier circuit. Then following terms, characterizing the property of f can be defined. The peak value of f. As the name suggests f= mod f max for all the time.

Similarly, average DC value, that is Fav, assume f to be periodic over the time period T. And Fav will be actually you have 1/T 0 to T f of dt. And if it is RMS effective, then f will be periodic over the same thing and the expression of the RMS will be under root 2 1/T 0 to T f square dt. Similarly. we will define the term form factor as f defined by f of F FRMS/Fav.

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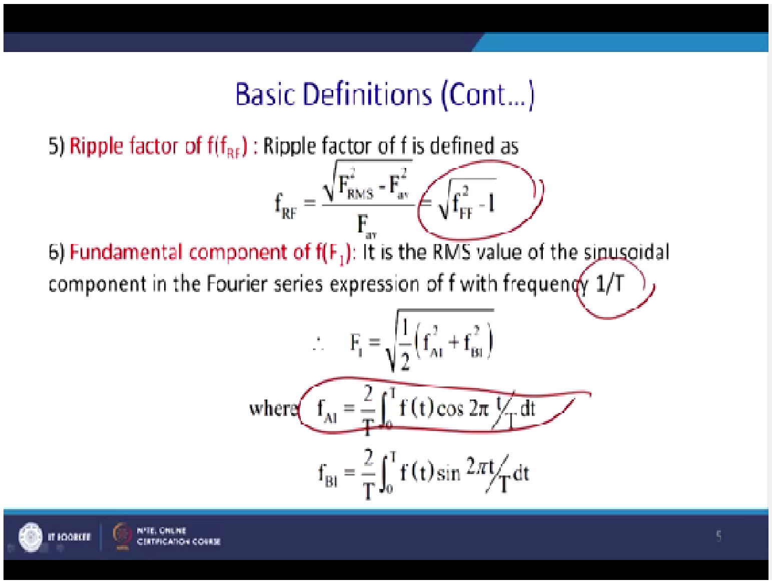

Similarly, we will define the ripple factor that is basically; form factor is a ratio of basically, the RMS is associated with the AC and average is associated with the DC since in any periodic functions, if it is bipolar in nature, average value comes out to be 0. So form factor is basically says that the ratio of actually AC versus DC. And another aspect is the ripple factor. Ripple factor is given by fRF.

So if I put I, then it is for the current ripple. If I put voltage, if it is a voltage ripple, that is FRMS square-Fav square/Fav. So ultimately it comes out to be basically the form factor square-1. And fundamental component F1, since it is contaminated with the harmonics, the inputs side we wanted to know what is the fundamental value of the fundamental component. And in our case, what will be the 50 Hz component of it.

Its RMS value of the sinusoidal component in a Fourier series expressions of f will be frequency

1/T because you have a sine and cos component. So it will be fA1 square+fB square. Similarly, we can calculate the term fA1 and fB1. These are basically the Fourier components. So in the same we have find it out the Fourier series coefficients, same way we can do it. So it is 2/T 0 to T ft cos 2pi/Tdt.

And similarly for fB1, we will have instead of cos, we have a sin term. Now for Kth harmonic, if I wish to know because there is a symmetric generally different kind of harmonics are present for the different kind of system. Sometime actually triplet harmonic is absent. Sometime actually we have harmonic content with a 6n+-1 and is fast, 5th and 7th, there after 11, 13 and so on.

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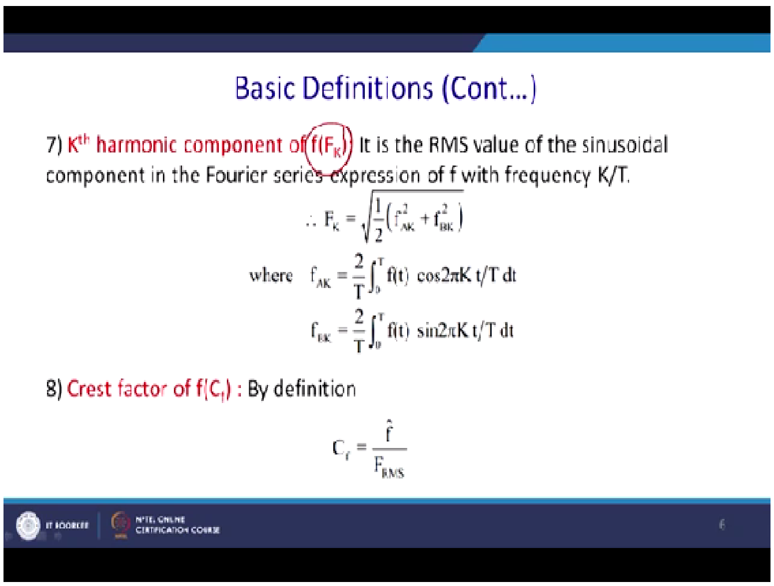

So if we wish to calculate the Kth harmonic component of this Fk, it is the RMS value of the sinusoidal component of the Fourier series expressions of f with frequency K/T. So Fk=under root of 1/2fAK square+1/2BK square. So from there, we can calculate the result fAK=2/T 0 to T ft cos 2 piKt/Tdt. Similarly, you can have the sin term that is basically 2/T 0 to T ft sin term. SO there will be a definition called Crest factor. Crest factor is by definition is (()) (09:00) f/FRMS that is the peak value/RMS.

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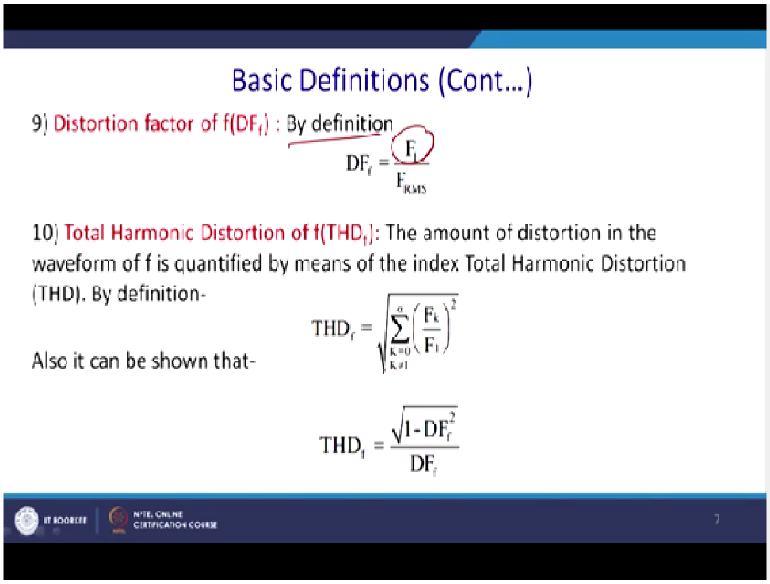

Similarly, we will have a distortion factor. Distortion factor is given by basically by definition, it will be F1, that is the fundamental component, /RMS will give you the distortion factor. And another term is actually total harmonic distortion. This is a very important classifier. We want that actually now I quickly practices says THD of the input current or anything equal to be a specified limit.

The amount of the distortion in the waveform, f is quantified by means of the index total harmonic distortion is given by THD=under root of actually K=0 to infinity Fk/F1 square and from there, actually we can derive, students are requested to refer to the any standard book and the derivations will be there. So we can find it out the THD=under root of 1-DF square/DF. So these are few terms we can use very frequently while analyzing the single phase and the 3 phase converter.

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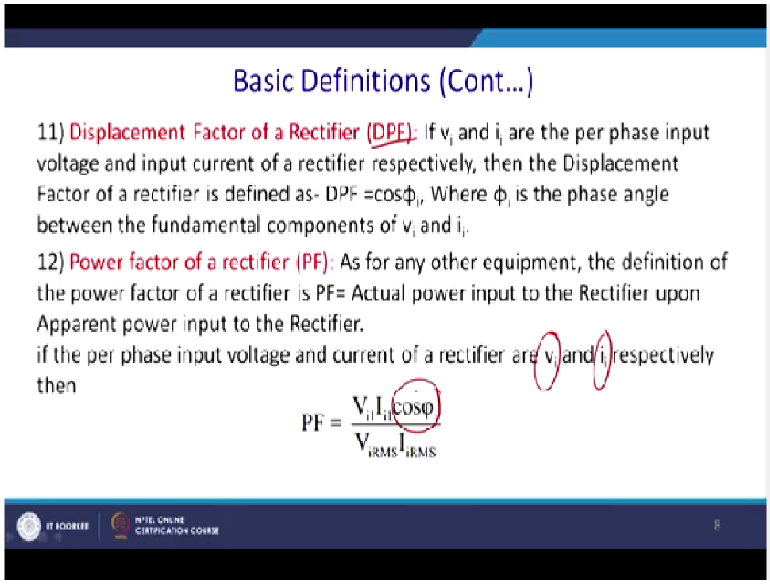

Another is the displacement power factor of the rectifier, that is DPF. Let us say if vi in a phase, an amount of the voltage and current of the rectifier are actually phase shifted, then the displacement power factor or rectifier is defined as that is cos phi 1/phi 1 as the phase angle between the fundamental components and current and the voltages. Let us understand what does it mean by this?

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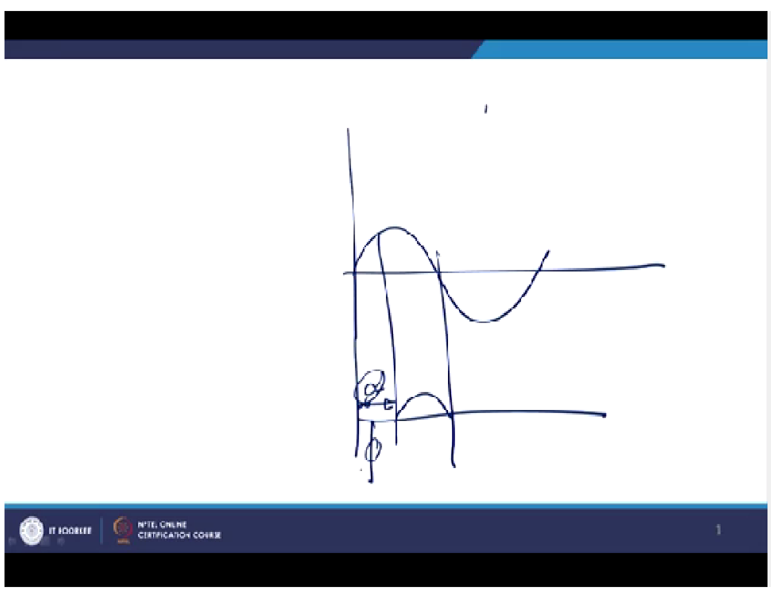

So let us consider that you know actually this is the sinusoidal voltage and you know you were triggering thyristors. So it will be delayed by an angle alpha. So current will start conducting from here. So then there will be delay. So this delay corresponds to alpha and that if you say that is phi, then let us go back and understand this definition.

If vi and ii are the phase input voltages and current of a rectifier respectively or converter, then displacement factor of the rectifier/converter is defined as DPF=cos phi i, is the phase angle between the fundamental component of the vi and ii. So we assume that voltage only have fundamental and it has lot of harmonics. So if you actually whatever its fundamental phase difference with the fundamental voltage, that will be actually defined as DPF.

Power factor of the rectifier, so as for any equipment, the definition of the power factor of a rectifier is the actual power factor of the rectifier upon the apparent input of the rectifier. That mean if the phase input voltage and current of the rectifier vi and ii respectively, then actually power factor will be given by Vi1 of fundamental ii1, that is the fundamental, *cos phi of i of the input power factor angle between the fundamental of voltage and current, which we have calculated here, /Irms and the Vrms.

So this will be the power factor in the rectification. These terms will be used and values will be, when assignment will be given to calculate those terms. If the rectifier is supplied from an ideal sinusoidal voltage source, then as I have drawn little bit ago, that is Vi1 and V fundamentals become same.

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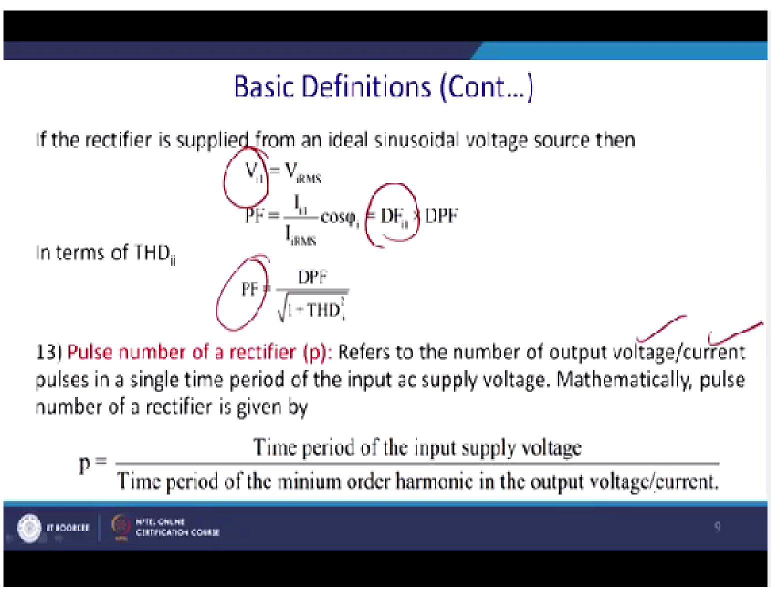

That is the PF, power factor will be Ii1/Irms*cos phi i, that is basically DF1*DPF. So we can replace them in terms of the THD. So power factor will be DPF/under root 1+THD square. Another important parameters of analyzing the rectifier and the converter is that, pulse number of a rectifier. Refer to the number of the output voltage current, whatever parameter you are analyzing, whether output voltage or current, pulse in a single time period in the input AC supply.

Mathematically, the pulse number of the rectifier is given by the time period of the input voltage supply/time period of the minimum order harmonic in the output voltage or current. So that required to be little understood. So it depends only mainly the 3 phase supply. So there we can see the different kind of pulses. How many number of pulses will be generating. So classification of the rectifier can also be done in terms of the pulse number.

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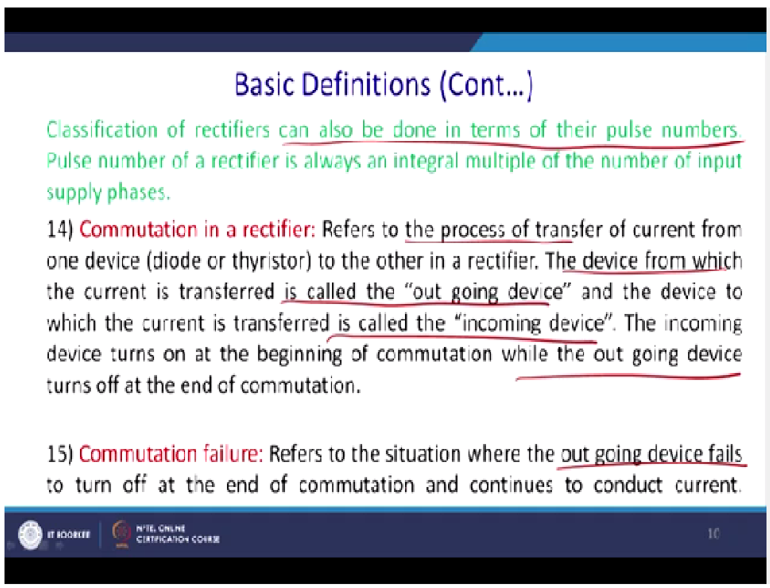

And for this reason, we have a different kind of pulse converter. In 3 phase, we say that it is 6 pulse converter. Because what happen you know we will discuss in detail while discussing actually the 3 phase circuit, if it is uncontrolled one pair of thyristors or diode or combination of the thyristors-diode in case of the semi-controlled, we will convert for the period of 60 degree. So you have a total actually 360 degree.

So you got a 6 pulses. So for this reason, classification of the rectifier can also be done in terms of their pulse number. Similarly, we can have actually a phase shifted by 30 degree and we can by a transformer and we can have a 12 pulse. Similarly, we have a 24 pulse. Similarly, we may have a 48 pulse. And we shall see the utility of it while reduction of the harmonic and the other characteristics that has been required.

Commutation in a rectifier. Rectifier to process the transfer of current form one device through the another device, mostly it is diode or thyristors, to the other rectifier. The device from which current is transferred to the other transfer, is called the outgoing device. And the device to which the current is transferred is called the incoming device. The incoming device turn on at the beginning of the commutation while the outgoing device turns off at the end of the commutation.

So we have sometime there is an overlap. We will come across it and we will see that what is the cause of the overlapping also. Commutation failure. It refers to the situation where outgoing devices fails to turn off at the end of the commutations and continues to conduct current and that is dangerous. Say you have a thyristors (()) (17:13). So you may actually some thyristors is going out and some thyristors comes in. Generally, if you have a, it may leads to the shocking of the (()) (17:26). So that is quite dangerous phenomenon.

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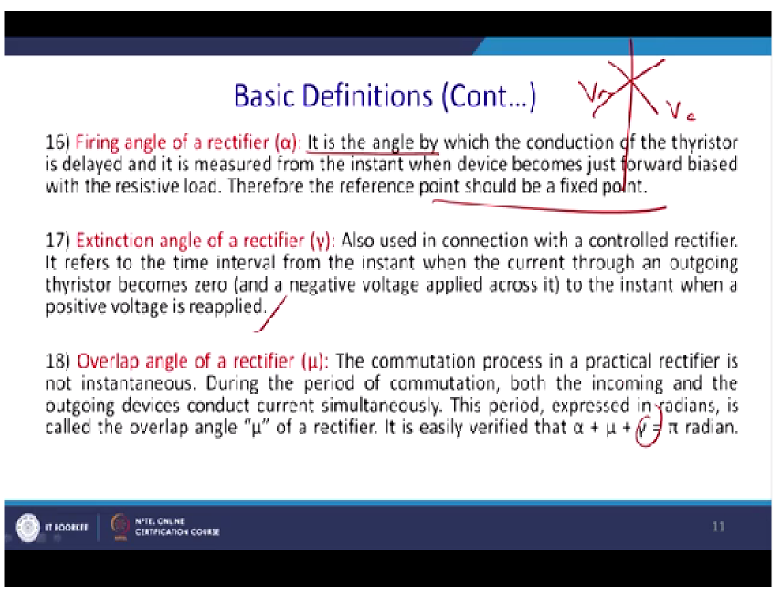

Firing angle of a rectifier, that is alpha, we have discussed in detail in the thyristors. So it is the angle by which the conduction of the thyristors is delayed and it is measured from the instant when devices become a forward biased with the resistive load. Therefore, the reference point should be a fixed point. So for the single phase, it is a forward 0 crossing and it is a for the 3 phase, in the place where actually this Vc and Va cross, so that place is considered as a firing reference.

We can start calculating firing reference from that point for the 3 phase. But today, our discussion will be mainly on the single phase. Extinction angle of the rectifier or converter. Is also used in connections with a controlled rectifier. Refers to the time interval from the instant when the current through the outgoing thyristors becomes 0 and the negative voltage is applied across it to the instant when a positive voltage is applied.

So within that time actually, that is said to be the extinction angle of the converter or rectifier, overlapping angle, that is called mu. it arises though we favour contradictions with our first assumption. We have assumed that actually source does not have an impedance. It comes into the picture when source got an inductance. Commutation process in a practical rectifier is not instantaneous.

During the period of commutation, both incoming and the outgoing devices conduct current simultaneously for a small period of time. This period is expressed in radians. All angles are expressed in radians and is called the overlapping angle of the rectifier and easily verified that alpha+mu + this actually the extinction angle, that should be equal to the total half cycle of the period that is pi. And generally this mu will be larger if there is a huge source inductance.

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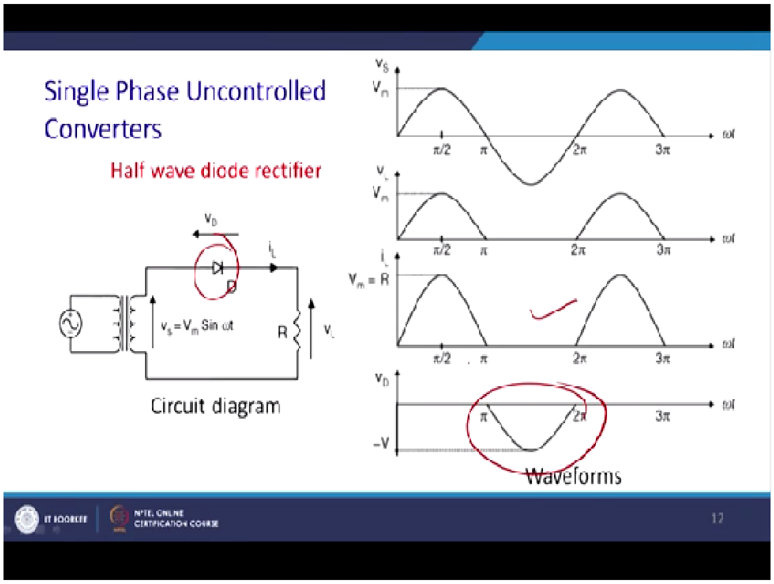

Now let us come to the first simplest circuit configuration that is single phase uncontrolled converter, half wave diode rectifier fitting a resistive load. So what happens here? Actually diode has to block the peak reverse voltage. So what happens when it conducts? So it has to be blocked the peak reverse voltage and this is basically the voltage across the load. And this is the voltage across the diode.

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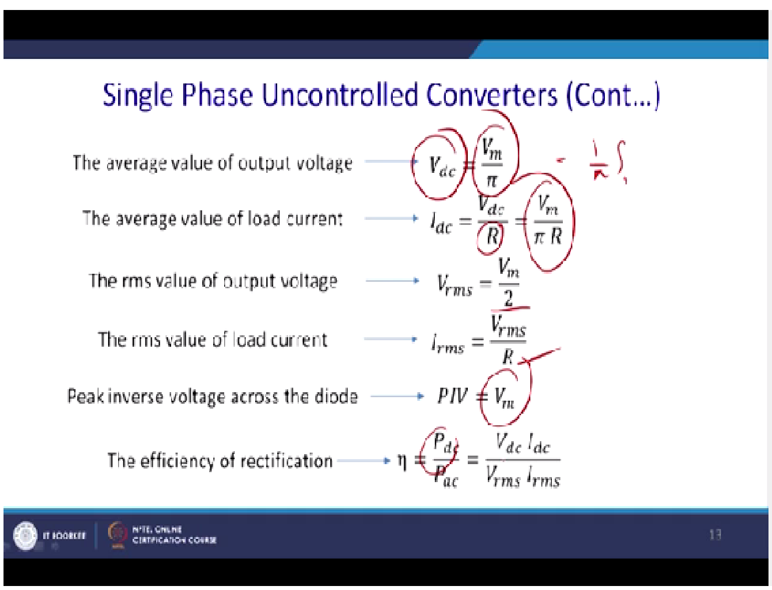

Now for a simplest circuit, let us calculate the parameter. Now we can calculate this parameter that is actually the average value of the voltage which we have shown there. So it is 1/pi 0 to pi and so on. So you get Vm/pi for the half wave for the single phase uncontrolled. Average output load current, you divide it just it by R, you get this value, Vm/pi R.

RMS value, you will get Vm/2. RMS of the load current, definitely Vrms/R, you get it. And the peak inverse voltage across the diode, will be Vm, that is what we have seen in the previous slide. And the efficiency of the rectifier is Pdc/Pac, so that will be Vdc*Idc Vrms*Irms and you can calculate what should be this value.

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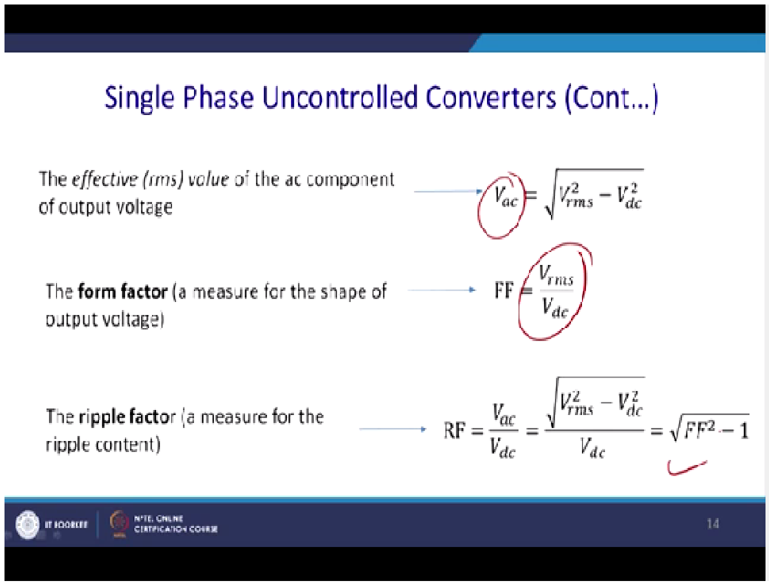

Similarly, effective rms value of the ac component will be Vac Vrms square-Vdc square. So Vdc is quite actually small for this is actually, this is a considerable amount of the ac inside it. The form factor, it is Vrms/Vdc, that is also high. And also ripple factor is Vac/Vdc, you can form it, that is form factor square-1, that will be a ripple factor that also will be quite high.

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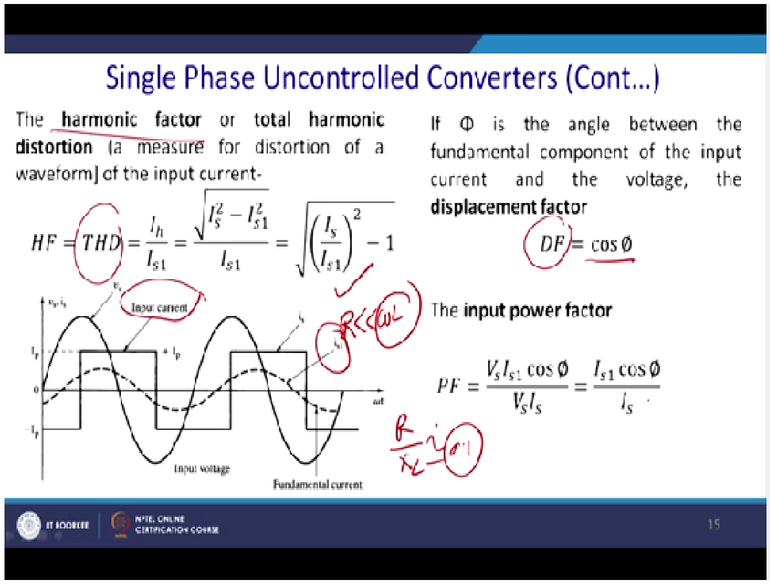

Now single phase uncontrolled converter. Total harmonic, the harmonic factor or the total harmonic distortion that is an important parameter for the current or the power quality. Measures of the distortion of the waveform of the input current that is THD=Ih/Is1, that is Is square-Is1 square/Is1. Ultimately you will be get this value. Essentially, if it is a very high inductive load, then input current will get this form. Otherwise, it will be Vm/R. So that will be different. So this will be applicable when actually R is much less than basically XL.

Generally, if R/XL, this ratio is actually around 0.1, then we can say that you know load current, current through this load almost constant and the input current will have this kind of profile. And there we are coming into the analysis, let us say. And ultimately this is your fundamental of the input current, Is1. And this is your input current. So from there, you can calculate the value of the other parameter that is DF cos phi and the power factor and other parameter also.

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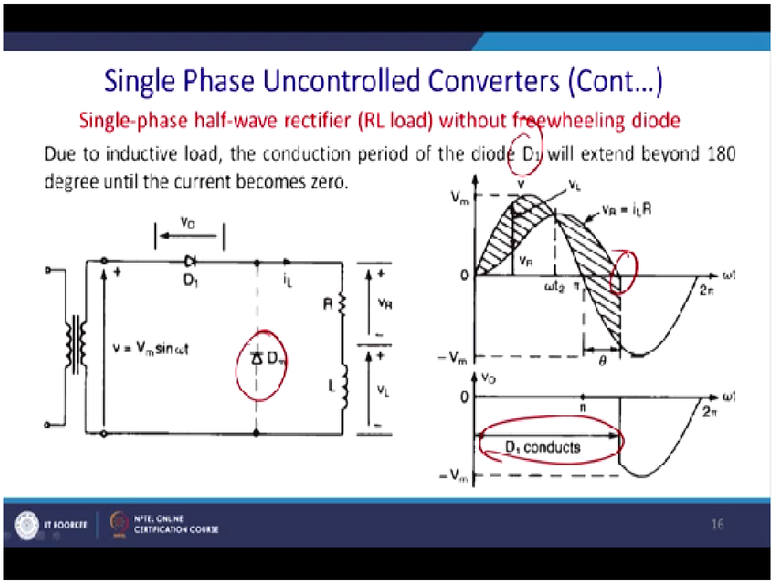

Now let us consider a single phase uncontrolled rectifier RL load with the freewheel. We have seen that different kind of topologies of the converter in our previous class with SPST switches. So you have got a diode and thereafter you got a VL and VR. So what happens, due to inductive load, the conduction period of the diode, D1, will extend beyond 180 degree because current will still continue to, after 180 degree, until the current becomes 0.

So this is the point where actually current becomes 0. This is the point where diode D1 conducts if this thing is absent. Now what happens, if it is actually closed or it has been put into the circuit?

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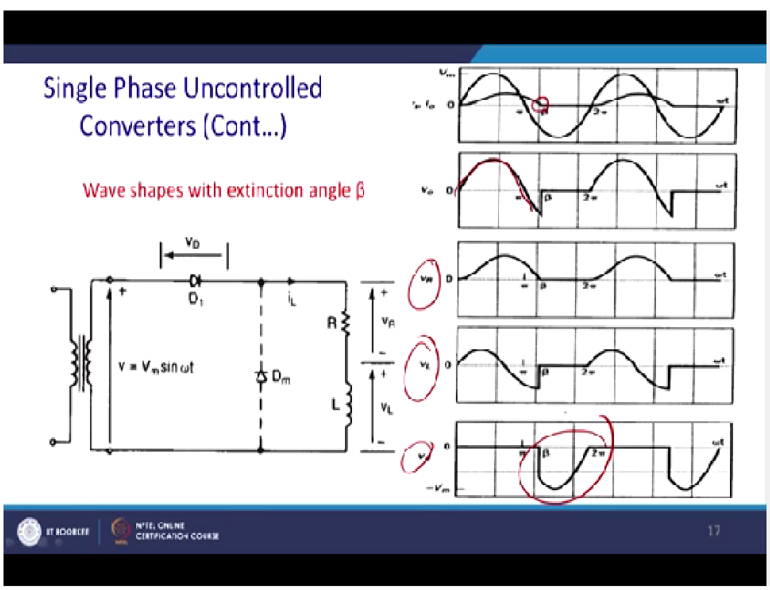

Then what will happen? Then there will be a change in the circuit. So this is the Vm and ultimately it will conduct till this time. Thereafter, there will be no negative input is associated with it because you know output voltage will come like this. And till actually the angle beta and this is actually the VR. VR will be basically the voltages across this actually the resistance of the load. VL is the voltage across the inductor, so you can see that change in the polarity takes place.

This is basically the VD. Ultimately when it conducts, so it is we assume that actually forward voltage term of this device is almost negligible and equal to 0. Then it is blocking this voltages of maximum Vm and this continues. So this is actually the RL load. Now what will be the average value of the output voltage, here?

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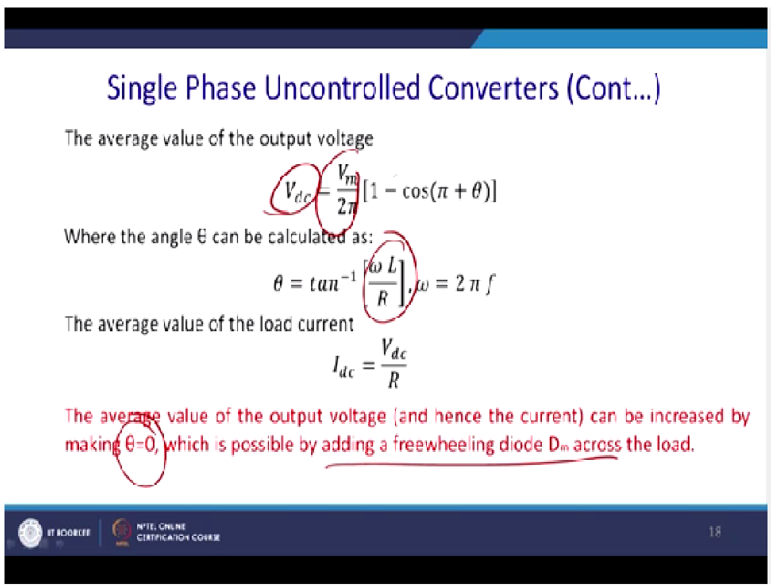

So we can calculate, you see that how it will change. So Vdc will be actually Vm/2pi 1-cos pi+theta where theta can be calculated basically that depends on basically this omega L/R ratio. And where omega is the supply frequency of the source. And from there, actually you can calculate the amount of the Vdc will come actually as the average value. And average value of the current definitely once you calculate, because the inductance does not contribute anything. Once you calculate the Vdc, divide it by R, you will get Idc. So average value of the output voltage.

And hence the current can be increased by making theta=0 so that this value becomes basically

-1 or -12, so you approaches to the resistive load and is Vm/pi which is possible adding a freewheel diode Dm across the load. So what does it do, you know? This diode with a rectifier, if you put a freewheel diode, will increase your average DC value available to the load. So this is the one utility of it. So for this we prefer to have freewheel action in a AC to DC conversion kind of applications.

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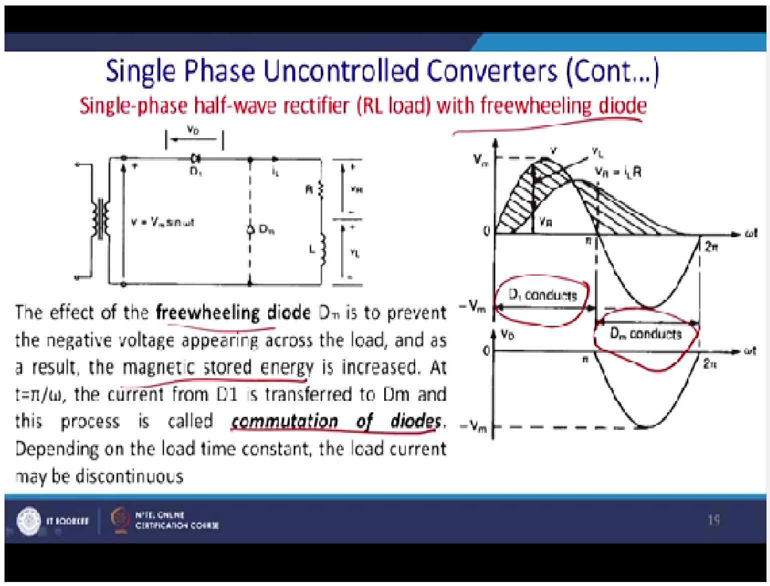

So single phase uncontrolled converter with RL load with a freewheeling diode, we are actually discussing. The effect of the freewheel diode Dm is to prevent the negative voltage appearing. Once the negative voltage appearing means actually it makes it more DC or more ripple. Negative voltage appears across the load and as a result, magnetic energy stored into the system increases at t=pi/omega, the current D1 transferred to Dm and its process called commutations of the diode.

So you take an example of it. So this is basically the Vm and this is basically the VR and this is the point where actually D1 conducts and this is the point where, actually assuming that very high load current, then only it happens. Otherwise we will have a discontinuous mode of conductions. So thank you for your attention. We shall continue to discuss AC to DC conversion in our next class. Thank you.