Advance Power Electronics and Control
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Lecture – 12
Three Phase Converter I

Welcome to our NPTEL lectures on advance power electronics and control. Today we are going to discuss three phase converter. We have discussed in details with a single phase converter now we are discussing with the three phase converter. We have we started with the same fashion as we have started the single phase converter.

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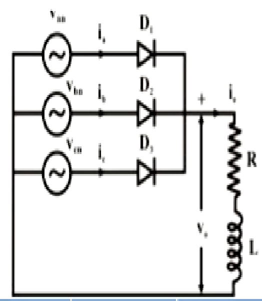
Three Phase half wave uncontrolled Rectifier



Voltage / Mode	V_{D1}	V_{D2}	V_{D3}	V_0
D_1	0	V_{ba}	V_{ca}	V_{an}
D_2	V_{ab}	0	V_{cb}	V_{bn}
D_3	V_{ac}	V_{bc}	0	V_{cn}

Since actually most of our supply is three phase three wave or four wave system and it makes sense for the high power applications for the dc motor mostly this kind of applications we convert directly three phase to dc. So this is the application part of it so we use this is basically three phase half wave uncontrolled rectifier fitted through the diodes and it is fitting data I assume that RL load.

So what happened? you can see that how conduction takes place. So the D1 will actually when it will conduct basically that would about to stop across it would be 0 and then you will get a voltage of Van across this diode RL. If D2 is conducting, then at that time basically it will block the voltage when D2 is conducting D1 will black the voltage of Vba it would be negative voltage and similarly it will block the voltage of the Vca.

So similarly when diode 2 was conducting so the third diode will block Vac sometime Vbc and once actually diode 3 is conducting then load will get the voltage Vcn. So load will get the voltage depending on the 180 degree mode of conduction for 360 degree Van Vbn and Vcn most positive phase will conduct so accordingly you will get the three different voltages.

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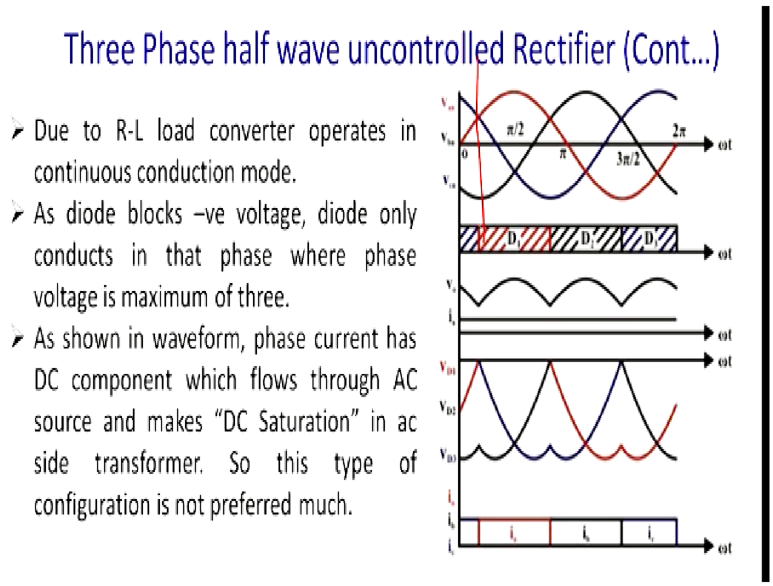

So let us see how it works this is the actually the three phase voltages and our starting point will be actually this point where the voltage A actually a crossover the voltage C and thus voltage A become the actually most positive. You can see till this region that when actually pi/6 to 150 degree actually most positive phase is Van. So definitely this will conduct for actually pi/6 to 150 degree so this will conduct. Similarly, after that you know Vb actually at this point crossover takes place

so since there is only a single diode in upper limb so crossover takes place and it will we have a crossover at this point where V phase becomes most positive place and thus it well conduct in this point. Similarly, Vc will conduct after actually the period to 70 degree and so on. So till this time D1 conduct till this time D2 conduct till this time D3 conduct and thereafter till this time D3 conducts and this is the output voltage. We will have a third harmonic oscillations we can find it out by analysis.

And this is actually the voltage blocking state or the different diode and this is VD1. VD1 will conduct actually this point to this point so it will be blocking the voltage red one. Similarly, VD2 will have this kind of fashion so and same way VD3 so it will conduct when actually at this instant so you will get a negative. So phase a or red phase will conduct for pi/6 to 150 degree for another 20 phase b and another 20 degree phase c.

So thus due to the RL load the converter operates in a continuous conduction mode if you assume that load current is quite high. As diode blocks the negative voltage the diode only conducts in that phase where the phase of voltage is maximum of these three. As shown in the wave form the phase current has DC component which flows to that AC source and makes DC saturation in the ac side of the transformer.

For this you know this kind of configuration we do not prefer so it may lead to the saturation of the input transformer. So three phase halfwave uncontrolled rectified we can see that what are the different values what we have seen in the say actually single phase.

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Three Phase half wave uncontrolled Rectifier (Cont...)

Input three phase voltages

$$V_{an} = \sqrt{2}v \sin \omega t$$
$$V_{bn} = \sqrt{2}v \sin\left(\omega t - {}^{2\pi}/_{3}\right)$$
$$V_{cn} = \sqrt{2}v \sin\left(\omega t + {}^{2\pi}/_{3}\right)$$

Output average and RMS voltages

$$V_{oavg} = \frac{3}{2\pi}\int_{\pi/6}^{5\pi/6} \sqrt{2}v \sin \omega t \, d(\omega t)$$

$$V_{orms} = \left[\frac{3}{2\pi}\int_{\pi/6}^{5\pi/6} \left(\sqrt{2}v \sin \omega t\right)^2 d(\omega t)\right]^{\frac{1}{2}}$$

Output average current and Input RMS current

$$I_{oavg} = \frac{V_{oavg}}{R}$$

$$I_{iRMS} = I_{aRMS} = I_{bRMS} = I_{cRMS} = \frac{I_o}{\sqrt{3}}$$

$$\text{Input Power factor (IPF)} = \frac{\text{Active powe Output}}{\text{RMS power Input}}$$

$$(IPF) = \frac{V_{oavg} \times I_{oavg}}{3 \times V_i \times I_{iRMS}}$$

So we have actually Van Vbn Vcn these are basically phase voltages and so output voltages you can see that from pi/6 to 5 pi/6 that means actually 30 degree to 150 degree. It will get a voltage of Van and so write the Van and you calculate over it similarly you can calculate actually output RMS voltage that is basically you get three such cycle so it does multiply by 3 same way for RMS value actually multiply by 3 pi/6 to 5 pi/6 root 2v sin omega t square dt.

So you can get this actually the values for this RMS value as well as the average value you can calculate I had left it to the student to calculate. So similarly you can have the load current so that is V average/R similarly i RMS = it should be same input RMS that will be same for since it is a balanced system Ia Ib Ic should be same and we can find it out that it tell value will be actually i0/root 3.

So input power factor that is active power output which we have shown also in a single phase system by RMS input. So that is basically IPF actually voltage average*current average/3*Vi*RMS so from there you can calculate physically the IPF.

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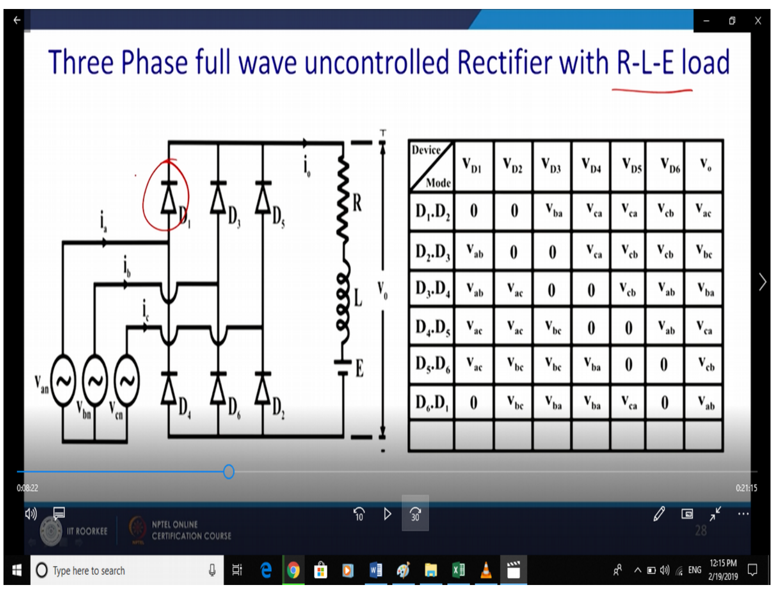

Device / Mode	V_{D1}	V_{D2}	V_{D3}	V_{D4}	V_{D5}	V_{D6}	V_o
$D_1.D_2$	0	0	V_{ba}	V_{ca}	V_{ca}	V_{cb}	V_{ac}
$D_2.D_3$	V_{ab}	0	0	V_{ca}	V_{cb}	V_{cb}	V_{bc}
$D_3.D_4$	V_{ab}	V_{ac}	0	0	V_{cb}	V_{ab}	V_{ba}
$D_4.D_5$	V_{ac}	V_{ac}	V_{bc}	0	0	V_{ab}	V_{ca}
$D_5.D_6$	V_{ac}	V_{bc}	V_{bc}	V_{ba}	0	0	V_{cb}
$D_6.D_1$	0	V_{bc}	V_{ba}	V_{ba}	V_{ca}	0	V_{ab}

Now, since we are discussed that this mode of the actually configuration is not preferred because it leads to the saturation of the transformer and the rate of the conversion of the power is very low generally use full control devices. The three phase full wave uncontrolled actually rectifier with let us consider the R L E load. Now in this condition one diode from the upper leg and another diode from the lower leg will conduct.

And will actually since or one diode will conduct for the period of 120 degree so we have a different way to actually nomenclature it. Since D1 will conduct after 180 degree of its conduction so for this is and you know actually nomenclature will have a difference of 3. So that is D1 and D2 that is D1 and D4 will be the first leg and similarly D3 and D6 will be the second leg and D2 and D5 will be the 6 legs the combination is the odd combination will be up.

So D1 D3 D5 and D4 D6 D2 if you do like that then you will find that actually this sequence will come. If you name it this way actually this sequence will come. So first phase 60 degree so of course we start from the point where actually phase A and C get intersects at this point and we have waited from this point for 60 degree intervals. So it is it starts from pi/6 to pi/2 so what happened in that configurations.

Diode D1 and D2 conducts and when diode D1 and D2 conducts for this is you can see that these are 0 so and there and it is the ones actually there after what happened diode D2 D3 conducts there after D4 D3 conducts D4 D5 conducts D5 D6 conducts and then D6 D1 conducts then after D1 D2 conducts. So this will actually be the column you will get 0s so here D1 D2 conducts therefore D3 D4 start conducting it is blocking the voltage of vba and vca.

Then it is blocking the voltage of actually vca and vcb and so on. So these are the pair of voltages that you continue to block. And accordingly you can actually find it out which voltage it is blocking and you can get the output voltage accordingly. So for this you know in load voltage will be delivered for this first 120 degree by actually D1 and D2 for 60 degree D1 and D2 and thus you get a voltage of actually PSE>

Similarly, you know when D2 D3 conducts you will get a voltage of bc. then after when D3 D4 conducts you get ba when actually D4 D5 conducts you get ca. When D D6 conducts again you will get actually reverse cb then when D6 D1 conducts you get ab and so on. So this cycle will continue and one pair of actually diode will conduct a 60 degree and thus one single diode will conduct for the period of 120 degree.

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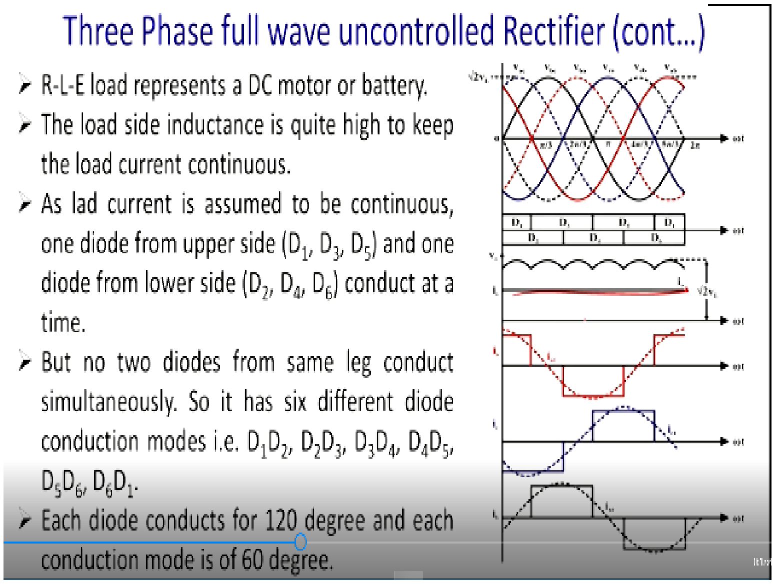

So this is actually a wave form so we consider the RLE load represents the DC mode or the battery and the load side inductance is quite high to keep the load current continuous. So we have a ripple but actually this is a Idc value and the load current assumed to be continuous one diode from the upper side is D1 D3 D5 and another diode from the lower side will conduct at a time. But no two diodes from the same leg will conduct simultaneously

Otherwise it surely leg shorting will take place ultimately no voltage will be delivered at right to the load. So it has 6 different diode mode of conduction these are D1 D2 D3 D4 and so on. Each diode conducts for as I told you 120 degree and a pair of diode will conduct for the 60 degree. So this is the wave form so D1 will conduct actually thereafter D3 will come into the picture thereafter D5 thereafter D1 again.

Similarly, at this time D1 and D2 will conduct thereafter after actually at this point you know D2 will be actually D1 will be the outgoing Thyristors at 60 degree and D2 will be conducting and D3 will be the inductance. So similarly it will conduct like that and since there is a 6 such changes in 360 degree so you will have a 6 phase wave form and this value is given by under root of 2 VL and we assume that load current to be constant.

And this will be the pattern of the input current. Input current will be the stepped square wave so since actually this time D1 conducts so for this what will happen current will be positive. There after interval you can see that D4 once start conducting at this region so we will get a negative pulse from phase A. Again there is another pulse of 60 degree again it will pick up. So in a cycle of 360 it will conduct within positive or negative cycle for mode of 120 degree there will be a assume of in between 60 degree.

So there is sufficient time to actually commute similarly this is a current for phase B and phase C and this is the wave form drawn this is a fundamental of the input line currents.

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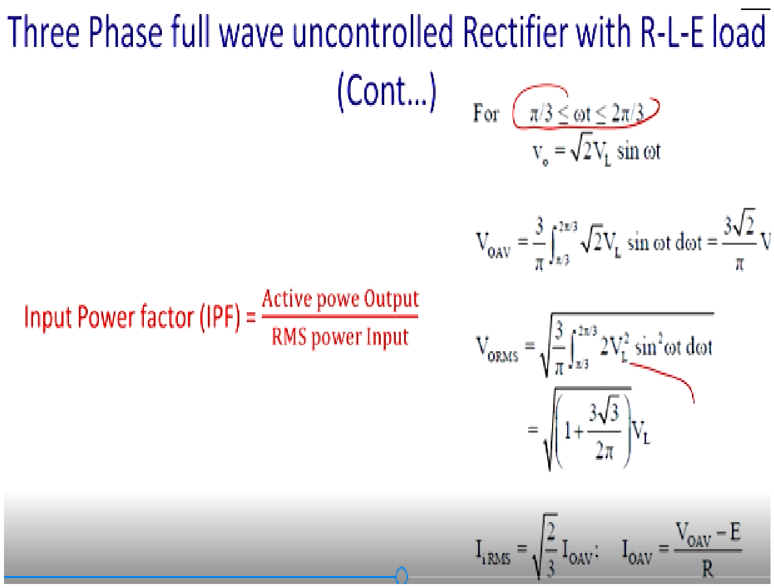

Now few parameters comes into the pictures now for as we start from this actually pi/3 to 2 pi/3 and AC is the amount of the voltage coming into the picture. So output voltage will be given by 3 pi/ 3 to pi 3 VL sin omega t from there we can get this basically the value of the RMS voltage. RMS voltage you can find it out at this 1+3 root 3/2 pi*VL. So from there of course you know you have a RMS voltage just divide by the you can find it out the current.

So current will be basically root 2/3 * which is assumed to be cost term that is output load current and the output load current is given by this basically Vab so that is the average voltage that is root 3/2 /pi *Vl -E /R. So from there we can calculate the RMS voltage as well as the RMS current. so input power factor for IPF will be the active power output/RMS power input.

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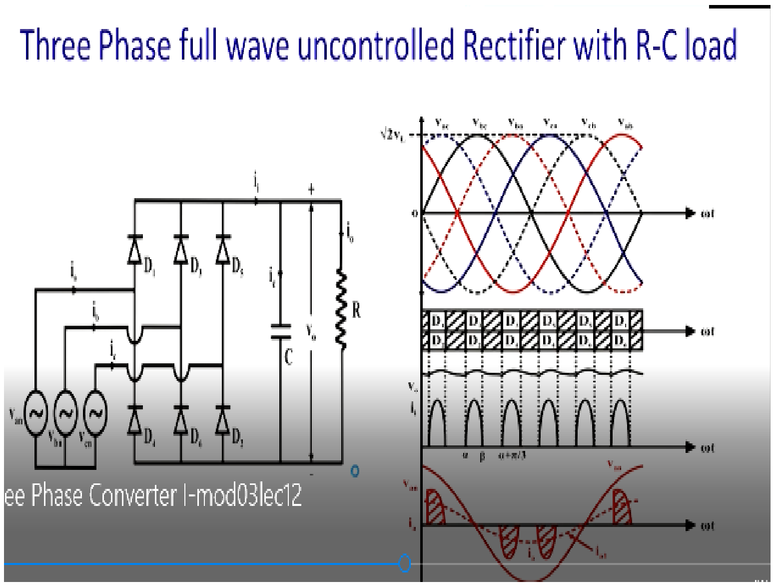

So now let us see that what happen if this actually three phase full wave uncontrolled rectifier fitting in RC load that is quite common you know actually most of the application nowadays are adjustable speed drive. In case of the adjustable speed drive actually you can have a variable kind of load and what happen you know you fit to an inverter to run it in the drives in a different manner.

And for this kind of wave form is quite common in case of this actually in different kinds of industrial applications and this capacitor essentially actually filtered out the ripple and gives you more or less a constant DC voltage. So similarly this is a three phase wave form as we have discussed so here what will happen till the input voltage this input voltage Van is more than Vac that will not conduct.

So output voltage you know tit will hold by the capacitor this will have this kind of value you will have a ripple that depends on the load current as well as the size of the capacitor. So due to that what will happen if so till this voltage is more than this voltage diode will not be forward by us and thus no current will flow and thus diode current might be picky. So it will conduct or the D1 D2 will conduct for this pretty small internal on time.

Let us see that it is alpha +2 beta similarly you know current will have this kind of choppy profile and it is quite disturbance and it is a unique problem to be solved for the this is one of the issues with the power quality because you can see that actually it gives a choppy current and you have an actually a sinusoidal voltage. So this is a problem once you have an actually artsy kind of load and nowadays its prevalence

Now let us come to the three phase half-wave controller rectified. Now since most of the application we required are constrained source in DC kind of application for this is an we prefer to have a control rectifier.

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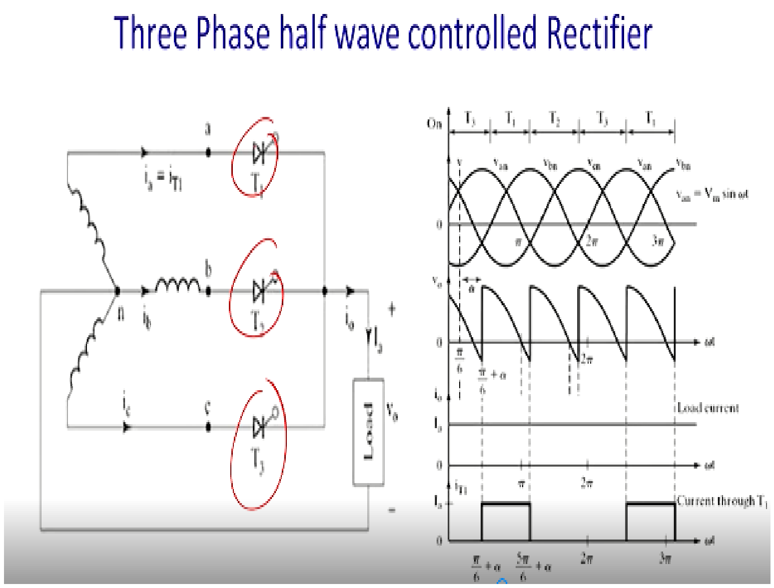

So there is a Thyristor iT1 and there is no difference in between the diode and the Thyristor we required to trigger the forward most forward Thyristor depending on the voltages and automatically other Thyristor will naturally commutate it. Because if this let us say that previously b phase was the most positive and Thyristor T2 was actually conducting the moment actually F has become more positive.

Or definitely the reverse bias will be applied and the thyristor will commute. So for this what we required to do let us assume let us start from the point where actually am is a most positive phase and it has been given at an angle delay angle alpha. So it will trigger at an angle alpha so that is the point where actually T1 will be triggered on it will continue till conduction there after you know when it is actually you see that actually most positive phase is actually T2 phase b.

Then T2 decode so each thyristors will conduct for a period of the same wave 120 degree and so this will be the profile of the load voltages and like that you know controlled rectifier you get since it is a we assumed that actually this load is RL type of load for this is the negative portion of that load voltage will come into the picture and we assume and since this is a lot current is assumed to be constant so we will have a input current will be given by like this.

And but problem of this halfwave rectifier or the converter is same because you can see that and actually this load current is positive in input side and that leads to the saturation of the transformer so for this is an it is not at all used when most of them we are phasing out it same way we have a calculations, we can do the calculations that is a 3 pulses 360 degree cycles.

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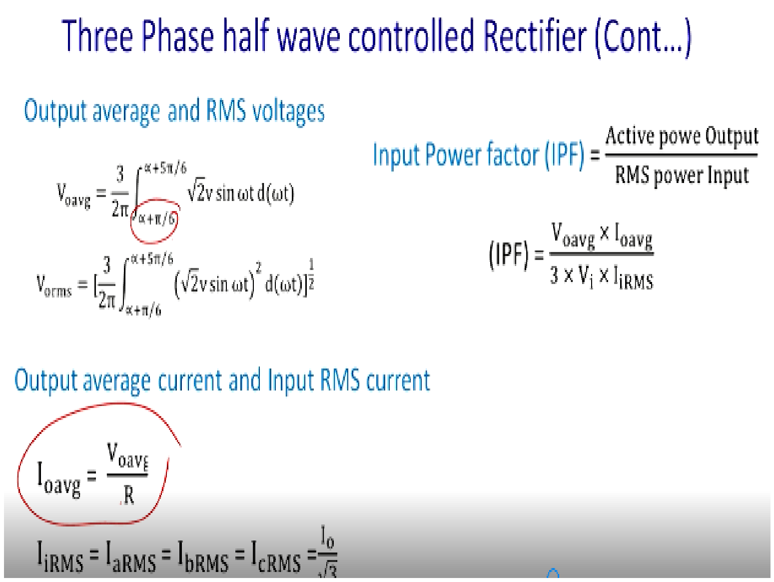

So it is alpha+ pi/6 to alpha +5 pi/6 from there we can calculate the vRMS and IRMS and ultimately from there we can divided it by R to calculate the average current and IRMS you will find that I0/root 3 by simple calculations since it is a square. So similarly we can calculate the input power factor that is V output average/ I output average *3*Vrms*Irms. So let us come to the more practicable solutions of the three phase.

And where load is assumed to be highly inductive three phase full wave rectifier and same the nomenclature we have used in case of the diode that is T1 T3 T5.

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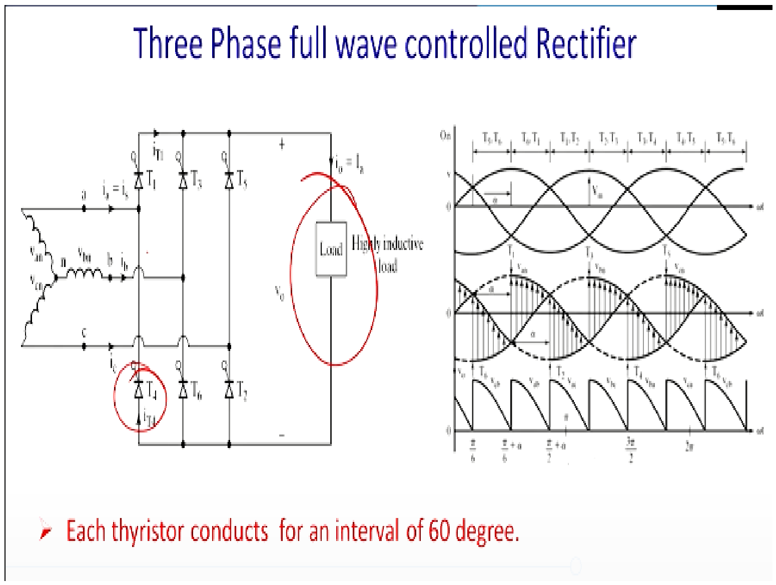

So since it will be conducting and one pair of Thyristor will be conducting for the period of 60 degree phi/3 and 1 thyristor itself will be conducting for the period of 120 degree and what will happen here in this case essentially we will have a same kind of actually nomenclature that is T1 T3 T5 are the upper thyristors and T4 T6 T2 are the lower thyristors. So you trigger the point where phase A and phase C are crossing over.

So given a delay angle alpha so you will start from this point so T5 will be the outgoing Thyristor from the top and so T6 and T1 is conducting. So you will get phase A B across the load. Similarly, there after T1 T2 is conducting and you get AC to the load there after you get T2 T3 is conducting you get CB to the load so on and frequently you will get so you can see that here it is inactive so you get Van into the load.

Similarly, you know you triggered this load Thyristor here there after you get Vbm to the load then you will get Vcn to the load. So here if you start from here so first you get Vab there after you get Vac across the load there after you get Vbc thereafter you get Vba there after Vca there after Vcb and this will continue. So this is the configuration of that full control bridge rectifier

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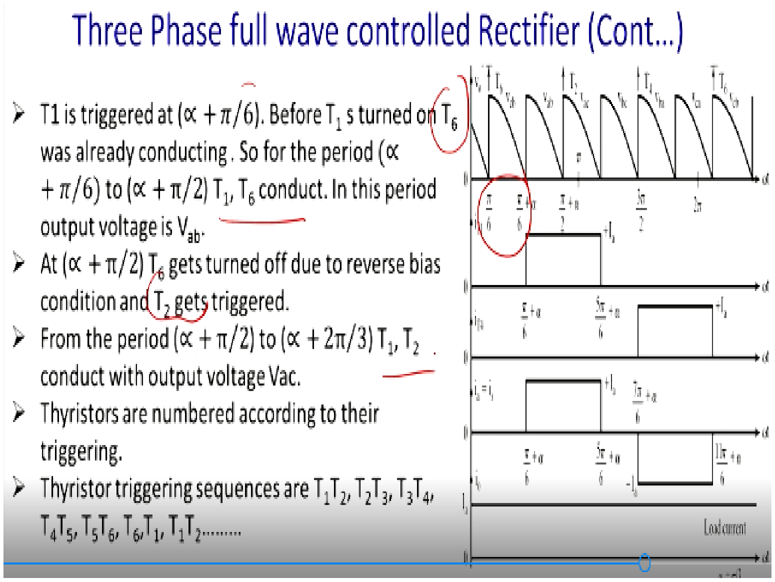

So here it is same as we have discussed in case of the diodes so it is triggered for an angle alpha to pi/6 before T1 is turn on T1 and T6 is conducting T6 is already conducting and T5 was the outgoing Thyristors. So the period alpha actually it is alpha + pi/6 to alpha + pi/2 where the point T1 T6 is conducting and this is the actually the configurations so you get cb there after ab and consequent voltages.

At alpha +pi/2 T6 gets turned off due to the reverse bias condition conduction and T2 get triggered. From this period actually alpha+ pi/2 to alpha +2 pi/3 T1 and T2 both are conducts. So Thyristors are according to be triggered in the sequence T1 T2 T3 T4 T5 T6 and so on and this is basically assuming that is a constant load current so this is the current through the thyristor T1.

And this is the current through the thyristors T4 that is the lower leg of the phase a and thus load current source current will be this and load current will be this since it is a positive or negative cycle so it can be used in case of the transformer also.

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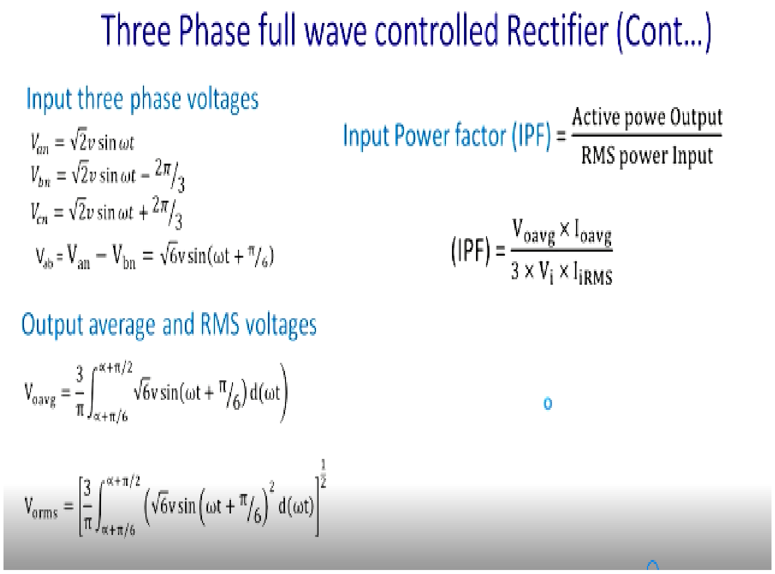

So it does not lead to the saturation on the transformer similarly we required to calculate that actually the Vrms and the average voltages. So students are requested to calculate this value you know actually this is a simple integrations and it is available in normal any textbook.

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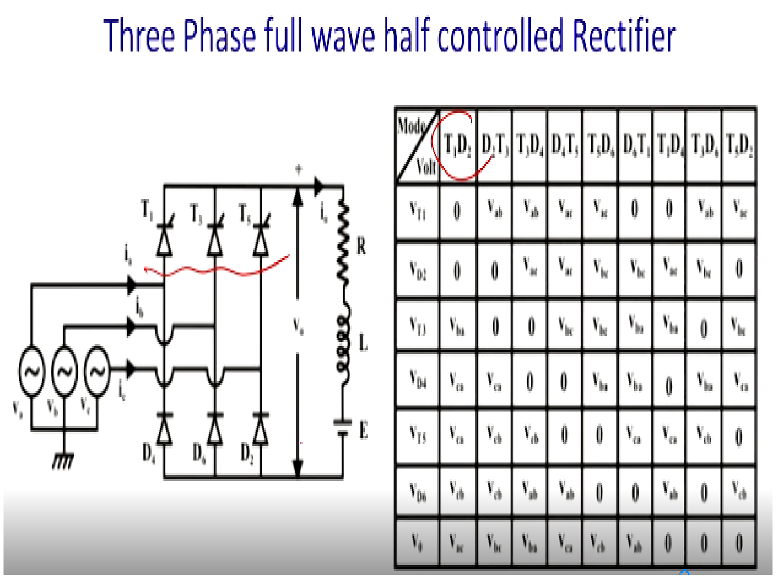

Mode / Volt	T_1D_2	D_2T_3	T_3D_4	D_4T_5	T_5D_6	D_6T_1	T_1D_4	T_3D_6	T_5D_2
V_{T1}	0	V_{ab}	V_{ab}	V_{ac}	V_{ac}	0	0	V_{ab}	V_{ac}
V_{D2}	0	0	V_{ac}	V_{ac}	V_{bc}	V_{bc}	V_{ac}	V_{bc}	0
V_{T3}	V_{ba}	0	0	V_{bc}	V_{bc}	V_{ba}	V_{ba}	0	V_{bc}
V_{D4}	V_{ca}	V_{ca}	0	0	V_{ba}	V_{ba}	0	V_{ba}	V_{ca}
V_{T5}	V_{ca}	V_{cb}	V_{cb}	0	0	V_{ca}	V_{ca}	V_{cb}	0
V_{D6}	V_{cb}	V_{cb}	V_{ab}	V_{ab}	0	0	V_{ab}	0	V_{cb}
V_0	V_{ac}	V_{bc}	V_{ba}	V_{ca}	V_{cb}	V_{ab}	0	0	0

So this is the pattern same way we have discussed in case of the diode now this is for half controlled rectifier or converter. So here upper legs will be Thyristors and lower legs will be diode. So you have a control over triggering the thyristor and automatically actually negatives phase will be triggered depending on the actually which phase is most negative. So thus what you can see that let us see that again nomenclature will be the same.

As used in case of the full control converter so it is D4 D6 D2 I so when T1 an D1 is conducting so voltage across the thyristors 1 is 0 and will continue till 60 degree that it is blocking the voltage Vab and ultimately what will happen though these are the voltage they will be blocking throughout it and so similarly when D2 is basically conducting and it will be conducting for the period of 120 degree.

So it will conduct till 30 degree to 150 degree thereafter other voltage will follow like that. So again it will be conducting here. Similarly, you can see that D3 will be conducting for the period here as well as here. So this is the case will be continue and its matrix will be actually featured him and accordingly it get a voltage.

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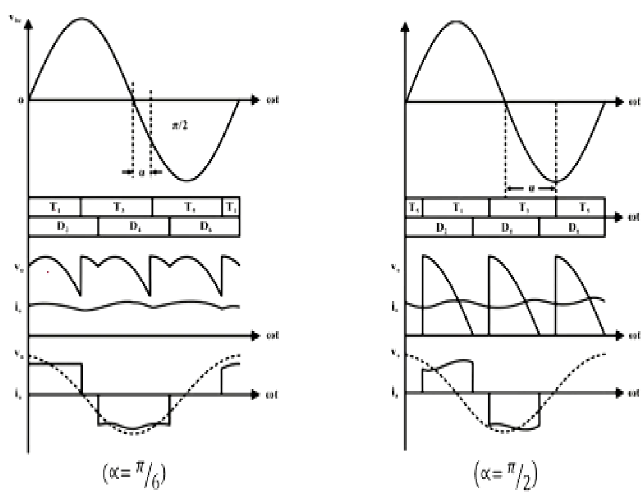
Three Phase full wave half controlled Rectifier (Cont...)



So this will be the pattern so T1 will be conducting for this period as shown here and we can apply a delay to it and output voltage since we can change the delay so output voltage can be changed depending on the profile and assuming that load current is almost constant and so this will be the actually the input current and this will be the fundamental. Same way if you have actually this wave form where have a large delay angle?

So then what will happen? so you can see that this will be the pattern first it will trigger with the T5 thereafter T3 T1 thereafter T3 thereafter T5 and but what will happen then you can find that actually lower half will continue as per the sequence so (()) (28:10) this leads to the actually a discontinuous voltage we had talked about discontinuous current. So we will have a discontinuous voltage when actually it will be discontinuous.

If the triggering angle will be more than 90 degree in case half controlled converter three phase half controlled converter. And this will be that this kind of way for full control this will be the continuous form. So pattern of the wave form will change till alpha =0 to 30 degree and thereafter alpha more than 90 degree. We shall continue our discussions with the three phase half controller with his mathematical analysis in our next class. Thank you.