Advance Power Electronics and Control
Prof. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology- Roorkee

Lecture – 11
Single Phase Converters III

Welcome to our NPTEL lectures on advance power electronics and control. This will be a third lecture on single phase converters. We shall continue with the single phase fully controlled converter; it will be half control device it is this Thyristor which will give a half wave control. Because it will trigger in a positive half cycle and negative half cycle it will be reverse biased and we are not supposed to use Thyristor while it is reverse biased so triggering should be off. So let us assume that it is typically feeding a DC motor kind of load for this.

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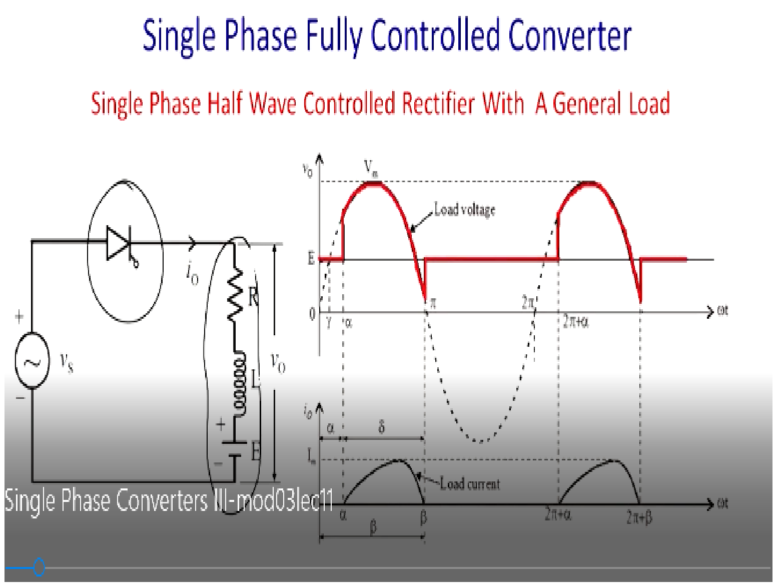

This is manifested by the R L E R is the resistance of the motor therefore they are huge filled it will be a shunt series motor that is been represented by L and the vacuum part will we actually pretty constant because it will run at a constant speed because electrical inertia is quite actually low compared to the mechanical inertia. For this is an actually vacuum may be proportional to the speed for this we can assume that vacuum is almost constant.

Or you can think of charging of a battery kind of thing also. So the red one indicates that load voltage with absence of the free wheel diode we will get a negative posture. It is triggered at an angle alpha then after it will continue till actually by pi there after we assume the discontinuous operation of the current. But due to this actually stored energy in the inductor current will be actually flowing into the negative direction.

There after once actually the energy is free then actually it will be automatically commutated then it will be off again the same cycle is repeated. But actual conduction angle is beta-alpha and where actually it is triggered at an delay angle alpha. Now we required to see there are few parameter to analyse that Lambda is basically is corresponds to Vm sin omega t. Vm sin lambda= basically the vacuum of voltage.

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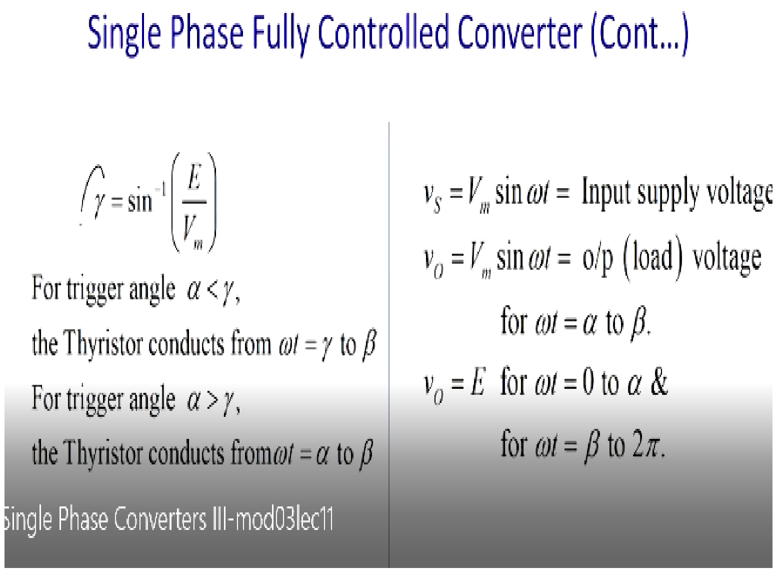

So in this case what will happen so lambda=sin inverse vacuum/Vm. So for the triggering angle there is a two conditions when triggering angle is actually < lambda then the Thyristor conduct for basically lambda to beta the conduction angle. And if alpha is actually more than that because still it is not actually what happened basically till the supply voltage is more than the vacuum Thyristor is not forward biased so for this Vm is triggered.

So Thyristor will not be conducting Thyristor required to conduct after actually it has reached the voltage > the vacuum. So for this same way the triggering angle alpha should be > lambda and the Thyristor conducts for an angle alpha to beta so vs= Vm sin omega t is the input voltage v0=Vm sin omega t for output voltage for alpha to beta and v0= vacuum for omega t =0 to alpha for this condition and for this negative half cycle that is beta to 2 pi.

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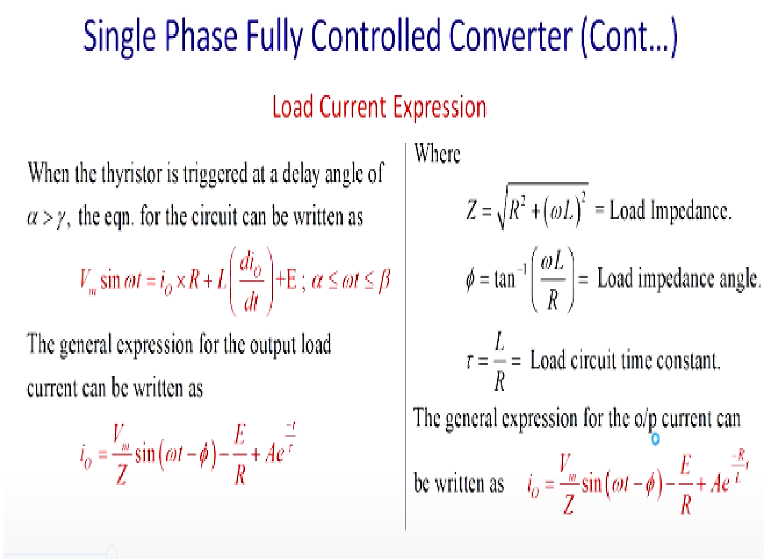

So we can actually find it out the conditions and we can write that actually differential equations to find it out the load current and its profiling it has been shown in the wave form. When the Thyristor is triggered at an delay angle of alpha, alpha is more than lambda then equations of the circuits can we give as Vm sin omega t =iR+L di/dt + the vacuum for this duration. Now in general expressions for the output.

So we can write that actually can solve this differential equation and i can find it out that that load current we will have Vm/Z sin omega t-phi we have discussed phi in previous class where actually phi is actually this one tan phi= actually omega L/R so E/R+ this term A e to the power -t/tau but tau is an electrical time constant of the system. So this is the Z value Z is given by this thing and tan phi is actually omega L/R.

Similarly, the tau time constant is L/R the load circuit constant and general expression for this thing if we substitute then we will have actually this value.

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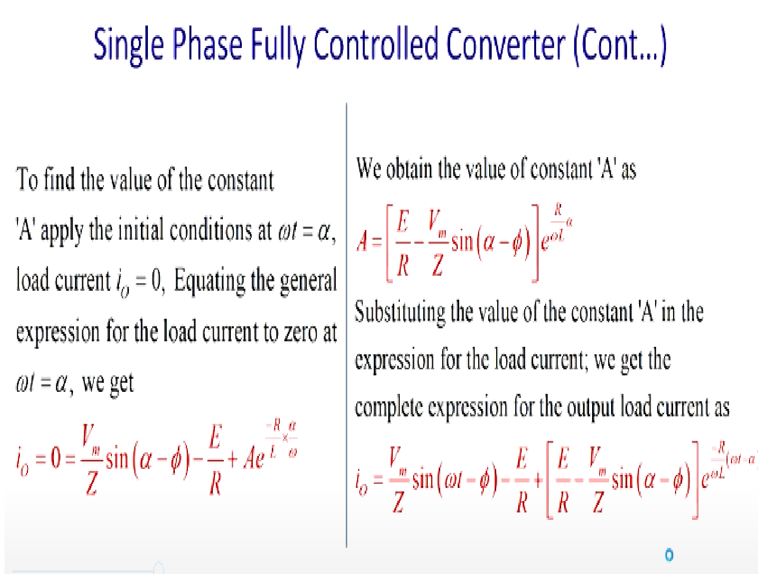

Then what you can do we got to find out the value of A that is unknown. So we got to find A which we have done in and that was rectified also. So by initial conditions so when current is 0 for this A if we actually apply the initial condition when omega t =alpha then load current i0 =0 so if we can equate it i0=0 Vm/Z sin alpha-phi -E/R +A e to the power -R/L alpha/omega from there we can get an expressions of A and that will have a component of e to the power.

So it is a varying component you can see that you know it is constant and there after a sinusoidal component and it is varied via actually an exponential component so here -sin is missing. So substituting this value A and we can have an expressions actually the load current so load current will take this format. So Vm/Z sin omega t-phi -E/R +E/R-Vm/Z sin alpha- phi e to the power -R/omega L omega t-alpha.

So from this equation this term this sinusoidal component can be 0 if you trigger alpha=phi. So ultimately then the sinusoidal component will come out you will have a sinusoidal component plus a decaying component. This will be a decaying component.

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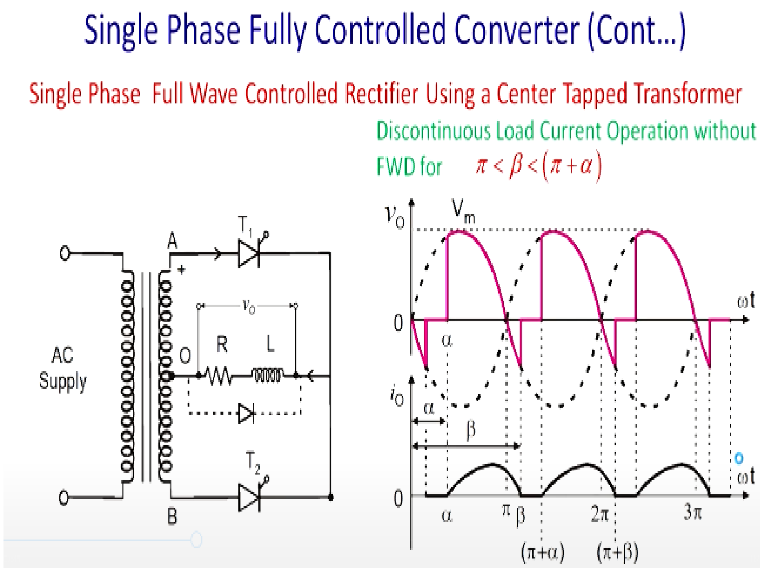

Now let us take a next class that is a basically full control converter with a central tapped topology. So midpoint is available because you have in that configuration negative cycle is totally omitted so for this in conversion ratio is very poor and you also have a high degree of actually ripples. So for this we prefer actually full control mode of operations so but problem is there if we use a transformer we require the central time transformer.

So same condition arises so let us consider that for RL load first. So we have a continuous and a discontinuous operation of the load current once we have a this is the current you can see that it is a discontinuous mode of conduction the red line shows that this is basically the voltage output available across this load and this is the freewheel it is optional whether it is connected or not. It generally comes through the switch may be.

So this wave form this half wave form shows that this continuous load current central tap full controller converters for triggering angle alpha for without any free wheel diode. So diode is basically not been placed into the circuit so far this is what will happen so a negative voltage will come that gives rise to the ripples or more DC and then after it will trigger an angle alpha then it will conduct so stored energy will mix this thyristor to conduct even in the negative cycle.

So you get this profile so all the energy is shared during this time so far this is and then we are no voltage is across is available and same way it will continue.

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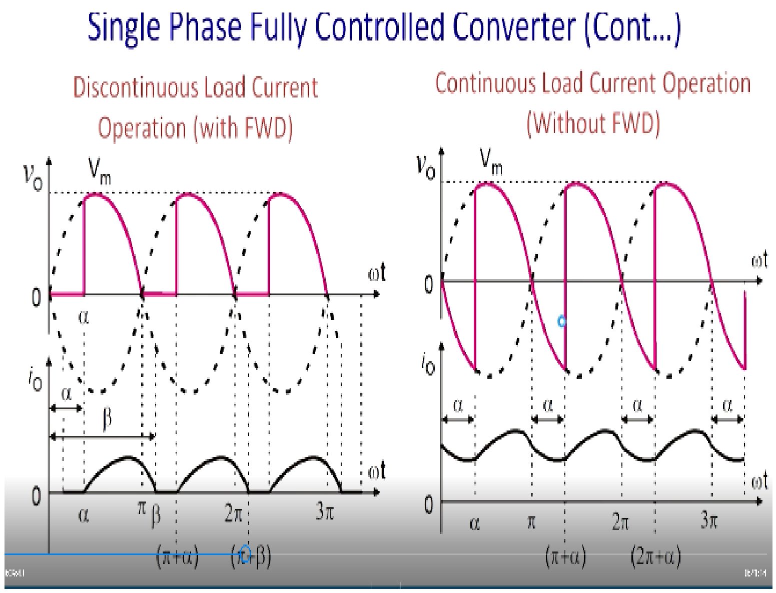

If we have discontinuous conduction with that free wheel diode, then you know this negative part get truncated there is no negative part. So what happened you know actually till load voltage will be positive and DC component will be more. So what happened then there after actually at this point actually Thyristors will be reverse bias due to the diode and free wheel diode come into that picture and current will free wheel through this path.

This is the free wheel direction till actually energy is stored into the inductor is dissipated that is for the duration pi to beta and if the load current is quite high then you may have a continuous conduction mode and in this case you can see that actually current still follows alpha thereafter what happened since Thyristors is conducting you will be actually this is without free wheel so for this you get a huge part of the negative voltage.

Then actually Thyristor will be triggered at an angle alpha so forward voltage you will get across the load then what happens is Thyristor is actually in a forward conduction mode due to the high current ultimately it will deliver negative load voltage so similarly it will continue. So negative load voltage can be truncated with the use of the freewheeling diode.

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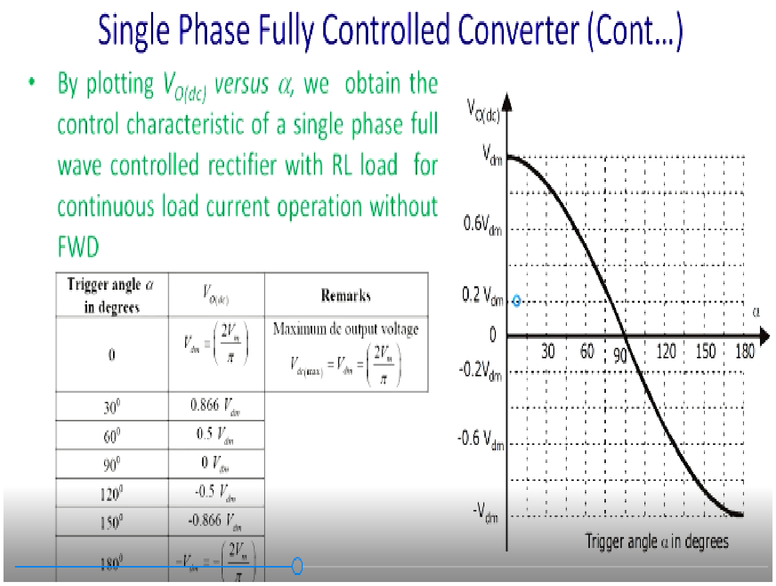

Now let us see there is a characteristics of this actually single phase fully control converter. So we will plot VDC versus alpha. So you can see that you can get a maximum value of VDC that is 2 Vm/pi that is add alpha =0 so control characteristics of a single and we assume that actually load current is continuous for this reason and without the free wheel diode that is this wave form so then what will happen you will find that at a 90 degree.

So this voltage deliver to the load is 0 thereafter if you increase this alpha beyond 90 degree then nearly a conversion operation. So it will be a bipolar so you can convert AC to DC as well as you can reconvert it into DC to AC. So actually so that load itself will actually then supply back the power to the source this is this kind of application is possible in case of the regeneration. So 90 to 0 if it is actually 120 degree then you can see that this -Vdm.

So on as 180 degree is the totally the inversion or inverter operation.

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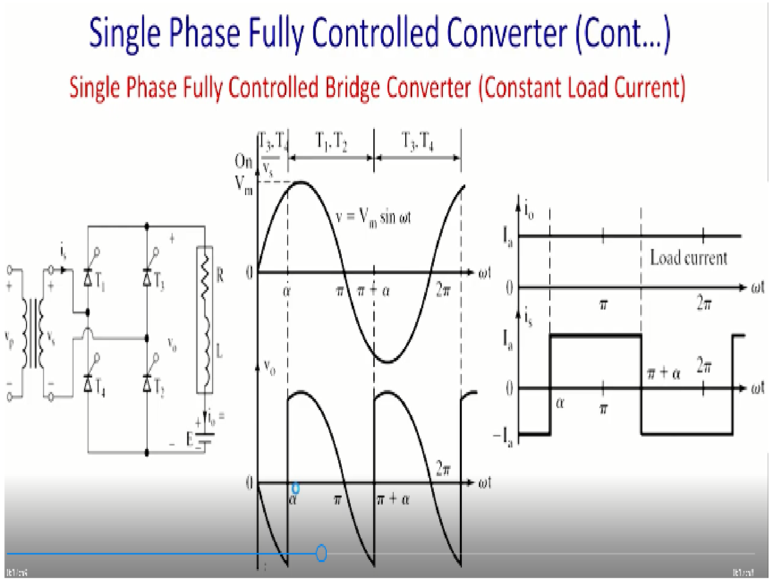

So let us consider that RME load with bridge configuration where actually we can bypass this central term transformer and also actually you may not require transformer if it is directly fed from the source. So now in forward half cycle we shall put this Thyristor in such a way that Thyristor T1 T2 will conduct and we assume that actually load current is actually continuous and constant that when it has got a very high level of inductance.

Generally, this can be approximated when omega L/R ratio is around 10. So time constant is around 10 second so for the period of actually 20 milli second it can be assumed to be actually constant. So it has been triggered at an angle alpha so before that the pair of Thyristors in negative half cycle was conducting and you are getting a negative voltage. Thereafter and same thing is applicable so since load current is continuous.

So effect of the vacuum is may not the same so there after Thyristor is triggered at an angle alpha it could conduct till alpha to pi+alpha. So 180 degree thereafter again T3 and T4 will come into that picture. So it is quite easy to analysis since load current we have assume this kind of fashion. So the source current will also have a square wave and we can do the Fourier series analysis all the odd harmonic will be present for the order symmetry.

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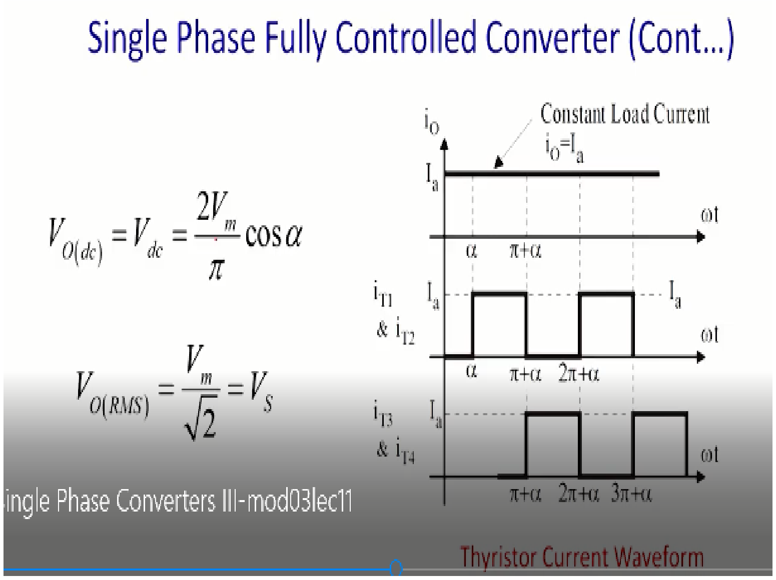

And thus we can calculate what is the amount of the actually Vdc and RMS and the corresponding current part of it. So Vdc actually 2 Vm/pi cos alpha so we can derive that expression in place simply by integration. Same way actually the RMS output voltage will be Vm/root 2 will be Vs and current to the Thyristor will be actually square wave. So this will be the current through across T1 and T2.

For the period of actually 360 degree similarly this will be the current for T3 and T4.

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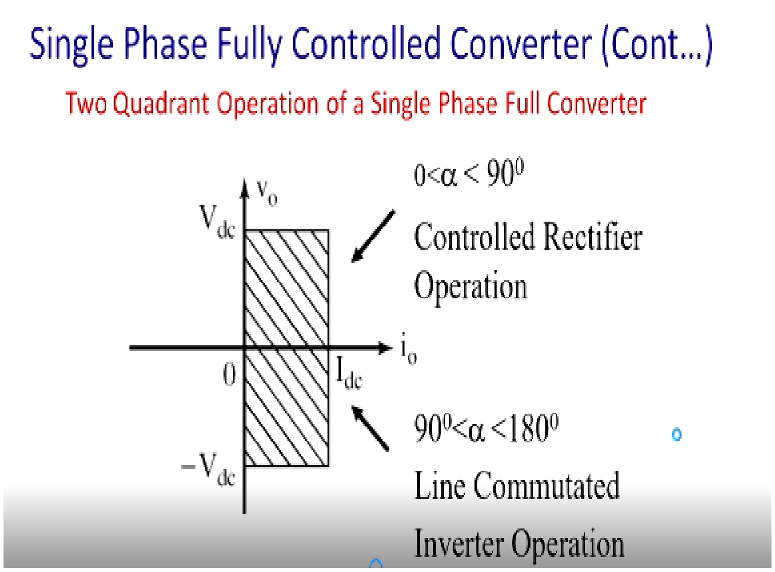

Now here this is a 2 quadrant operation so you know while discussing switch we have described the quadrant operation here current is unidirectional. So current is always positive in the load but voltage can be negative and positive depending on the triggering angle. So if alpha is actually more than 90 degree in this case then it will be an inversion operation and alpha is < 90 degree you get a controlled rectifier operation.

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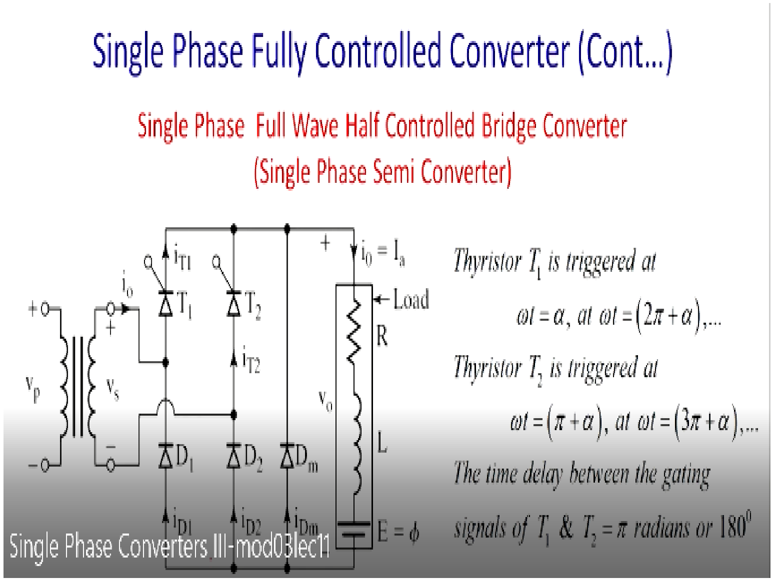

Now let us see the condition when there are three changes has been made this is called half control you can have a different combination of half control you can as asymmetrical or symmetrical configuration. So here you know upward to a Thyristor lower to a diode we can have another configuration where one leg is of thyristors and another leg is of diode. Then if you do that then we need not have to give a actually the freewheeling diode in that case.

Let us consider this configuration this configuration is called single phase fully controlled rectifier this is a single phase semi controlled converter rather so and it is fitting a RLE load. So it is omega t =alpha it has been when triggered and we assume that load current is quite high and continuous so actually it will fit till omega t=2 pi+alpha thyristor T2 is triggered and an angle 2 pi+alpha and 3 pi+alpha. So accordingly this time delay between T1 and T2 is going to be the 180 degree.

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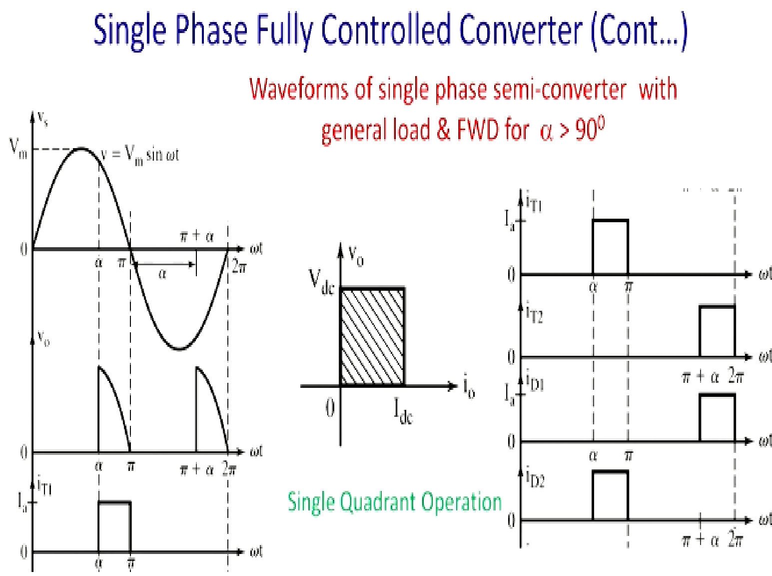

So see then wave form of voltage you will get so you have triggered here this is your angle. So ultimately you will get a voltage like this and please see that you know since the diode into the pictures. So negative voltage it is not possible to have because diode will conduct and free wheel truncate this actually the negative voltage and thus this part is been actually omitted so you only get the first quadrant operation that is actually the rectifications or the converter operation.

Same way current through this thyristor is T1 and T2 and this is a D1 and D2 so on and this is a single quadrant operation.

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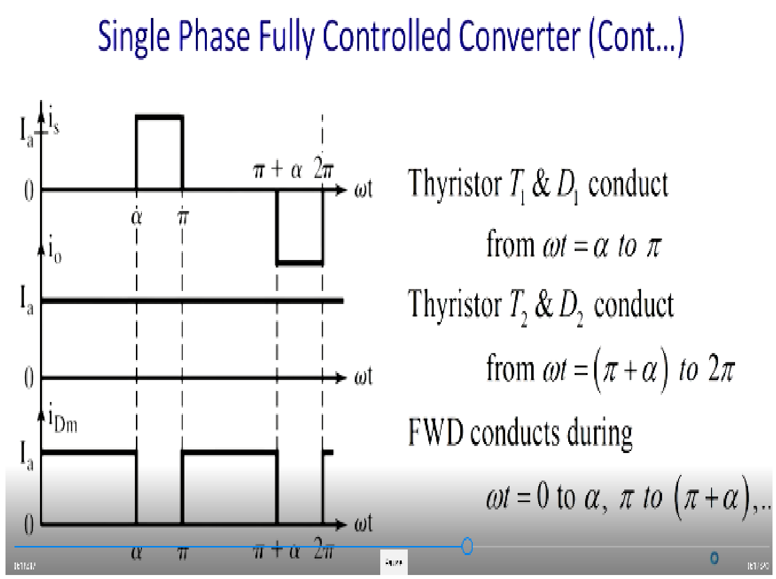

Now actually this is Ia this is a source current and it will conducting for a very small interval of time alpha 2 pi there after pi+alpha to 2 pi in negative half. But since the value of the intact is so high that you get a constant actually the load current and similarly you can find that rest of the current is flowing through the free wheel diode. Current through a free wheel diode will be very high and this is the amount of the current flowing to the free wheel diode.

So thus T1 and D1 conducts for this duration for alpha to pi T2 D2 conducts for a period pi+alpha to 2 pi and for omega t0 to alpha that free wheel diode conducts again pi 2 pi +alpha free wheel diode conducts.

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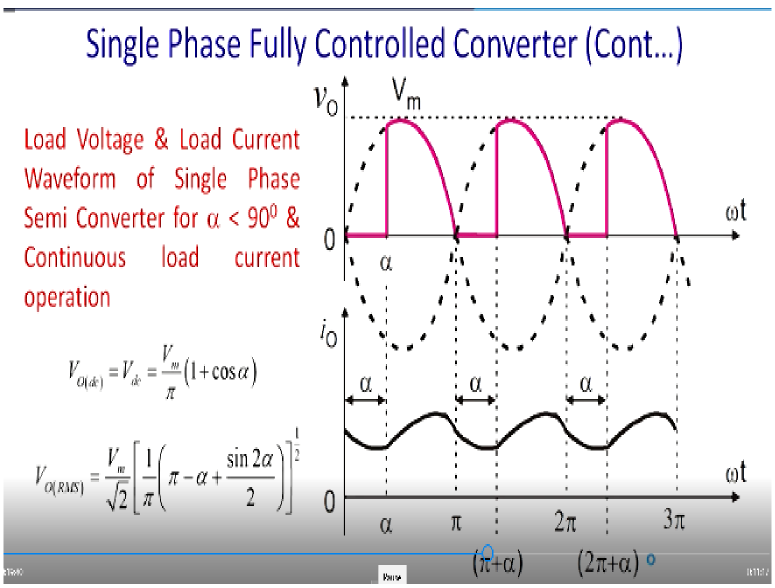

So this is the wave form of it the pink line actually shows the load voltages and from there we can derive the equation of the load voltage that is actually VDC that when we integrate over it is a very simple thing you will get Vm/pi 1+ cos alpha. So you can put any value of the cos alpha you can find that actually even if you put cos alpha =180 degree this value will be 0. So you will have a single quadrant operation.

Same way we can actually find it out the RMS value by actually integrating over it so you get Vm/root 2 1/pi pi-alpha +sin 2 alpha/2 so you can expect that in voltage there will be some oscillation of the double frequency. So due to that double frequency oscillation will come. So if you divide by R definitely you will get the I RMS and if you divide it by R you get the I DC which is assumed to be cost and this comes square root kind of a thing.

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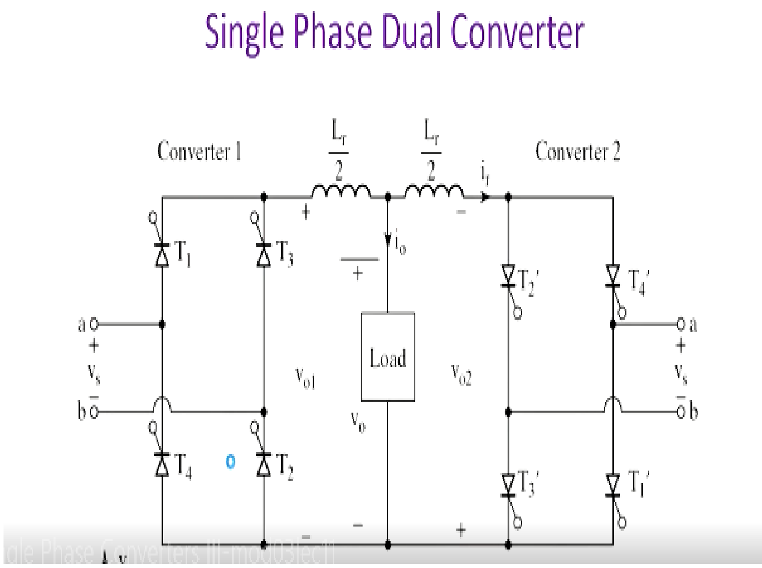

And mind it since it is a square wave so average and the RMS value should be same okay now let us come to the single phase dual converter. So it a 4 quadrant operation so this Thyristors is a is a full control converter so thus it can operate + - actually 0 to 90 degree as a mode of converter and 90 to 180 degree as a mode of the inverter. Same way what you see that polarity of this actually Thyristor is reversed.

So what this is and it will be - alpha and since that there can be this pole voltage may have a instantaneous difference of the voltages. So due to that you require to actually put a blocking current blocking inductor so that it can block the instantaneous voltages between these two pole voltages. So what happened in first mode let us assume that you know.

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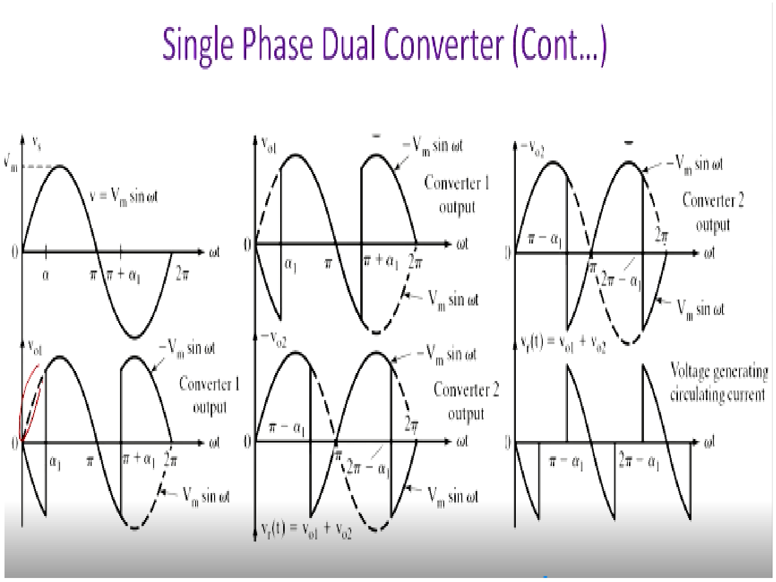

This is the input voltage and essentially you have chopped out this voltage and since it is a foot control operation you will get this kind of wave form and similarly you feed the same voltage and if you trigger the logic of triggering of the dual converter is that if you trigger that one converter and an alpha another converter required to trigger at pi – alpha. So you have triggered pi - alpha so essentially you will get actually this part of the voltages.

So essentially what you will get at the output voltage is v1+v2. So this will be the voltages across the load and unfortunately due to that there will be a circulating current flowing like this when there is no cancellation of the instantaneous voltages. To block that instantaneous voltages, we have put an inductor.

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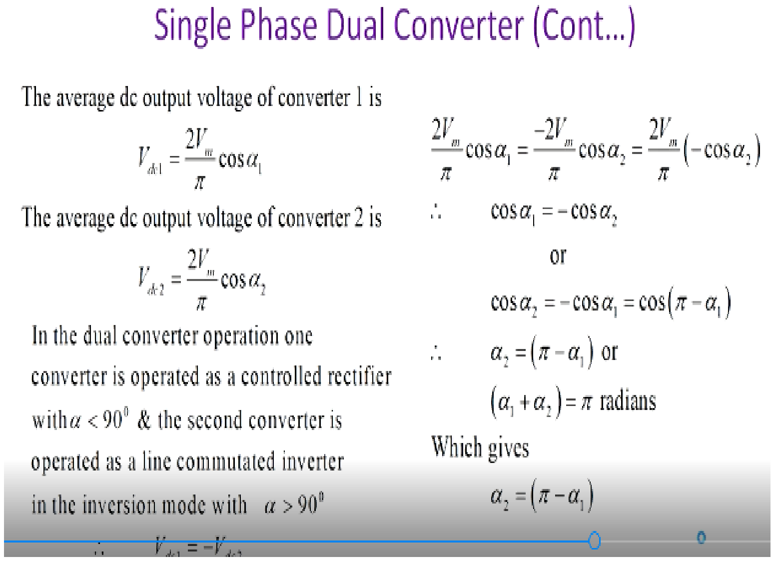

So let us do some analysis so of course since it is the full control converter for first converter in left hand side it is this value will be this average voltage or the Vdc 1 will be 2Vm/ pi cos alpha 1 similarly output voltage of the second converter V dc 2 that will be 2Vm/pi cos alpha 2. The dual converter operates one in a converters operating under the controlled rectifier another actually was triggering angle is < 90 degree.

Another is basically it has to be more than 90 degree and we hold this equation further if it is trigger an alpha another is triggered 180 degree -alpha so Vdc1 should be =-Vdc/2 so if you can equate this two equations ultimately you find that basically alpha 2=pi-alpha 1. So this is the constraint so alpha1+ alpha 2 should be =pi so for this is in this mode of operation has been continued. So dual converter can we operated it in two different modes of operations.

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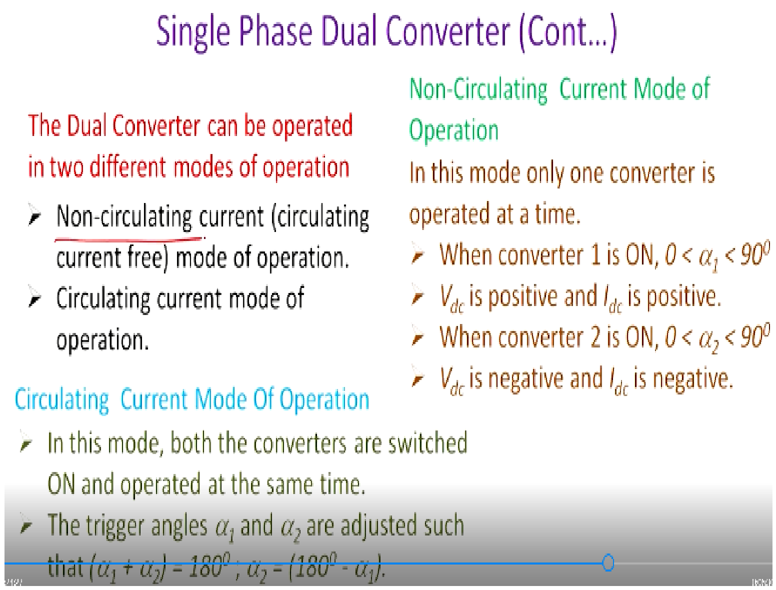

Definitely, so one is non-circulating current circulating current free mode of operation we can make the instantaneous for the same at all the time so that no sacrificing current flows and circulating current mode of operation. So in non-circulating current mode of operation this mode only actually possible in one instant mode is in this mode only one converter is operated one time.

So both converter are not operated so when converter 1 is on that means alpha 1should be =0 to 90 degree and Vdc is positive and Idc is also positive and where converter 2 is on, it should be actually < 90 degree and Vdc is negative and this should be also negative. So then what happened since you are operating one converter at one time and thus there is no condition of flow of current.

But what happened then actually power delivering capabilities is decreasing in circulating mode what happened. In this mode, both the converter has switched on and operated at the same time and the triggering angle alpha 1 and alpha 2 are adjusted in a way alpha 1 and alpha 2 =180 degree or alpha 2= 180 degree-alpha 1. So when this mode is generally more preferred.

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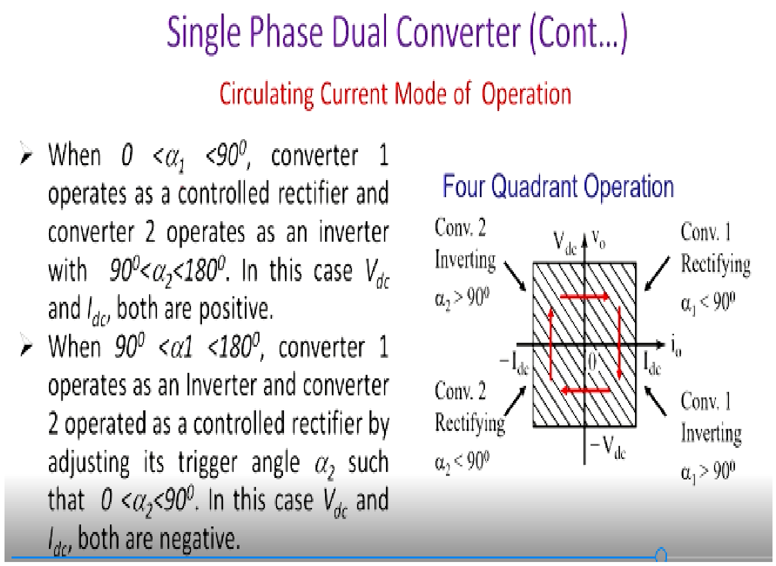

So when alpha 1 is basically < 90 degrees converter one operates in a controlled rectifier and converter 2 operates in an inverted mode. And in this case Vdc and Idc are both to the preferably assumed directions. When it is change when actually this condition is satisfied is alpha 1 is more than 90 degree and < 180 degree then converter 1 operates in the inverter mode and converter 2 operates in the rectifier mode.

And thus what happened we get a negative dc. After this we have a four quadrant operation so converter 1 is in rectify mode thereafter converter 1 is inverting mode this is 1 of this quadrant operation in this condition Idc is positive. So this is a conversion this is actually we have described in case of the full control converter similarly we can make so converter 2 < 90 degree then what happened basically Idc will be negative but Vdc will be positive.

And this is a third quadrant operation both Vdc and Idc both will be negative where actually you are putting the converter to more than 90 degree.

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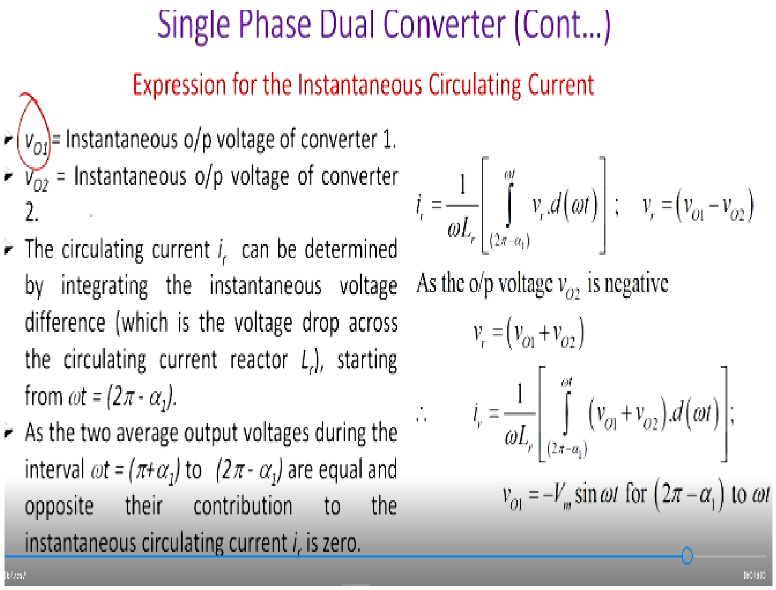

So let us understand the few aspects of it so let us assume that the instantaneous output voltage converter 1 is V01 and Instantaneous output voltage of convert 2 is V02. And the circulating current are we required to calculate and we required to block their circulating current which may harm actually the Thyristor unnecessarily. Because it is not getting into the load circulating current ir can be determined by integrating the instantaneous voltage difference.

Which is the drop across the circulating current along Lr so let us start at omega t=2 pi-alpha 1 as the two average output voltage during this interval is omega t = pi+alpha and another is 2 pi-alpha positive opposite to their contributions so you can put this limits so ir =this thing 2 pi-alpha to omega t where actually Vr is this. So we can actually find it out the what should we the value of this circulating current. Substituting v01=-vm sin omega t or 2 pi-alpha 1.

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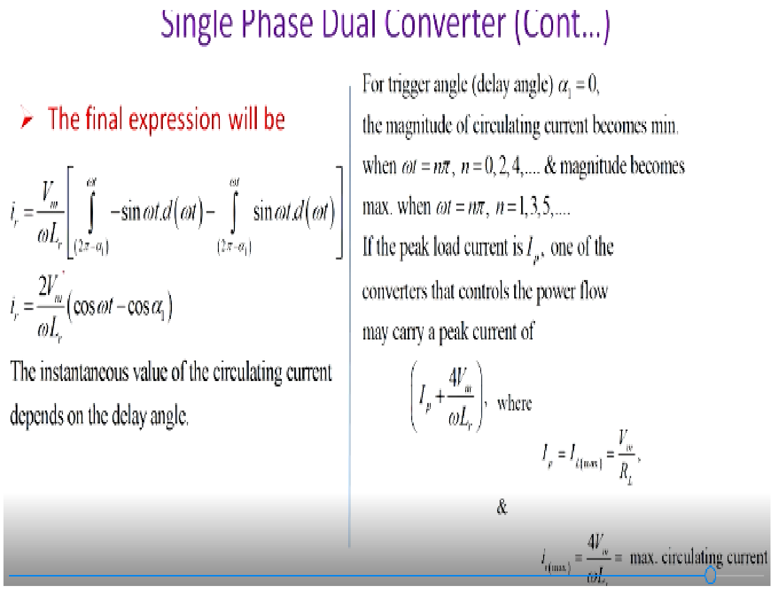

So either substitute it and you get the results ir=2 Vm/omega Lr cos omega t-cos alpha so you can see one thing that you can actually make the circulating current 0 suitably controlling alpha 1 but it is not impossible most of the time. So for triggering angle alpha =0 the magnitude of the circulating current becomes minimum 1 omega t =n pi. So magnitude become maximum and when omega t =n pi actually for the odd harmonics.

The peak of the load current Ip one of the converters is actually giving you the current. So this is where the expressions of it so Ip + 4Vm/omega L where Ip=IL max that is =Vm/RL and that is Ir should be equal to this is the max peak value of the circulating current that is 4Vm/omega Lr. I continue you with the next class with the converter, we are looking forward to discuss more interesting detail about this converter. Thank you.