Power Electronics

Prof. K. Gopukumar

Centre for Electronics Design and Technology

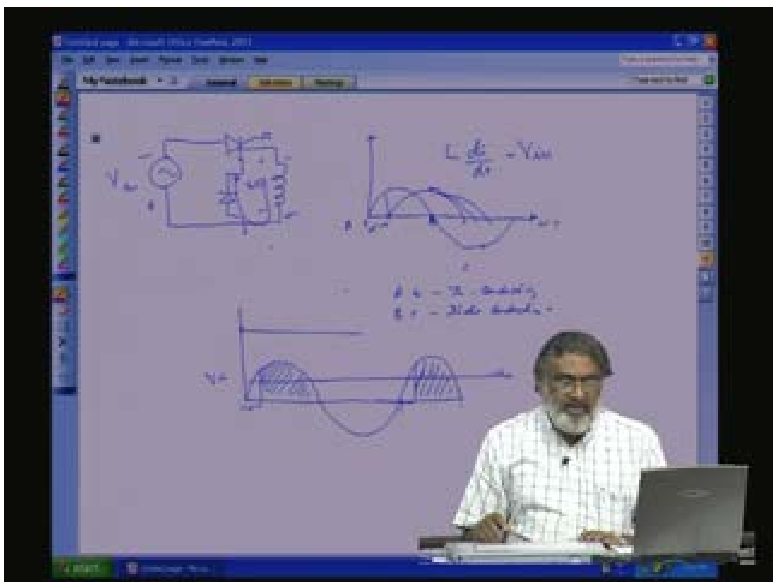
Indian Institute of Science, Bangalore

Lecture - 2

Controlled Rectifier Part-I (Single Phase)

So, last class we studied, we just concluded with a single phase half controlled rectifier and then we introduced the resistive and inductive load. So, with inductive load, let us draw the diagram once again.

(Refer Slide Time: 1:26)



This is our mains, then we have the thyristor our device, then this inductive highly inductive load, we will assume. This is our across this one, we will say this is V_0 (t), this is this point is our input. Let us drive, let us draw the output voltage ripple with respect to a particular firing angle alpha. This is our axis; this is our omega t axis. Now, we will draw our input sinusoidal, input sinusoidal voltage like this. We will be firing at this point alpha, alpha we will be measuring from the zero point to the instant of firing, this is alpha.

Now, with inductive load, the moment this thyristor is turned on giving gate pulse, the input will be connected across the inductance. Now, if you see here, the current will, the current through the inductance cannot change instantaneously. So, the moment the gate V is given, current will slowly rise slowly rise such that the rate of change multiplied by inductance l into di by dt will be the voltage across the inductance that is the mains voltage. Now, the device is on. At omega t is equal to pi where our input mains voltage goes to when comes to 0; what happened?

The current through the inductance or the load will comes to its maximum point and thereafter it will slowly reduce. So, at this point, it will be di by dt will be 0 so that the voltage input voltage and the load voltage will be, Kirchhoff's voltage will be matching. Then, the moment voltage goes negative; so there is a current in the inductance, current through the inductance cannot change instantaneously. So, what will happen? Unlike in the case of resistive load, the thyristor will not switch off immediately and the stored energy in the inductance will make the current to flow again continuously so that slowly current will try to decrease from this point onwards.

So, at what point it will come to 0 that depends on the inductance and the initial stored energy that also that depends on the peak value of the current. Now, this di by dt is negative. So, l into di by dt is equal to V_{in} assuming the diode drops is negligible. So now, the di by dt slope is negative from this point to this point. So, what will happen? The polarity across the inductance will change; this way, this way. That is true here also; voltage has, you see voltage waveform, so Kirchhoff's law will match here also.

Now, this voltage L di by dt minus this voltage; so this voltage will force minus this voltage will force this thyristor in the forward conduction stage and thyristor will continue to conduct till the current come to 0. The moment current comes to 0; the thyristor will switch off because thyristor cannot conduct in the opposite direction. So, this point where the conduction has come to 0 is not in our control. It depends on the inductance and the initial load current, the maximum load current flowing through the system.

So, with various inductances; sometimes it can extend this way also, sometimes it can extend this way also. So, what it means? We lose control. So, we do not know what is output ripple coming across the inductance. So, the previous equation with resistive load, with the firing angle, V output with respect to firing angle alpha is equal to Em by 2 pi into 1 plus cos alpha is no more valid here because there is a negative conduction that is negative in the sense, when the voltage input voltage has gone negative. So, for this equation that is output DC value to be valid here also, this negative sign we have to remove. That means there should not be conduction or there should not be a negative ripple coming across the inductance.

At the same time, there is another requirement. Current cannot stop instantaneously in the inductor, current cannot abruptly change. So, we should provide out another path for this inductor. There the concept of freewheeling comes. What it means? When this voltage becomes positive here that is during this portion if we want the thyristor to go switch off from this point onwards, at the same time, we want to give an alternative freewheeling path across the inductance; what we can do? We can provide diode here.

So, when the thyristor is forward biased, when the thyristor is conducting that is during the positive half cycle, this point will be positive with respect to this point and this is shortened because the thyristor has come down, this diode will be reverse bias. So, the current will flow through this way. The moment di by dt becomes negative, this diode will get forward biased and the current will freewheel through this path, during this portion. That is if we mark ab till c. ab region, thyristor will be conducting thyristor conducting. During the bc region, diode will be conducting.

Now, what will be the output voltage ripple across if you see here, we can draw it here. If this is the input voltage V_{in}, our V_0 will be if this is the firing angle alpha, our V_0 or the voltage ripple across the inductance will be this one. Again, it will repeat the next positive half cycle. So, this voltage ripple across the load, now the load is whether it is resistive or inductive, you do not have to worry. With this freewheel diode, automatically this voltage ripple will appear across the load and this equation is valid for the output V_0 volt V_0 that is the DC, this is the DC value with respect to firing angle alpha.

And if you see here, another problem with this case is even though we can draw power from the mains, we are only we are only drawing during the positive side, negative side we are not utilizing. So, maximum power utilization is not there. At the same time, if this is the V_0 that is the V_0 alpha, V_{dc}, there are ripple associated with the output voltage. So, this ripple voltage; what is the frequency of this ripple voltage? It repeats every cycle.

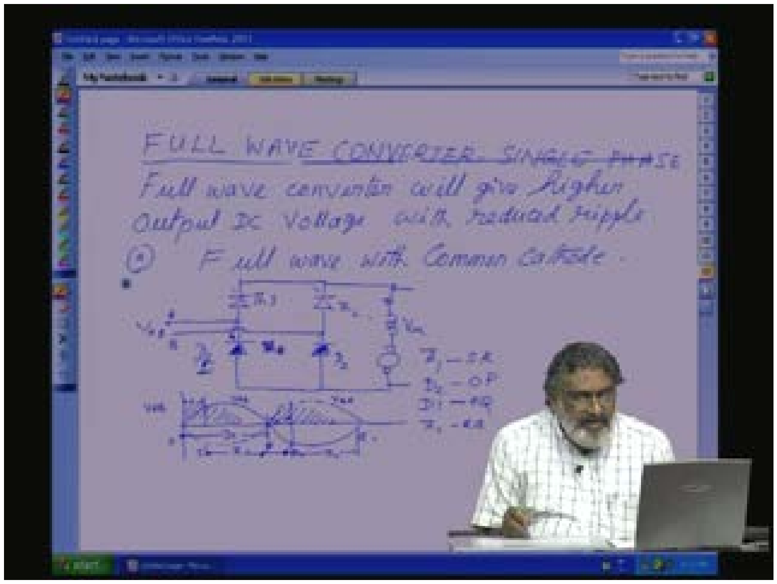
So, this ripple voltage, this frequency component will have the fundamental; then third, fifth all harmonics will be there. For higher harmonics the impedance L omega will become more and the current drawn by the inductance is less. So, if you want to have a pure DC, we have the load even though I have mentioned this one purely inductive; mostly we will be talking we will be talking this one in the conduction of DC motor drive application. So, we have an inductance that is armature inductance plus the back emf. So, we want for a motor, it is a pure DC we require. So, that means the ripple, the current, harmonic currents due to the ripple voltage should be as low as possible. So, even though the half wave, single phase half way rectifier is available in text book; this is seldom used in any application, this is only for understanding the basics of rectification.

Now, let us talk about rectification; also we have introduced the freewheeling concern. During the negative, this is freewheeling. That means energy stored in the inductor is circulating here; it is like cycle, when you pedal it and after remove it, it will keep on rotate that is freewheel and due to friction, it will come to a stop. Same way, the energy stored in this one slowly circulates through the diode and slowly it can dissipate. That is called freewheeling action.

Now, let us go to not the half bridge concept, let us go to the full wave converter. Let us go to the next page. Full wave converter will give higher DC voltage that means we are using both the input - positive side as well as the negative side to transfer energy with reduced ripple. So, this is basically a rectification; whether half bridge or full bridge, this is rectification. So, the input ac is rectified and brought to the output. It has DC as well as the ripple content that is high frequency component. But full wave rectification will give higher DC voltage with reduced ripple.

What do you mean by reduced ripple? That once you draw the waveforms and once you study that you will get to know the thing. Reduced ripple means the DC value current along with its ripple value will be much reduced compared to the half bridge converter. So, let us draw the full wave rectifier.

(Refer Slide Time: 13:14)



Single phase full wave converter: full wave converter single phase, this is the single phase full wave converter. Full wave, what is the advantage of full wave converter compared to single phase? We will state it here. Full wave converter will give higher DC voltage, higher DC voltage compared to our half wave rectifier; higher output DC voltage, higher output DC voltage with reduced ripple with reduced ripple. There are different configurations possible with this one. Some of the configuration possible with the single phase rectification, full wave rectification we will study and its merits and demerits, we will analyze just for understanding.

So, let us take one full wave with common cathode a, full wave with common cathode, full wave with common cathode. The schematic is like this; we have thyristor 1, thyristor 1 I will make it as Th 1, then you have the Th 2; sorry here not the Th 2, here it is D $_2$, let us remove this one, this is D_2, we will try to remove that one. Then comes Th 2, because we were talking about the common cathode, then D_2 D_2. So, D_1 D_2 here, this is the mains V_{AB}, we have the load here, we will represent with DC motor armature inductance and the resistance, D_1 D_2 here.

Let us see, how the output voltage ripple that is output voltage coming across the load here, V_0 alpha, how it looks? Let us draw our current ripple. We will take, we will go to the current ripple sorry voltage ripple; these is our VAB and also mark the negative of V_{AB} here, this is V_{AB}, this is the V_{BA}, V_{AB}, this is V_{BA}. Now, let us take a firing angle here, alpha, starting from 0. So, what will happen? Here, we would be firing Th 1. Th 1 from here where it will go where will come to zero state.

So, let us take Th 1 is fired. The moment Th 1 is fired, diode would immediately forward biased because this point will come here and this is already negative, this diode will conduct. So here, diode will conduct, this D_2 will conduct whenever V_{AB} is when this point is negative with respect to this point. That means during the full negative portion that is V_{BA}, this point; D_2 will be conducting, D_2 will be conducting for the negative point.

So, when the voltage V_{AB} comes to 0; what will happen? D_2 was conducting, Th 1 was conducting; now what will happen during this? But we will be firing the next thyristor Th 2 through here only that is alpha here, same alpha from the zero point. Then during the V_{AB} negative, we will be firing Th 2. So, what will happen? The moment at this point, the voltage has gone negative, the moment it has that means this point has one negative with respect to this one that means this diode will be switched off, immediately D_2 will conduct. But for Th 2 Th 1 to switch off, Th 1 to switch off; what we have to do? We have to switch on Th 2 and make a reverse bias across the Th 1. So, until Th 2 is turned on, until Th 2 is turned on; Th 1 will not switch off. So, Th 1 will conduct for this full period that is from here to this period. That is we will mark this point as O, P, Q. So, full this period OP; Th 1 will conduct, from here to this point, upto this point, Th 1 will conduct.

Now, when this voltage goes negative that is this point, at this point P; at this point let us say OPQ, this point I will make it R where the Th 2 is turned on R. Then let us make this is S. At point R, here only we will be turning on Th 2. So, Th 2 will conduct from R to Q but what will happen during the interval P to R? P to R, V_{AB} that is A is more negative than this one. So, D_2 will conduct. But still, Th 1 is conducting. So, Th 1 will conduct note SP Th 1 will conduct upto this point, Th 1 will conduct from SR, Th 1.

Th 1 will conduct full SR duration but during the P to R; Th 1 is conducting due to this portion when this has gone negative, the diode D_2 will be conducting. During the PR period, D_2 will be D_2 will be conducting sorry there is a marking mistake, this is D_1, this is D_2. So D_2, this D_2 will conduct during when this is positive and this is negative that is from period O to P.

So, D_2 will conduct period O to P, the period, duration O to P. Diode D_1 starts conducting here. So, as long as this point is negative that is the BA is negative with respect to B, D_1 will be conducting. So, D_1 will be conducting for the full PQ period, PQ period and from R to Q, Th 2 will conduct. So, what will be the final ripple coming across this one? When it freewheels; Th 1 and D_1 simultaneously conduct, the load will freewheel. Similarly, when Th 2 and D_2 will conduct, load will freewheel. That means the voltage across the load is 0. So, during the period, when Th 1 D_2 conducts or Th 2 and D_1 conducts that time only, the output ripple will be coming across the load. That means the ripple, this portion this hatched portion will be coming across the load.

So, with properly placing the diodes; what is the advantage we can have? Full wave control is also possible, at the same time for inductive load, freewheeling action is also possible. That is freewheeling action; when one thyristor when the diodes conducts and the Th 1 conducts, the freewheeling. So, during the freewheeling period, the voltage across the load is 0 and the output ripple is coming or output ripple is appearing that all part of the volt input voltage waveform is appearing across the output only when the firing angle alpha is initiated for both the thyristor. This is the advantage. What is the advantage?

Assume Th 1 D_2 are conducting and if the L by R ratio is very high that is the time constant L by R is very high; what will happen? Current will not decay, current would decay very slowly. So, the moment V_{AB} goes negative that is A goes negative with respect to B point, the current will freewheel through Th 1 and D_1. Now, to switch off Th 1, we have to switch on Th 2. The moment Th 2 is turned on, now already B has become positive and A has become negative, this Th 2 is turned on and this point, the positive point coming across the cathode of Th 1 and Th 1 will be reverse biased and Th 1 will be switched off.

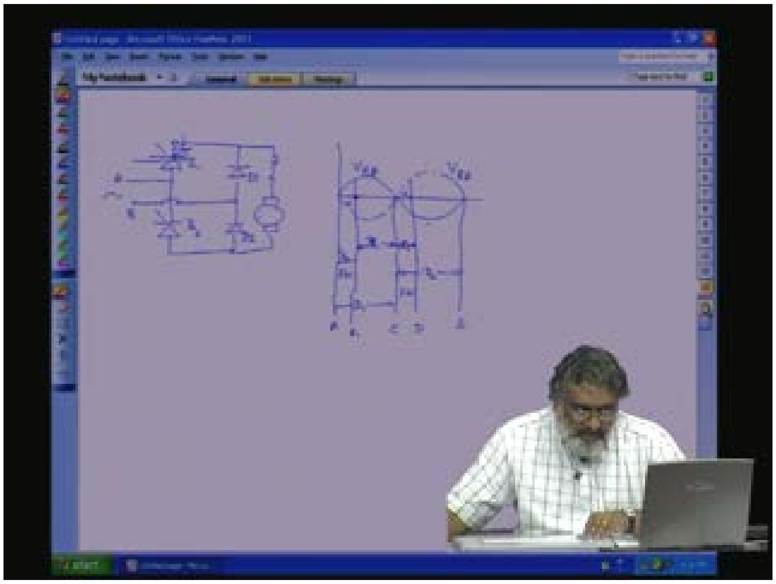
Now, take a case if Th 2 gate pulse failed that means due to some mistake Th 2 fails; what will happen? Current will keep on freewheel through D_1 and Th 1 and the load is highly inductive, current will not decay. It will keep on decay and the next time when voltage goes negative at the B point, diode will conduct. So, through Th 1 and D_2, as a half wave rectifier, it will keep on supplying power to the load.

So, what is the advantage? What is the disadvantage here? So, we lost control. The moment lost control means output should disappear. That is one thing but here, we lost control and at the same time, the power converter is supplying power to the load. So, how to avoid that one? What I mean to say, this converter if something fails, till the inductive energy is there only it should conduct. After that you should slowly conduct and should come back to 0 that is the best way. System should automatically come to stop. But here if the Th 2 gate drive fails, we will fail to turn on Th 1and the load is highly inductive, the load will freewheel through D_1 and Th_1.

So, how to avoid this one? One way to avoid this one is to give a freewheeling diode. That means do not allow the load to freewheel through the thyristors. Let us go by least resistance path by giving a diode across here but one problem here is when we give suggestions for voltage control, we have to give a cost effective solution. But the problem here is that because of the freewheeling diode, one more additional component has come. So, this will freewheel through this one. But this can be, so we can say that this one diode by changing in some other way, another modification of this single phase full wave converter. We will talk about that one now.

So, let us remove this one. Let us go to the next page. Now, to avoid one extra diode, also to get the same performance as before without the freewheeling extra diode; the configuration is like this. These are some of the different alternate configurations for single phase fully single phase converters. So here, if you see here, we are not using four thyristor; we are using two thyristors and two diode. That means only two devices only we have control. Other two device, the moment it is forward biased, it will forward it will turn on but thyristor to turn on, it has to be forward biased and at the same time, during the forward bias period, we have to give a gate pulse. So here, we have only, half the device only, we have the control. So, let us have; how it looks?

(Refer Slid e Time: 29:52)



See, we will do it in a different way. Th 1, then for one limb, we will connect thyristor Th 1, Th 2. The other limb, we will connect the diode, here the load. So here, how is the conduction state? Let us draw the conduction with respect to our input mains AB. This V_{AB} and then this is the negative side that is V_{BA}; V_{AB} and V_{BA}. Now, our firing angle starts from here, alpha. For the next device also firing angle starts from here for symmetry.

So, what will happen? This period when V_{AB} is turned on, no sorry when the V_{AB} is positive, we are turning on Th 1. So, Th 1will be conducting from this point to this point. So, we will mark all the points, Th 1 will be conducting from this point to this one that is this period. Why? The moment this point goes negative, the moment this is positive and this is negative, we are turning on this one; the moment V_{AB} goes negative, what will happen? This becomes positive, this will turn on, it will freewheel through this way.

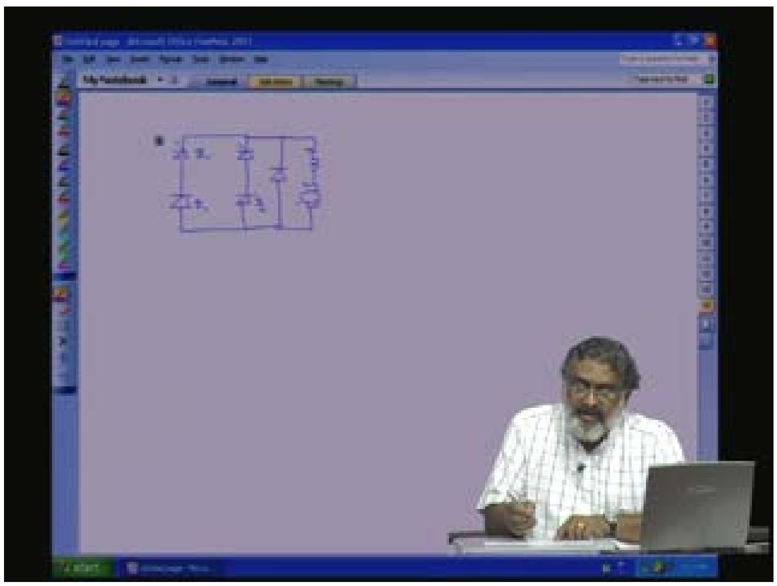
So here, let us mark this is D_1, this is D_2. So, this period, D_1 will conduct, so D_1 is conducting. Now, this V_{BA} from this point onwards, V_{BA} is conducting. So, from this point upto this point, D_2 will also conduct. So, it will freewheel. So, during this period, this is the freewheeling period freewheeling period. Similarly at this point also, this is the freewheeling period. Here, what will happen? For the full duration here, positive duration, D_2 will conduct. This is D_2 and this is D_1. So, full this positive period, D_1 will conduct.

So, what happened? D_2 is conducting here, we said during this portion also D_1 will conduct. By the moment thyristor is switched off, the moment this voltage becomes negative here; what will happen? This thyristor will be switched off, load will freewheel through this path till the next thyristor is turned on. So, D_1 will conduct this period as well as this period, D_2 will conduct this period as well as this is D_2 period.

So, when the both diodes are conducting that is whenever the V_{AB} becomes negative, anything slightly negative, this load voltage becomes negative. It will try to freewheel through this. The moment it freewheels; this load inductance, it will forward bias D_1 and D_2 and D_1 D_2 will conduct and by the time thyristor and Th 2 will be switched off. So, you have D_1 conducting here and here D_2 and D_1 will be conducting this period. Let us mark A point B, then C, D and E.

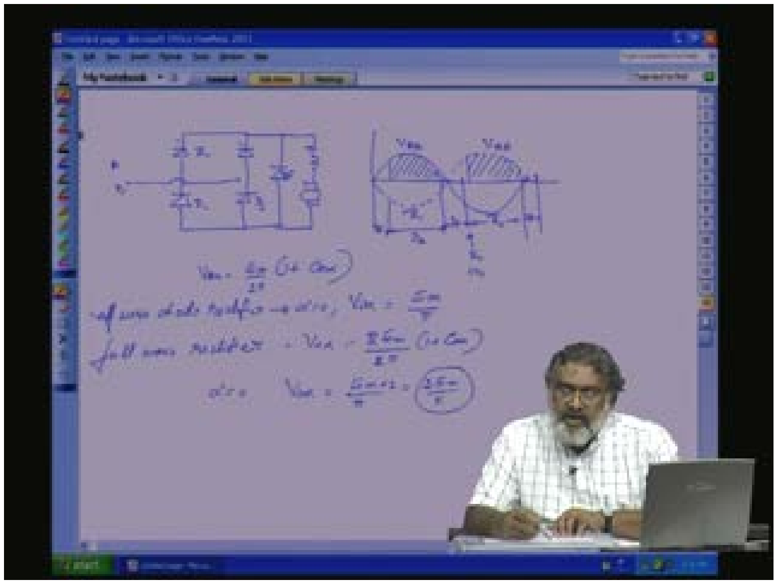
So, during this period, D_1 will conduct from here to here, Th 1 will conduct from here to this period. That period when Th 1 and when Th 1 and D_1 conduct no sorry this is marking, this is Th 1 conducts and D_2 conducts. So, let us let us talk about the single phase converter with 2 thyristors and diodes and with a freewheeling diode. So, to avoid the failure of one gate pulse, we will lose control of the thyristor as explained previously. So, we can let us draw the full wave converter now here.

(Refer Slide Time: 35:52)



This is the diode, this is Th 1 and D_1; then, Th 2 and D_2. Now, instead of having the freewheeling through the thyristor and diode, we will give a small low impedance path that will connect the freewheeling diode across here. Then we have the load; so here, how the conduction happens? Let us draw the waveform.

(Refer Slide Time: 36:44)



This is the V_{AB} and negative side is like this. This is V_{AB}, this is V_{BA}, we are firing at this point, we are firing at this point thyristor 2. So, what will happen? The voltage ripple will be like this across the load. When the firing angle is fired, during this portion; what will happen? If load has an energy, it will free feel through the diode DF. So, this is the DF period. The moment Th 1 is turned on from here to here; Th 1 is turned on, Th 1 will come here, this is positive, diode will be this diode DF will be Th 1 will be turned on and V_{AB}, the V_{AB} through Th 1 come across the cathode of diode DF and diode will be switched off here and from here, this point to this point, Th 1 will be switched on and we know this point D is already negative. So, D_2 will be, diode will immediately forward biased D_2 diode and D_2 will be turned.

So, during this period Th 1 and D_2 will be turned on. Now, the moment the voltage goes negative; what will happen? This voltage goes negative means the inductive load, we saw the inductive load that slight negative, it will forward DF and during this portion again, DF will conduct, DF will conduct. Again, when thyristor Th 2 is turned on here, Th 2 is turned on, Th 2 is on; tilll this period, Th 2 will conduct, Th 2 will conduct and here the freewheeling, again the freewheeling, till the Th 1 is turned on, freewheeling will work out.

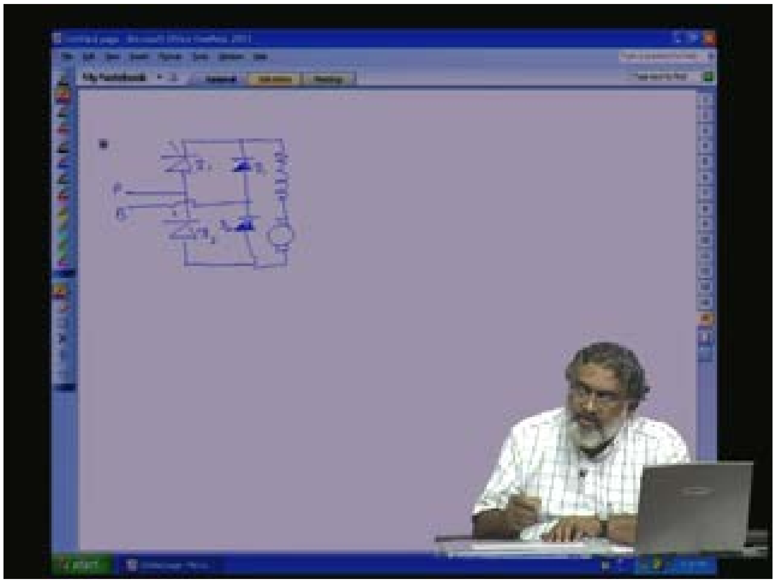
So, this is a full wave rectification if you see here with firing angle control. So here, what will be the output load voltage? For half wave rectifier, we know it. We have talked about the half wave rectification, we got V_0 is equal to V_0 alpha is equal to for half wave, it is will be equal to Em by 2 pi into 1 plus cos alpha. For half wave diode rectifier diode rectifier that is firing angle alpha is equal to 0, this implies alpha is equal to 0, so V_0 alpha is equal to Em by Em by pi.

Now, this is for full wave rectification. So, the negative side also we are getting the same ripple across the load. So, for the present full wave rectifier, V_0 value will be equal to 2 Em by 2 pi, 2 times the half wave. 2 2 will cancel, it will be Em by 1 plus cos alpha. For alpha is equal to alpha is equal to 0, V_0 alpha is equal to for a full wave rectifier, it will be Em by pi into 2 that is equal to 2 Em by pi.

So, instead of thyristor, if we use diodes for rectification; then, what will happen? It will have a ouput voltage will be equal to Em by pi, Em is the maximum voltage not the rms voltage; Em, 2 Em by pi, we will get the output DC voltage. Now, we have introduced the DF; DF is another we have the power circuit, one more diode that is another extra cost. Can we do away with this DF at the same time that correct freewheeling is ensured?

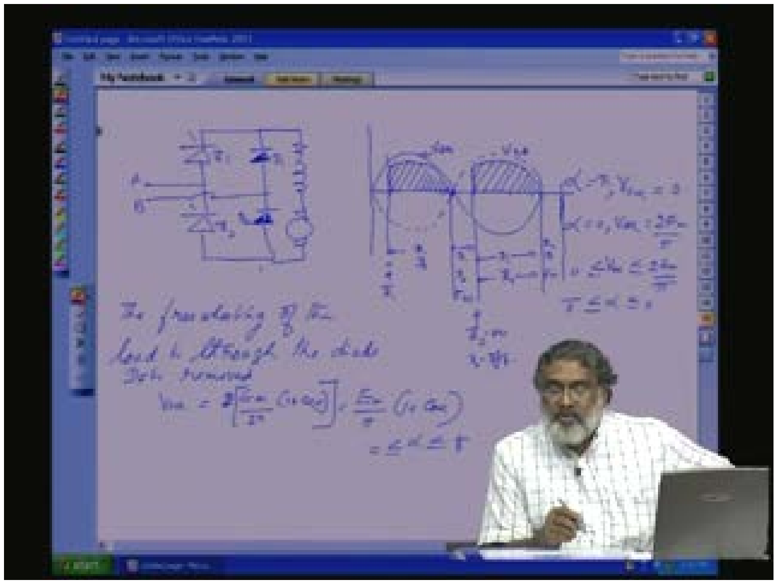
So, let us think about another configuration to our DF. Let us go to the next page. This configuration is like this. See, we want to give a least resistant freewheeling path through the diode not the thyristor; so in that case, we can have this configuration.

(Refer Slide Time: 42:20)



Diode we will connect here, AB. So, for the load, always it will freewheel through the diode. Let us see, how it happens? This is Th 1 - thyristor one, thyristor 2, then D_2 that is D_2 and D_1, this is the diode.

(Refer Slide Time: 43:12)



Again, let us draw our mains voltage; how it looks? This is our V_{AB}, this is our V_{AB}. We are now here also we are firing with respect to firing angle, alpha. The moment Th 1 is fired, at this fired, we are turning on Th 1. So, what will happen? Th 1 and D_2 will conduct Th1 and D_2 will conduct. So, from this point, Th 1 and D_2 will conduct. The moment voltage become negative at this point; what will happen?

The moment this point that is the moment this point becomes negative; what is V_{AB} becomes negative? V_{AB}, V_{BA}; V_{AB} goes negative at this point, D_2 was conducting, Th 1 was conducting. The moment it goes negative and this side become positive, V_{AB} D_1 will immediately conduct and the load will freewheel through this path. So now, here, till the next thyristor is fired, D_1 and D_2 will be conducting. This is freewheeling, this is freewheeling, D_1 and D_2 will conduct, till this period. At this point, Th 2 is turned on.

So, during the freewheeling, output voltage is 0. So, during the positive half cycle, this much voltage ripple, input voltage is this much part of the input voltage is coming across the load. Here, D_2 and D_1 will conduct. Now, D_1 is conducting. The moment Th 2 is turned on, see Th 2 is turned on because A is more negative. So, Th 2 is forward biased and the moment this is turned on, D_2 will be switched off here; Th 2 on, D_2 will be off here.

So, what will happen? From here onwards, D_1 and till this point, D_1 and Th 2 is turned on. So, this much voltage ripple is coming across the load due to the firing angle. So, this way it happens. This is a full wave controlled rectification. The moment voltage goes negative here that means A again becomes positive. What will happen? Till this, till thyristor T 2 is fired; till this point, D_2 and D_1 will conduct. This is freewheeling. So, what is the advantage? Freewheeling is transferred to the diode. Here, the freewheeling of the load is through the diode.

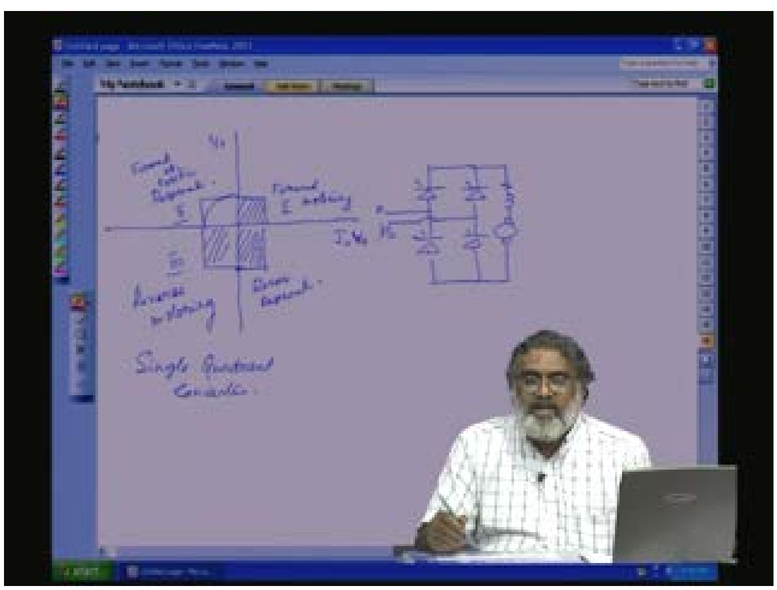
So, one extra DF, the previous DF is removed, extra D F is removed. Here also, the output voltage V_0 alpha that means output V_0 dc with respect to firing angle alpha is equal to how much? 2, here also 2 Em, for half wave it is 2 Em by Em by 2 pi for half wave, Em by 2 pi into 1 plus cos alpha. Now, the other half also, during the negative portion also, we are getting the output ripple. So, it is 2 times; 2 E m by 2 that is equal to Em by pi into 1 plus cos alpha. This is the output voltage ripple. So, these converters if you see here, alpha can be varied. What is the range of alpha? Alpha is varied from less than is equal to pi 180 degree less than or equal to 0.

So, if you see from the ripple here, when alpha is equal to pi, output voltage will be alpha is equal to alpha is equal to pi, V_0 alpha is equal to 0; alpha is equal to 0, V_0 alpha is equal to maximum is equal to 2 Em by pi. So, that means by varying alpha, V_0 alpha can be varied between 0 to 2 Em by pi for alpha less than is equal to 0, less than is equal to pi. Alpha varies from pi to 0, alpha varies from 0 to pi. Alpha when is 0, it will be maximum; when it is pi, it will be 0.

So, that is output DC. What it shows? This converter can give only variable positive DC voltage with a maximum is equal to 2 Em pi. Em is the maximum, phase maximum voltage, peak voltage not the rms. But many drive applications; let us take the DC motor drive application, we require the machine to go in forward as well as in the reverse direction also. So, from the DC motor principle we know for a separately excited machine, the V_{DC} is reversed. For a particular DC, one polarity of DC, the motor will be running in one direction; the polarity in the reverse polarity if the motor is running, the motor will run in the opposite direction.

So, we require both speed forward rotation as well as revere reverse rotation. So, many of speed control system for DC motor; this is AC to DC control, phase controlled converters with firing angle control. These type of converters are called these of converters with instead of eventhough four switches are there, two are only controllable; we can only have positive voltages. That means only one quadrant operation is only possible. What is meant by one quadrant? Let us see.

(Refer Slide Time: 51:11)



If you take the output, V_0 alpha and output current that is V_0 and sorry we will take V_0 here according to my diagram; this is the output current. V_0 and I_0; V_0 is positive, I_0 also positive, only this quadrant only possible. But many of the drive application, we require all four quadrant operation. That is one, this one that is voltage is positive, current is negative. Voltage is positive, current is negative; what you mean by that one? The net power is negative. That means load is sending power back to the mains.

So, motor system when it is rotating the stored kinetic energy, it will transfer back to the source and system will decelerate. So, this is called regeneration, this region, regeneration and as I told voltage is positive, so direction is in one direction. Let us take, when the voltage is positive, let us take the direction is in positive direction. So, that is positive regeneration. This is or forward regeneration, forward rotation, positive or forward direction, forward regeneration. So, in that case, this quadrant is called forward motor.

Now, in this region, this region that is quadrant 1, let us take this mark quadrant 2, quadrant 2 is forward regenration. Now, quadrant 3; this is both output voltage and current are negative. So, the power is still positive that means power is positive, powerflow is from the source to the load that means from the source to the motor side. So, it is still motoring but the voltage is negative. So, motor must be running in the reverse direction. So, this can be called reverse motor, this is called reverse motor.

Then what is this region, fourth quadrant? That is voltage is negative, so motor is in the negative direction but the current is positive. So, that means power is negative. Power is negative, power flow is from the load to the source. So, this is called reverse regeneration. So, the motor, if the drive system has to work in all four quadrants, we should be able to generate negative output voltage as well as negative output currents. But so far what we have discussed? The converter with two thyrisors and two diodes; voltage is only positive and current is only positive. So, this this type of converters are called single quadrant converters, single quadrant converters and are not preferred for any motor drive applications when you have, the high load inertia of the system is there. Why? To slow down the system, you have to take back the energy from the machine. So, power power has to be momentarily it has to be negative, so it is not possible here.

So, let us think about next. First, so it is only on a single quadrants, thinking about converter, atleast we can have positive or forward regeneration. Forward motoring is possible, forward regeneration is possible or reverse regeneration or the voltage can go negative. So, let us take from the converter point of view. So, current can only go in one direction because of the thryristor and diodes connection or even if you use instead of two diodes, let us think about using four thyristors; so current can only go in one direction. Let us think about let us we can have a negative voltage. So, atleast we can have two quadrant operation; out of the 4, 2 quadrant means voltage is negative. That means forward motoring and reverse regeneration is possible

How? The converter is possible with that one. That means we are talking about current is in one direction and voltage is in both direction. Here we can use naturally let us see the next change in the converter is instead of diodes let us use four thyristors; so these converters are also, the previous converters are semi-controlled converters. Eventhough we are using 4 switches, 4 devices, only 2 switches you are using for controlling the output voltage. So, it is called semi-controlled converters.

Let us take about fully controlled converter. Fully controlled converter will be like this; we remove all the diodes and put thyristors. So, we require 4 thyristors to be controlled A, B and the load will be like this. So, I just generally put a load to show that this load is not purely resistive, it is fully highly inductive. So, we are not talking about you know, so I put simply a load where we can both voltage can be power positive or negative. So, let us see whether in this configuration, whether we can have both positive and negative voltage. This will we study in the next class.