Power Electronics

Prof. K. Gopakumar

Centre for Electronics Design and Technology

Indian Institute of Science, Bangalore

Lecture - 4

Controlled Rectifier Part 3 (Three Phase)

Last class, we concluded with three phase mid point configuration and the firing angle range for inductive load. Now, let us take the discontinuous operation of this three phase mid-point configuration. This will happen when you have a resistive load; this is for understanding the firing scheme of how the converter works.

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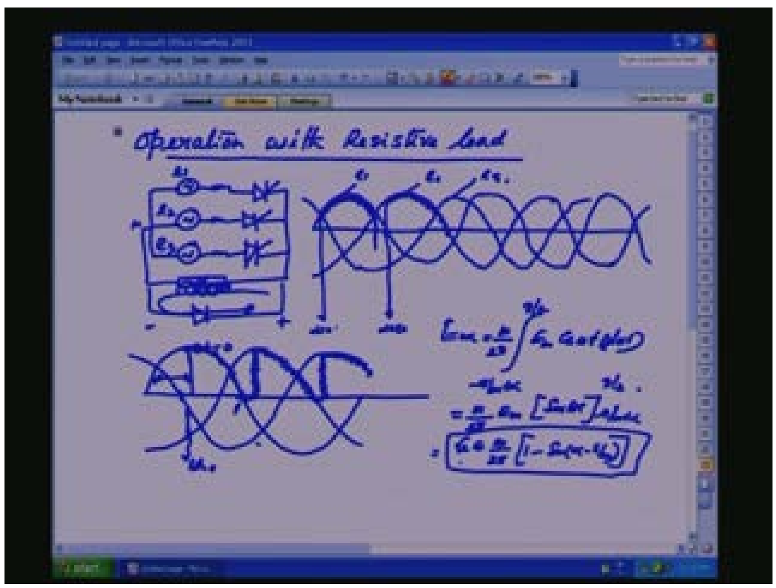

So, operation with resistive load with resistive load; we are talking about 3 phase midpoint configuration. So, the three phase midpoint configuration that last time we have drawn, it will be e_1, e_2, e_3, this is our neutral, e_1, e_2 and e_3. So, we have the small leakage inductors. Take care of the finite on and off duration so that we can avoid the dead short circuits between the phases. So, these are highly inductive load.

Now, in this case, suppose the load is resistive that means resisting, load is resisting; in that case, what will happen? Let us draw the three phase waveform. This, with practice you can do it; A phase, this is the B phase and this is the C phase. So, from this, let us this is okay, this is our e_1 this is our e_2 or e_3 it can be.

Now, last time we told that the firing angle starts from here alpha is equal to 0 here and there are three devices. So, each device will be conducting for 180 degree no sorry 120 degree. So, alpha is equal to 0, this is the envelope that is the e_1 envelope coming across the node when alpha is equal to 0.

Now, let us take when alpha is equal to 30 that means alpha is equal to 30, suppose next phase we are going to switch to alpha is equal to 0 or efi is going to switch on at alpha is equal to 30 that is here; alpha is equal to 0 here, this alpha - alpha is equal to 0 here, alpha is thirty here. Then what will happen? Immediately it will go here, it will come here; like this.

Again, the next phase starts here. So, for resistive load, if you see here the voltage wave current waveform will be in phase with the voltage waveform. So, if slightly voltage goes negative here, it is not possible here. There is no inductive load, so the inductive current - di dt cannot change, the slot current change and you cannot force the thyristor in the on state. So here immediately, the moment voltage come to 0, resistively current will also come to 0 because voltage and current are in phase. The thyristor will switch on immediately. But for voltage control, alpha as I said told before, alpha can go from 0 to 180 degree.

Now, let us take alpha more than 30 degree, alpha more than 30 degree. So, I will again re draw for clarity. This is our A phase, this our B phase, this is our alpha more than 30 degree, alpha 30 here more than let us take at this portion. So, the envelope will be like this. At this point, the commutation stops, the current thyristor switched off. But the next thyristor again will be turned on here only. So, the voltage ripple coming across the load is different from that of an inductive load. So, this is that portion.

What it shows? With resistive load, there is a discontinuous conduction depending on the firing angle. That means alpha more than 30 degree, there is a discontinuous conduction. Now, what will happen as alpha increases? The repel part, the input mains; what are the mains coming across the load will slowly get reduced at alpha is equal to 180 degree, the output repel will be coming across load is 0 that means output voltage is equal to 0. So, this way also a resistive load, we can have a 0 to positive voltage variation possible.

Now, see is it totally possible with a resistive load? Can we have a discontinuation with discontinuity hope with an inductive load? It is possible that means when the voltage waveform goes negative, we should give alternate path for the inductors so that instead of forwarding the thyristor and the current flowing through the thyristor, it can free feel through another path. So, it is possible.

Suppose, the load is inductive or see, if you give a diode like this; this is inductive, load is inductive and with diode. The moment the voltage waveform, this is positive, it can only positive, any time it is negative; what will happen? Current will free feel through this way. This is possible. So, this way we can ensure. Suppose, output voltage we want to limit it, we do not want output dc voltage or instantaneous voltage, we need not want to go to negative, we can use a free willing diode and with the firing angle variation, we can have a output voltage variation from 0 to positive.

Now here, what will be the output dc voltage equation with respect to the firing angle? That we can find out here that is E_0 alpha. Again for a general m phase, it will be 1 by 2 phi m. So, m by 2 phi integral; so integral - lower limit and upper limit depending on whether we are sine omega t or cos omega t. So, let us take Em - maximum value of the phase voltage and cos omega t d omega t. That means we are finding the area in the period and divide by the period. That will give the average value that will give the dc value.

Now, what will be the lower limit? Sine omega t means, cos omega t means here. So, firing angle minimum is here. So, it will be this distance, from here to this distance. This will be for three phase, it is phi by 3; for m phase, it is phi by m. So, lower limit is if omega t is equal to 0 here, omega t is equal to 0 here, for cos omega t waveform. So, when you go to the lower limit, it will be minus phi by m then plus alpha. Alpha can vary from 0 to vary from here to here for symmetry operation that is that we have studied in the last class for example inductive load.

But for a resistive load, the upper limit is for a cos omega upto here. You know that output repel is not coming across the load, this can be used as conductor. So, upper limit is phi by 2. So, if you do the integration here, finally you will get m by 2 phi into Em into sine omega t minus phi by m plus alpha upper limit phi by 2. So, final equation in terms of rms value - root 2 E, E here is the rms value m by 2 phi into 1 minus sine alpha minus phi by m. This is the general equation.

So, for a three phase waveform, for the three phase case, three phase midpoint configuration with the resistive load or inductive load with the free willing diode; why free willing diode? We require the thing to go through the diode only. The output repel waveform will be 0 to positive. Negative, it will not be going, we can plot it. This will be for a three phase case.

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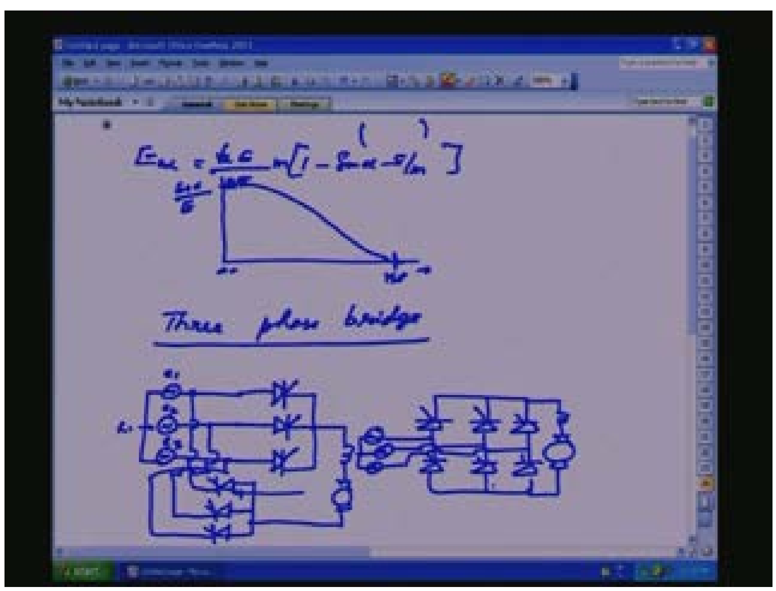

For a three phase case, from the previous equation that is E_0 alpha, it will be equal to root 2 E divide by 2 phi into m into 1 minus sine alpha by phi by m. For a three phase case, we can put all m is equal to 3. So, approximately the curve, approximately will be something like this; at omega t is equal to 150 degree we will have to start this continues conduction. Maximum will happen alpha is equal to 0 degree. This is E_0 alpha by E rms, E_0 alpha by the maximum value that is what is the maximum value? Ed_0 maximum here; so when you do it, it will go like this.

Now, we have studied about 3 phase midpoint configuration. Now, again for high power applications, also to increase the output dc voltage and also to reduce the repel content that means increase the repel voltage, we have to go for three phase fully controlled converter. That means same like single phase fully controlled converter, we have to go for the three phase fully controlled converter.

So now, we will start studying about the three phase fully controlled converter that is three phase or three phase bridge, three phase bridge. So, how the configuration will be for the three phase bridge? Let us go to let us start studying about the three phase bridge. Three phase bridge here; same like three phase half controlled bridge, we will be rectifying the waveform during the negative portion also. So, this can be returned like this to start with. This is our previous positive side; we will go for making the figure clarity better, so we are removing the inductance now. We have the mains here - e_1, e_2 then e_3, this will go here. As before, cathodes are connected to wave.

Now, we want the negative portion also. So, what will have? We will connect diodes like this no sorry thyristor like this, 3 thyristors. So here, the cathodes here are shorted together. So, for negative, here we will anodes are shorted too. So, the load will be across this one and it will be connected here. Now this side, this would again, it will be connected to e_1 side. What will happen? This will go to e_2 side, then this e_3 will be connected here, this in the negative side also.

So, from the analysis from positive side, we are exchanged to negative side. Negative side also we want to connect, the thyristor to conduct and the current conduction that is current will conduct in this direction that will be even though that will be done through the inductive load, it will force through this one.

Now, in a simple way, we can again but this is the way it extends from positive side to negative side. Now, if you see, the actual rectifier in the text book, it will be like this. That means this the same connection, in a simple way we can represent like this where this is for the positive part and this is for the negative part and here is our load. e_1 and e_2 are here; e_1, e_2 is this way, e_3 is this way as before. This is the neutral point that is this point. So, this is an exception of this one. The concept, negative side also we can use it; the same way then opposite to way the thyristor has to be connected and this three phase fully controlled configuration can be derived this way.

Now, let us see what is the firing angle range? And, where the alpha is equal to 0? What is the output waveform, output dc, output repel and also the output dc with respect to firing angle? We will we will study now. So, let us go to the next page. So, we will redraw the three phase wave again here for clarity.

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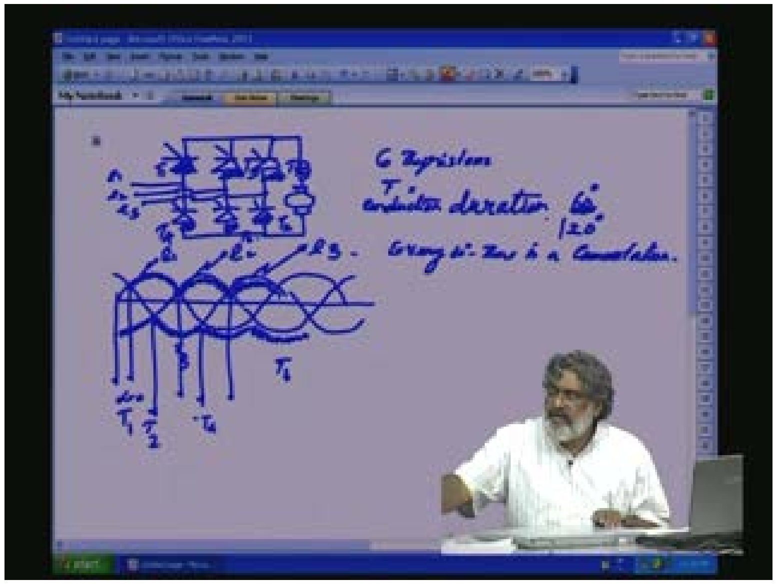

This is the positive side, this is the negative side, so we are trying to make use of the input waveform for power transfer positive as well as negative side. So, maximum utilize says now the three phase mains. This is e_1, e_2, e_3, load is here. e_1 e_2 e_3 this e_1 e_2 e_3 can be represent as a b c or r y b.

Now, how the commutation starts? What are the sequences of switching? If you see, there are 6 thyristor and in the cycle of operation that means ts period, the period fundamental period is equal to T, it is a 360 duration. So, each thyristor, the conduction duration for symmetric operation, the conduction duration for symmetric operation, the conduction duration for each thyrsistor will be 6 means how much it will come? It will be equal to 60 degree. See, each thyristor will be conducting, totally only 60 degree duration in a 360 pm interval.

Now previously, when we discussed about the top and bottom, each thyristor for the half bridge, each thyristor will be conducting for 120 degree and every 120 degree, there is a commutation process initiated. Now here, how it will happen? Let us first draw the three phase mains waveform. All these phases control converter using thyristor, these are naturally computational that means the incoming thyristor will force the previous conduction thyristor by applying the reverse voltage across it from the incoming phase.

So, let us draw the three phase waveform. This is our A phase, 120 degree, we have the B phase, then 360 degree, we will have the C phase or e_1 e_2 e_3 . So, this is e_1, this is e_2, this is e_3. Now, alpha is equal to 0. Let us take e_1 when the e_1 phase is, at this instant, if you see here, if you take omega t is equal to 0 from here, omega sine omega t, we are staring from here. Let us take for e_1 to turn on, the positive e_1 is positive here. So, from this point to this point, for the positive side, if you see here e_1 will be conductive sorry e_1 is positive and T 1 will be conducting. So, this is T 1. So, this is positive, this is T 1. So, e_1 will be conducting.

Now, e_3 is here; if you see here, e_2 is more positive from this point to this point sorry e_2 is more negative. So, the thyristor which is maximum, negative e_2 negative, so that will be conducting now. So now, we have initiated the firing angle from here that is initiated the firing angle process of alpha is equal to 0 from here. Now, from here to here, e_1 will be conducting but at this point, after that this point, e_3 will become more negative. e_3 is more negative means the next thyristor to be turned on. First 1 is turned down, then next is this is T 2. So, this is this direction is for T 2. So, e_3 negative, so this is T 2, next is T 2. See, as I told before, see the positive sides and negative sides are independent of each other from the previous diagram.

So, as before, the conduction duration for the upper limit as well as the lower limit is 120 degree not 60 degree. So, this is 120 degree not 60 degree. But if you see here, every 60 degree, there is a commutation. That means there is a new thyristor turned on. This is T 2. Now, at this point; so we are turning on, alpha is equal to 0, we are turning on T 1 here. Then at this point, we have turned on T 2. Now, upper limit; e_2 is going more positive, so T 1 should be switched off and T 3 should be turned on, next is T 3. So, this will be T 3, this is T 3, this is T 3 so but at the lower side, here e_3 will be e_1 more negative.

So here, it is T 4 e_1 more negative means T 4 means here, this is T 4. Now again, e_3 will become more positive here at this point. At this point T 4, T 1, T 2, this is T 4, this is T 3, e_3 become more positive, e_3 will become more positive here sorry at this point, e_3 become more positive; so which has to be turned on? Now, the T 4 is on. The next thyristor will take as T 5 here. Then here, e_2 become more negative after 60 degree that is T 6, this is T 6. So, we will again draw the waveform and the conduction duration again we will again write for clarity. So, let us go to the next page now.

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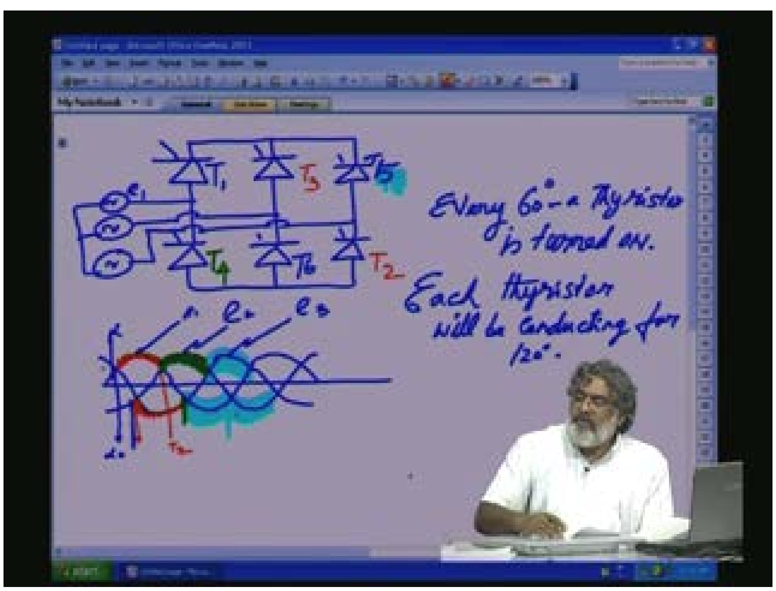

So, this is one thyristor, we will make it bigger; then each phase will have a positive and negative part and this can be independently triggered also as I told before, these are independent because this is the positive half bridge, this is negative half bridge. Now, this is the e_1, e_1 here, next one e_2, next is e_3, this is our neutral, e_3 here.

Now, let us draw the phase waveform again. This is e_1, 120 degree you can have approximate, e_2. Now, you can have e_1 e_2 e_3. So, our alpha is so we will try to understand again for alpha is equal to 0, so e_1, this is e_1, the first one is e_1 that is this one e_1, this is e_2 and this is e_3. Now, alpha is equal to 0, we are firing here. At alpha is equal to 0, e_1 is more positive. So, thyristor one is fired. So, e_1 side positive, this is e_1, this is e_1, the positive side thyristor will be this one that is T 1. So, T 1 conduction duration will be this period, upto this period, T 1 will be conducting. Then only the next positive side T 2 will conduct. So, T 2 conduction were this is the T 2 conduction period. At this point, we will be initiating T 2.

But if you see the negative side that is this portion, if you see here e_3 is more negative, after e_1 is more positive, e_3 will become, so each phase whether positive or negative limping be at the same firing angle alpha, alpha is equal to 0, we have to use for positive also negative. So, positive alpha is equal to firing angle here; for negative, the firing angle alpha starts from here. The firing angle alpha that from there the phase becomes maximum negative, here the maximum negative will be e_3. e_3 will be maximum negative. So, here the T 2 thyristor will be conducting; this is T 2, T 1, T 2.

Now, e_1 is still conducting. So, at this point, e_1 at sorry e_1 phase is not positive, T 1 will be conducting and T 2 will be conducting. Now, at this point e_2, the phase e_2 become more positive. So, T 1 has to be switched off and next positive one thyristor at the positive side has be turned on that will be T 3. So, T 3 will be e_2 positive will be this is T 3. So, T 3 conduction period is from here. So, we can mark it now with a different color that will give clarity. So, let us take green. So, this is the conduction duration for T 3.

Now, after some time, after T 3 is turned on, after 60 degree that is this point e_3 e_1 phase become more negative. So now, the T 2 has to be switched off and next thyristor has to be turned on. So, next is T 4 at the e_1 phase maximum. So, this is T 4. So, T 4 duration will be let us mark it with another color, let us take this color. So, this is the duration for T 4. Now again, positive is after 60 degree, there is a conductor initiation is required at e_3. e_3 because more positive than e_2, so T 4 is our next positive side will be next side will be T 5 at the positive side of this one. That is T 5, then, last e_2 becomes negative that is from this portion onwards that is T 6.

So, if you see the sequence, 1, 3, 5, in top and 4, 6, 2 that is T 6, T 6 is this one sorry so the next phase will be so I will just clear this part. So, next side part will be here it is T 6, this is T 6. So, the sequence if you see, T 1, T 3 and then T 5, this is T 5; T 1, T 3, T 5, T 4, T 6, T 2, this way we have to turn on, this is the sequence with which we have to turn on the devices, alpha is equal to 0. Alpha is equal to 0 for positive side, negative side at the same point that is whenever the two adjacent phases just cross equal that is the point that is for positive side, this is alpha is equal to 0 starts here; for negative side, this is the way and these 2 are independent.

But for symmetry of operation if you see, every 60 degree a thyristor; every 60 degree duration, a thyristor is turned on is turned on. Each thyristor will be conducting for 120 degree, 120 degree duration. So individually, we have written the repel content for alpha is equal to 0 for positive side and negative side. So, what will be the net output repel? Net output repel will be the positive minus negative. If you see, instantaneously will you give the next output repel, that you can do it.

So, if you see, the output repel will have a 6 pulse content. So, in a 360 degree, the duration will be that means every 60 degree you are initiating. So, it is like a 6 pulse waveform. The repel have a frequency will be 6 times the fundamental. How do you do it? The positive side and negative side; positive side, assume the previous as I told you, positive side if you see here that is this portion that is this portion, this voltage or this voltage with respect to the neutral here. Let us take this is VA - upper side. V, this is N, VN. So, total voltage across the repel that is instantaneous voltage repel, this. Let us see, this is B. So, Van that is half bridge, positive half bridge repel minus the negative half bridge repel. AN minus BN will be, it is already negative, so when you subtract, it will become again positive. So, AN minus VN is a repel content. You can, this we can find out easily. So, output repel will be the positive repel minus negative repel. So, as the alpha is increased for the positive side, the corresponding increase for the negative side also should be increased or symmetry operation.

Now, let us take this is for highly inductive load. What will happen if it will be a resistive load? Or here also as before, if we do not want the output voltage, we do not want the output voltage, negative portion is not required. Three phase, we are using just before some power converter application where we require large power. So, high voltage is required but at the same time, we do not want the negative voltage that is firing angle control. We do not have to control in such a way so that output should not got negative. Then what will, then how this can be achieved? See, here, we can, lets go to next page.

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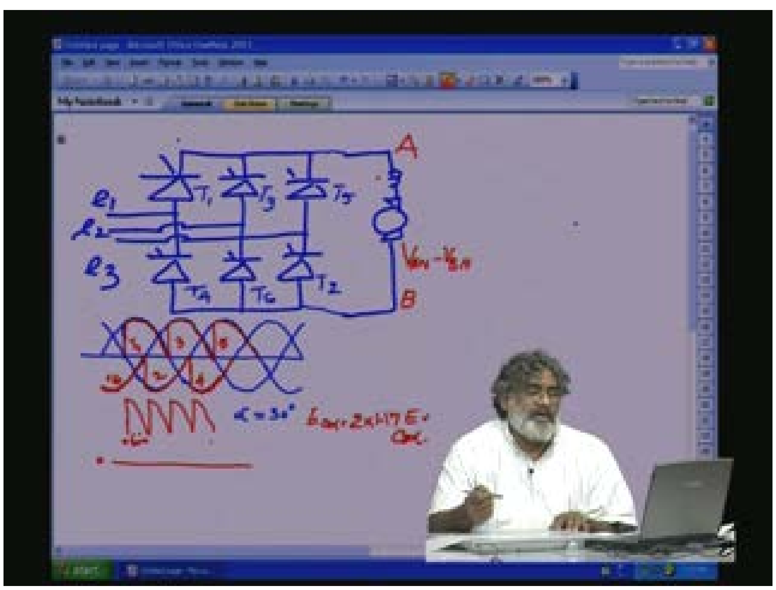

As before, for the single phase and three phase mid point configuration, we can conduct we can connect a diode. This is our one way to e_1 e_2 e_3. See here, if you do not want a negative, negative repel if you do not want to appear on the load side, you can put a diode. Then, same like midpoint, you will get a discontinuous conduction. So before coming to that one, let us find for a three phase fully controlled converter, what will be the output voltage repel, output dc with respect firing angle? For the three phase half bridge converter, we found it is e_0 alpha is equal to 1.17 E rms into cos alpha - This is for three half phase.

So, we can assume for the fully controlled converter with inductive load, not with freewheeling diode, freewheeling diode is not there that means we are trying to get more both positive as well as negative voltage. It will be for the three phase, e_0 alpha three phase fully controlled converter. It will be two times with symmetrical firing angle. For the both positive as well as negative, it will be 1.17 into e cos alpha. So, this we can easily derive or we can draw the repel and we can find the integration also, we can find out that one.

Now, if we put an output diode, whenever the output voltage repels goes negative, the load will freewheel through the diode. So, that means the negative portions will be clamped to zero level across the load. So, this means with firing angle, we can have 0 to positive voltage here. But before coming to but we require one extra diode here. So, in a similar in the same way, what we have single phase case; can we get away with diode? Then we have to use a three phase semi converter. Before coming to semi converter, let us find out what is the type of repel for a three phase converter without diode. What is the type of nature of output voltage repel that coming across the load?

Let us take for a firing angle alpha is equal to 30 for this converter, for the three phase converter. So, we will remove this diode for the time being and we will connect the load here. That is load is connected here. So, let us see how the output repels comes and again we will mark the thyristors. This we know, this is T 1, this is T 3 and this is T 5; T 5, 135 then this is T 4, T 4 then this is T 6 and this is T 2.

Now, let us draw the output repel for the three phase fully controlled converter. Let us draw the three phase voltage waveform V1, V2, V3. This is e_1, this is our X axis e_1 that is e_1. Now e_2, this is e_2. Now e_3, e_3 will be 240 lagging with respect to e_1 or 120 lagging with respect to e_2 . We got the waveform. Now, we can think about the positive half as well as the negative half. The positive half, the firing angle alpha is equal to 30 that means we are firing alpha is equal to 30 here, 30.

Now, for the T1, alpha is equal to 30 means starts from here. Probably, we will use this is e_1, we will use a different color so that the clarity of the repel will be here, we will use red. So, this is the voltage repel coming across the load when T1 is turned on, T1, this is T1. Now, at this point that means we are taking the positive half bridge, three will be fired. So, three will be means it is here, here three. That is thyrsistor three. Then here, the thyristor five, it will be turned on this is 5.

Similarly, for the negative, when the phase voltage goes negative, the bottom devices T 4, T 6, T 2 has to be switched on. So, let us say when Vy and Ve_2 is negative that is this is when e_2 is negative that is this portion, the thyristor T 6 will be turned on. So, T 6 will be V 6 T 6 portion. Then, after T 6, this waveform; this waveform is the e_3 waveform, e_3 going negative means T 2 will be turned on. So, from here, T 2 will be turned on, this way. At this point, e_1V 1 negative maximum negative; here T 4 will be turned on. So, it repeats like this; this is 4, this is 2 and this is 6. So, we have repel voltage for the positive and repel voltage for the negative.

So, if you see here with respect to our mains negative, mains neutral, the positive part, we can call as positive part we can call as A, the negative part we can call as; instantaneous values of the repel due to the positive, we can call as AN, AN is the neutral point BN. So, the net voltage output voltage is positive instantaneous subtraction of positive minus negative that is V_{AN} minus V_{BN}. So, V_{AN} minus V_{BN} will be there.

So, the positive say that the positive repel is here, the positive repel is here and the negative repel is here. So, what will be the net? What will be the net repel coming across the output? V_{AN} minus V_{BN} that means instantaneous values; the positive as well negative if you subtract, the repel waveform will be like this. So, this will go, the cycle. So, this is 60 degree duration. So, we have the repel will be 6 times the fundamental, this is 0.

Now, as the firing angle varies; so this will have an average dc voltage when alpha is equal to 90 degree, here also it is output voltage is equal to output voltage is equal to e_0, alpha is equal to 2 into 1.17 into E rms into cos alpha. So, alpha can vary from 0 to 180 degree. When alpha is equal to 90 degree, the repel will have equal positive and equal negative output dc will be 0.

Now, we want the output voltage fully from 0 to positive and we do not want the negative excursion. Then I told you that we can put a diode across the load so that load can freewheel but one more extra diode is required. So, here also three phase fully controlled converter can work as in a semi converter mode that is three thyristor can be controlled; other three can be used diode so that the voltage can go from 0 to positive all the time. How it will be? Let us see.

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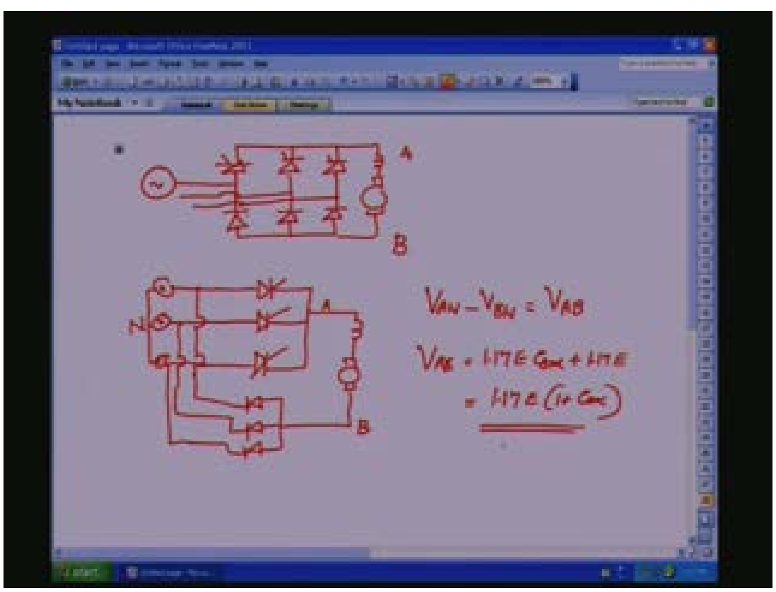

We want only positive voltage 0 to positive output dc voltage, so the bottom converter, the semi the converter we will use diodes. The bottom switches, we will use diodes. So, this is the e_1 e_2 e_3, here is the load.

Now, we have diodes here. The diodes one advantage of diodes; the moment it is forward biased, it does not require a gate pulse to turn on. The moment it is forward biased that is anode is positive with respect to cathode, it will conduct immediately and as I told before sorry we will just correct it. We will redraw once again.

So, this is diode, so here diode, so that the diode will; so here, the moment the diode is forward biased, output will be quickly, diode will be forward biased, immediately it will conduct.

Now, as I told before, these two can also independently we can control as the previous case of midpoint conversion during the positive, converted during the positive half cycle of the waveform converted during the negative half cycle of the convertor. So, that means we have the e_1 here, e_2 here, e_3 here. So, the positive side, it will be like this. This is our A side that is A side. In the A side, we will connect the load.

So similarly, the diodes are like this; here this point will go here, this is called B, this is also B, e_1 e_2 e_3, this our neutral point, load is connected like this. e_2 we will redraw this one that is e_1 and here, this is our neutral three phase neutral side. Now, output repel, total output repel is output repel due to the top thyristor converter that is V_{AN} minus V_{BN} is equal to V_{AB} that is a instantaneous voltage repel across the load. So, we can consider these two independently, then we can find out what is the repel. Independently means the top thyrsistor with firing angle alpha, the bottom diodes with firing angle alpha is equal to 0. So, the net voltage V_{AB}, we know for that V_{AN} will be equal to 1.17 E rms into cos alpha.

What about V_{BN}? V_{BN} is due to diode with firing angle alpha is equal to 0. So, it is already negative. So, minus of that one will be plus positive. So, this will be equal to 1.17 E rms because diode cos alpha is equal to alpha is equal to 0 cos alpha is equal to 1. So, the net voltage for the semi converter is equal to 1.17 E into rms that into 1 plus cos alpha.

Now, in the previous slide, we showed that for a three phase fully controlled converter output repel is 6 times the fundamental frequency. But let us see what will be the type of repel for this diode, thyristor and diode configuration? Here, we have introduced diode configuration so that output voltage we do not want to go negative. If we does not want to go negative means let us see whether this will happen that means we can only with the firing angle, we can have only it can have only 0 to positive value. Let us see a typical output voltage repel for firing angle alpha is equal to 60 and alpha is equal to 90.

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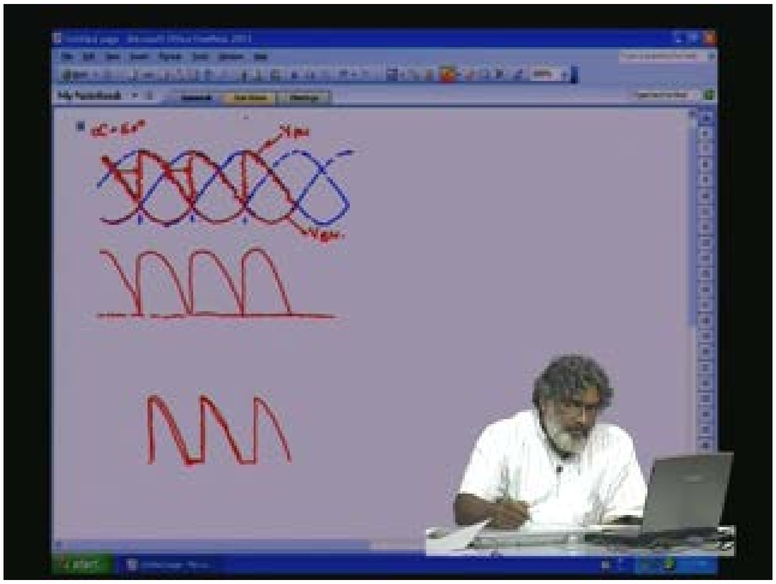

So, let us draw the waveform for alpha is equal to that is upper bridge alpha will be turning will be firing with respect to angle alpha is equal to 60 degree. So, let us draw the V_{AB} e_1 e_2 e_3 waveform. This is our e_1 waveform. Let us draw e_2. e_2 will be 120 degree lagging with respect to e_1. Let us draw the e_3 waveform.

Now, let us take the voltage repel due to the diode. Diode will conduct at when firing angle alpha is equal to 0. So, alpha is equal to 0 any phase starts from here; here and here. So, the conductance, so the repel due to the diode, the negative side is like this. This is the diode. Diode will act as negative side. That always for act as a three phase half bridge configuration, three phase half bridge, three phase half bridge rectifier. So, the repel is like this.

Now, depending on the firing angle, the upper limp repel will vary. So, now here, in the present case, we are studying for alpha is equal to 60 degree. So, 60 degree means it will be like this. See, this is the from here to here and then from here it will immediately go here, this way. So, this is so every 60 degree, it starts from here. So, this is 60 degree. Similarly, this is 60 degree. It will come here. So, this is the repel, this is the AN repel, this is the V_{AN} repel and this is the diode that is the V_{BN} repel, V_{BN}. So, V_{AN} minus V_{BN}.

Instantaneous value if you plot it, it will be like this. Here if you see, this is the 0 line, alpha is equal to 0. The repel exactly comes to zero line and then switch. But if you see, compared to the fully controlled converter, the semi converter repel is three times the mains. But the fully controlled converter it is 6 times. So, the repel content the 0 repel current the current the repel current repel content of the current will be much less in a three phase fully controlled converter compared to three phase semi controlled converter that means with thyrsistors and diode. So, this is 60 degree.

Now, let us say alpha is equal to 90 degree; alpha is 90 degree, we can draw it. Then the repel will be like this; alpha is equal to 90 degree, this portion goes negative. The moment goes negative, the thyrsistor and diode will act as a short circuit. So, they are discontinues that means output repel will suddenly, output is shorted equivalent to putting a freewheeling diode. It will come here, this is the one.

So, as the firing angle increases, slowly this discontinuation period will increase and output voltage will come to 0. So, the equation for the output diode using thyristor and diode as I told you, Ed_0 into 1 plus cos alpha for the semi controlled converter; so, it will come like this.

Now, why we have come to the semi converter? So, many drive application, we may not require the output voltage negative. We want only a voltage control from 0 to positive. Then we need not use thyrsistors because thyrsistor if we use, with using thyrsistor and with alpha control, we can have always from 0 to positive voltage. But the problem is with thyrsistors again we require extra gate drive circuits. So, it is expensive. So, instead of that one, we can do away with diode that is the purpose.

Now, so far, we have assumed that the conductions are instantaneous; conductions are instantaneous and that there is no delay between the incoming switch incoming thyrsistor and the commutating thyristor. The moment reverse bias is applied; we assume that the conducting thyrsistor will immediately switch off. But that is not the practical case. In many practical cases, there is a finite time for turn on and turn off process. So, let us see what will happen due to finite time required for turn on and turn off process? Is there, we will introduce any problem in the output voltage? Let us study that one.

Now, so we will go to the effect of finite on time. So, this is called commutation process. So far, the formulas derived in the previous sections are based on the assumption and commutation process is instantaneous. There is a current switch on and off are instantaneous. But due to the presence of line inductance AC supply, the transformer and the SCR circuitry will not permit instantaneous current change. See, even though the thyrsistor can be easily turned on and turned off but there will be if finite line inductance, transformer inductance. So, we are conducting limp cannot switch on switch on or switch off the current instantaneously due to the finite inductance.

So, apart from the finite turn off and turn on time, the circuit inductance because of the circuit inductance, the leakage inductance, due to wiring or power circuit bus structure or the due to the transformer, there is a delay in the turn on and turn off process. So, this can create a decrease, even though the decrease in the output dc voltage due to this commutation overlaps. What I mean, turning on and turn off time, they are not instantaneous. There is a period, the commutation process goes through. That is called the commutation overlap. Due to that, there can be a reduction in the output voltage. So, we will study about that one in the next class.