High Voltage DC Transmission

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Module No. # 02

Lecture No. # 05

Testing of Hypothesis – III

Let us start the lecture 5 of module 2. In this lecture I will continue the analysis of the converter circuit and we are discussing about the 6 pulse converter circuit and it is rectifier. Last time we saw in the rectification mode we saw the various voltages including DC voltage and also we saw the valve voltage and we also found this current in the various as valve as the phases current and of course the DC current we have assumed that this is a constant.

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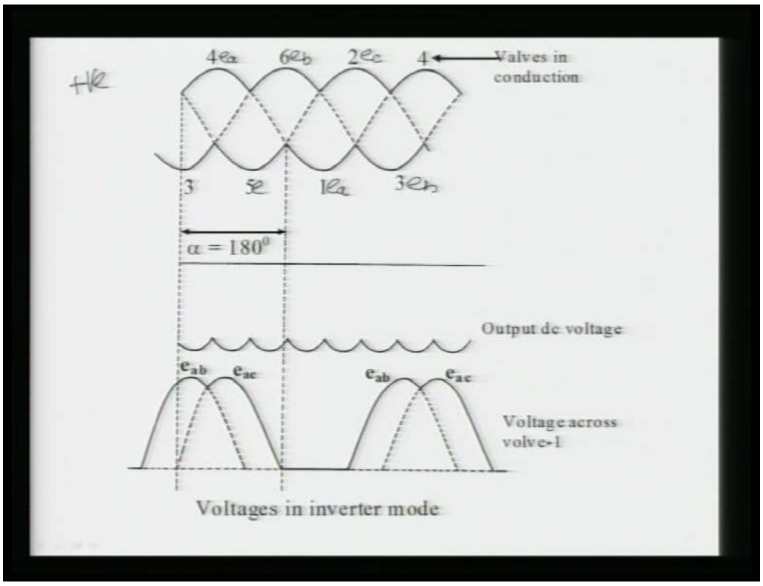

To know the inverter operation again the circuit which I had shown here this is 6 pulse rectify with the numbering of valve 1 3 5 and 4 6 2 we have the 2 groups.

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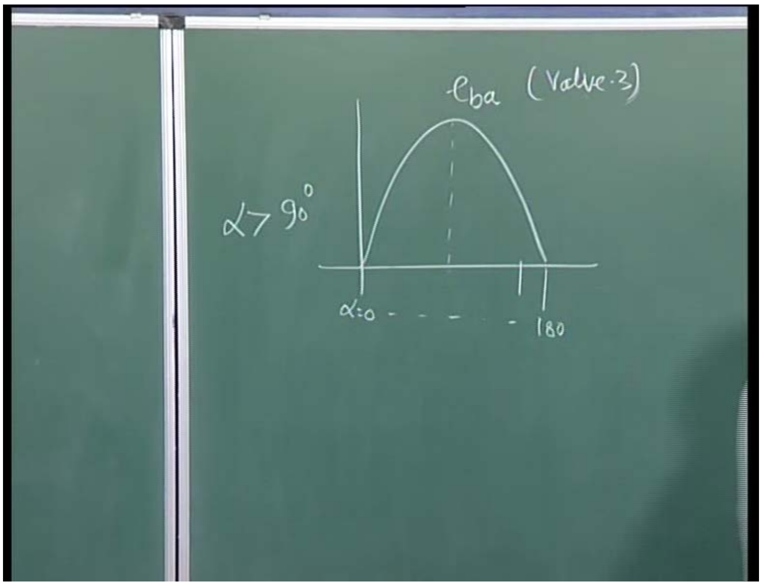

Now in the inverter operation what we do we have to delay the firing of angle as I said the commutation voltage of a valve 3 it is e b a. This is a commutation voltage of the valve 3 here done valve 3 is this valve will be fired if the gate pulse is available from here. This is a alpha is 0 and we can to go up to here alpha is 180 degree. In the rectification mode if your alpha is still here 90 degree you are getting the 0 voltage at 90 it is 0. Just before here you are getting the positive output across this converter circuit and once your alpha is more than 90; the voltage going is to be reverse that is negative and we can fire in this duration because the voltage across valve will be positive and then we can get the gate pulse and 3 will be fired.

So, this is your commutation voltage of the valve 3 in the inverter operation means a alpha is a delayed means alpha is greater than pie by 2 are 90 degree. In ideal case if alpha is 180 degree means we are firing here. Although there is some minimum angle required that we cannot fire between this spirit normally this is a safer portion and we should avoid and will see later on. This is called the extension angle or the commutation margin angle. But, for ideal case let us say the alpha is delayed up to 180 degree than we can get this following voltage. Here you can see the valve number are in this figure it is given that is valve 4 6 2 and 4 means they are conducting during that period the first here the portion it is showing the voltage at their first terminal this terminal here I can say. This is the terminal one; link here is the one here is two I can say top and bottom.

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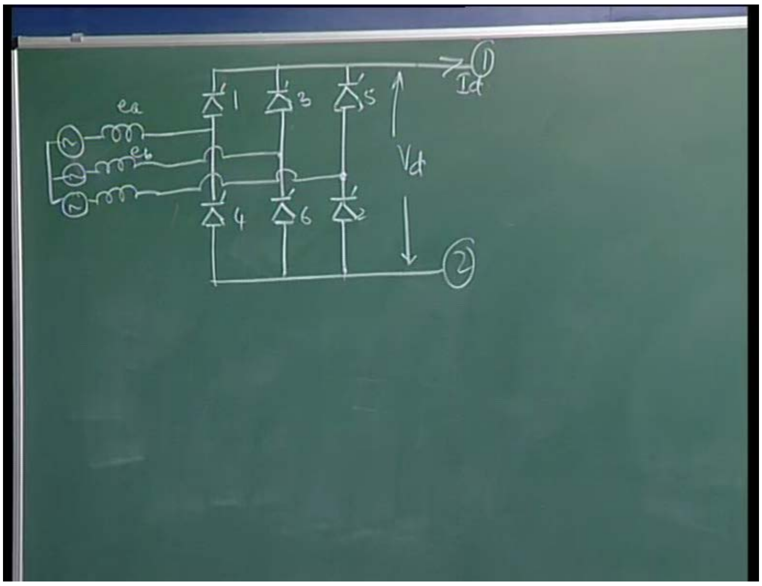

So, the upper portion source that your top voltage and below one this one and your output voltage will be in the first I can say the voltage this minus this will be the instantaneous voltage across the link. Now, you can also see if valve four is conducting what will be output voltage at that plane? Four is coming means here it is your nothing, but, it is your e a because 4 is connected to phase a. So, here if this is conducting means voltage here will be appearing your phase a voltage and similarly, if 6 is conducting than e b, 2 is conducting than e c. Similarly, here 1 is conducting than e a this 1 3 is conducting than e will be appearing and so on so forth. So, if valve numbers are written to you than you write what wills the voltages that is a phase voltage that is appearing on upper and as well as lower limbs. So, here the 6 it is your e b here 2 is e c and so here similarly, you can see 1 is your here e a 3 is your e b and 5 your e c I know the voltage the final the top voltage minus below voltage will be our output voltage. Now, from this phases whatever here it is shown if we are going to write this minus this, you are going to get this voltage and this is you can see, this is your excess here we are getting the line to line voltage and that is the 6 pulses are coming in one cycle and this can get your voltage. If this terminal becomes negative this terminal will become positive and so on so forth. So, this is a concept of the negative and if you will see the valve voltage here now it is coming this one when it is conducting to be 0 and most of the time here it is the positive. Here alpha is assumed as 180 degree mind it. If alpha is less than 180 degree will have the different, let us say and that we can see in the next week.

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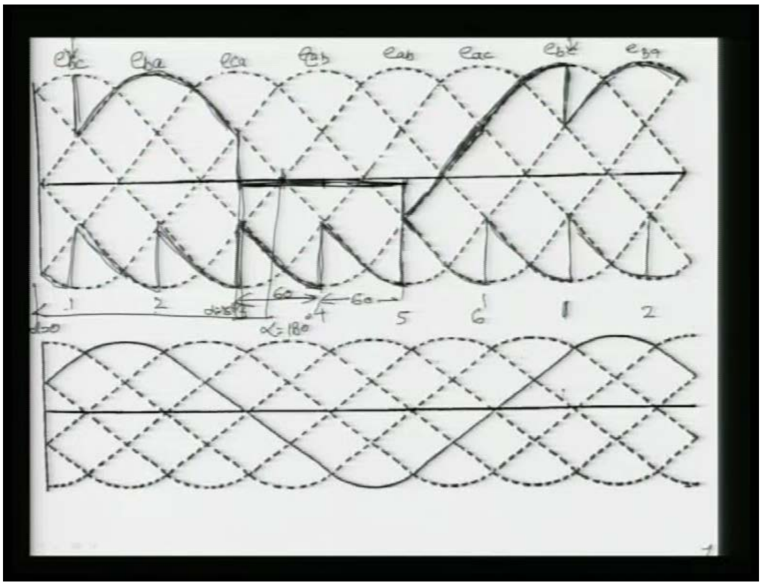

Let us draw what will be the output voltage in the case of inversion means your alpha is, let suppose take alpha is 150 degree in the previous case.

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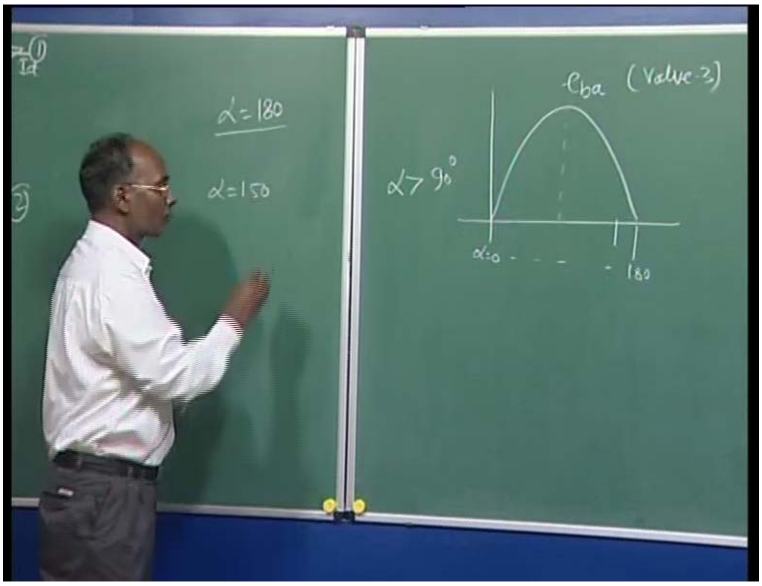

It was your alpha was 180 it was just equivalent to a rectifier circuit the voltage magnitude will be the same when alpha was 0 only the quality is different. Now, I am going to take if alpha is 150 degree means where you are just you have to draw what will be the output voltage across this and we will also will find what will be the voltage across any valve on the same figure. Again here in this this is a top figure that is showing it is a line to line voltage and the below one can be taken as the phase voltages. So, I can start here is writing it is nothing is given I can write e b a and this e b a is a you know the commutation voltage are the valve three. So, we can fire our valve any period from here from here to at this point we can. So, as I said here e b a is the valve three commutation voltage and we can fire here from this up to here when your e b a is positive means alpha here is 0, here alpha is 180 degree. Now, I said I want to draw the output DC voltage. Let us first draw and for knowing this output voltage we had to know the various line and voltages and already I have to mark e b a than we have to mark other line to line voltage very clearly than we will get the output voltage. So, this is e b a. Then 120 degree will be displace that will be your e c b here this voltage and then another will be your e a c. This is your c b. So, we have marked 3 voltages because you have to again go for cyclic one. So, e b a you have marked. So, b become c and a becomes your, a become c b and here e a c similarly, we can write this. Now, you can see this is your this voltage e a c here it is nothing, but, e c a just you can see from here this is reversal of this voltage on the top and similarly, we can write here this will be your e a b. Before that we can write this voltage is the reversal of e b c. So, these are the line voltages. How I wrote? Here from very well I just define first one e b a and then you can is the 120 180 degree now another 120 degree this is the 60 and 60. So, that will starting here it will be your b becomes c and a becomes b. So, I have written e c b. From this cycle you can see again 20 degree here. Now, it is your c becomes a and b become c and this is that. Now, for intermediate you can see this voltage is coming here this is the reversal of this. So, it is become c a rather than a c because just we have reverse the minus sign. Similarly, we wrote here the b c it is the reverse of c b and so on so forth. So, you have to mark very clearly line to line voltages top as well as the bottom. Now, as I said I want to draw out put voltage corresponding to alpha is equal to 150 degree. Now, you have to see where is a alpha alpha start here mega t is equal to 0 at the beginning of this graph. So, now, this is a 180 degree, this whole cycle of this. So, you are going to have here this is your alpha is 150 degree because this portion here, 60 degree. You can see in this this is 60 60 and 60. So, 180 degree. So, this is your 60 degree and half of this is 30 degree. So, 80 minus 30 is 150 degree it would be line here and we find this is a cross section here 30 degree.

Now, we had to now we are just giving a firing pulse at this point here you three is going to fired once your 3 is going to be fired. Now, what will be the output voltage you can see from here as you know this is three is fired now here we are getting e b and before that we assuming this one and two are conducting and three is giving the pulse 2 were there. So, here it is your e c was there. So, the voltage here e b minus e c will appear. Now, you can see where is e b c is there in this graph. Now, you can find this e b c here it is starting at this point. This is e b c you can see as I marked here also this is a once you're giving a pulse here suddenly it follow the e b c because this was a e b c. So, this is starting from here and now this will go up to 60 degree. Again after 60 degree your valve 4 will get the pulse and once your valve 4 is getting pulse means just you move here ahead. It will be, this is coming here will see and before that also we can plan, but, right now let us see we are going to give the 60 degree here it is firing means your 60 will arise here. Because the 30 and 30 always, here it is your 30 degree it is conducting then next here 30 degree means 60 after all the valves are getting beginning I assume the valve are getting pulses after every 60 degree. So, at this point your valve 4 will get pulse and once valve 4 will getting a pulse here; now you can see this is coming here it is a and this was your e b means we are going to have e b a. So, we have to find where is e b a and then it will suddenly follow and you see where is e b a at this pulse. So, e b a you can see here it is at this point it was showing here till and then it is going to follow here e b a. This is your e b a it is going to follow you see e b a and then it will again go here till again 60 degree here where your valve 5 is fired. Here wall 4 is fired just we are writing the valve it giving the gate pulses because you can see the different between here than here it is 60 degree. So, next 60 degree here, it is your and it is a sequential firing 3 4 5 6 1 again it gives a cycle one. So, it was here it was coming here than it was coming here and now we have reached here. Now your valve 5 is getting pulse now valve 5 is getting pulse now what will be the output voltage it will be e c e c a and e c a you can see it is suddenly here it will jumping this one because e c a is this one. So, your output voltage you will see it will be continuously it will be like this. It will be going like this and here again here this is. You can also complete for one cycle. You can go before as here and will find this is your, this is a it was going like this and like this.

So, it was 3 2 and 1 you can also verify that this will be the output board because 3 again 1 2 3 4 5 6 1 2 again it will be going cyclic order. So, this is your output DC voltage which is appearing across this in case of inverter mode and we had taken alpha equal to 150 degree. If alpha is not 150 degree, it is 180 degree this firing will start at this point here and that it will go, this will be ugly, this line will be sitting like this, but, it will be coming here at this section and than we are having this pulse. All the pulses will give in.

Now, this is your output voltage that is appearing across your, this link and this is you can see this is always the average here if you calculate it will be you're the DC and also you can verify by your output voltage equation. You can just simply v d you can just find your v d o cos alpha. Put alpha equal to 150 degree it will be negative and some value will be appearing. Now, the main important here although this is a very simple case we are assuming the overlap 0 means commutation from one valve to another valve will be the sudden instantaneous because when you're getting the pulse three is taking complete current from here and sudden sweep is there. But, it is not true, but, we will see in the next cases for when the various mode of operation will be there. Now, I want to draw the valve any voltage here let us suppose I want to draw the valve three voltage, again on the same plane. Here, I will also draw here because the voltage will come on the. So, it will be here clearly visual now you can see once valve three is fired we can start from here, the voltage across this will be 0 and it is continuing up to here because each valve is conducting for 120 degree. So, the voltage across here actually here it is no colour so, but, we can write here this is a volt here we are coming up to this one. So, this is valve 3 is conducting during this period. So, the voltage will be 0. Now, after that three is off and fifth is taking care. Now, we can see if the fifth is taking care here. So, voltage across this is coming your e c and this will be e b always.

So, the voltage across this will be e b c and once fifth is going to be fired is fired than the voltage across this will be e b c and we have to see where e b c. E b c you can see this is your e b c is coming all the way here this is going here and suddenly it is coming here e b c and it is following this because this is your e b c this portion e b c you see this is e b c is coming. So, it is going here and it will continue let us see once your 6 is here getting pulse once 6 is getting pulse there be no change it will follow the same because here 6 is pulse still the fifth is conducted. So, what will happen here? It will follow till even though 6 is fired here and it will continue. the Here the change of the valve voltage will only occur if there will be any conduction here in the upper layer if we are talking about this. So, this is conducting or this is conducting then it is going to change. Changing here will not change here because that time was same valve was conducting. So, it will follow even though up to the 6 wall firing; it is going to be your, this one and it will be going up to here. This is 6 is fire and still it will continue and here one is going to be fired. So, it will be going up to this portion here this is your valve voltage I am trying, the thicker line. Now, 1 is fired than a is coming under cathode of three valve and this also there. So, the voltage across three is a b a. Because b is here and a is coming here. So, this is e b minus ea voltage always we are trying the direction. So, e b a and now you have to see where is e b a. You can see e b a; e b a is a then this 1 this is your e b a e b a and it will follow here and then it will continue. So, here one is fired then even though the two is fired it would not affect voltage because it will continue and it will go till three is fired.

Once three is fired means it will be 0 now come back this side because we have to draw complete cycle. So, it is not completed than we can come another side here and we have to complete this. Means when the three was fired before that your valve one and two were conducting. So, one and two were conducting this means the voltage across 3 is again e b a because one is coming, 1 is coming ea is coming on top and here is e b. So, e b minus e b a and now you can see what is the e b a. So, your e b a here before the, it was conducting this is your e b a and it was following. So, it was here even though it was following till your, this complete it was here and it was e b c here.

You see because one was fired here, two firing will not affect anything because the voltage will be same. Now, e b c you can see from start from here just you can see we have started here. So, it is a complete cycle. So, the valve voltage you can see here because it was coming here e b c here again the cycle is completed. So, e b c you can see suddenly here. Now, e b a following e b a following once three is getting pulse suddenly it is 0 and then it is continuing and this is your voltage. So, this is valve one voltage. Similarly, you can have valve three voltage similarly, you can draw the voltages of any of the valve. You can see here in the valve voltage, in this case this valve is experiencing the voltage passed through all the time except during this period. So, this is a negative voltage of appearing across valve 3. This is conducting snow matter, but, remaining period it is passed here and that is that is why invert of operation. This is a big deal because whenever there is any spurious signal, the valve may conduct even they you can say there is huge db by d t is there. There are be also be there sudden jumps in the voltage, sudden jumps in the current that may lead to miss firing of this valve and that is a called commutation fairly or after something have a problems. So, that is an inverter operation is very risky and very cautiously maintained.

So, anyway we will see over effects and mall operation of converter service later on. But, here again this voltage were say off inverter and converter I will be using and then we will see what is the various possibilities of the mall operation of the converter circuit. So, this is your DC output, the ideal when the snow overlapped angle, this u is 0 the DC output in inverter operation when the alpha is more than 90 degree and less than 180 degree and the valve voltage for three we draw it here.

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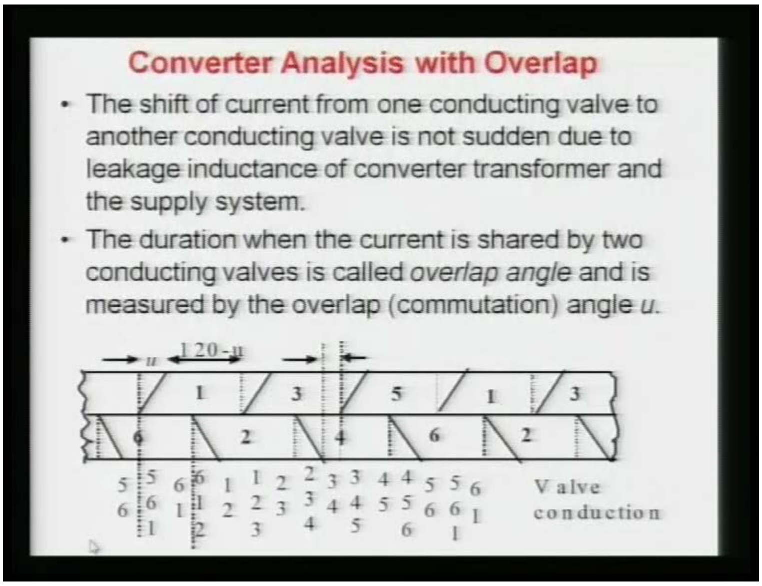

Now, let us go far now the realistic case far overlap this for the ideal case which is not existing very rarely. Now, we have to go far and there is some overlapped angle. Again I will just I remind you this overlap angle is the angle when this the two valve in the same limb same upper or lower they are taking time of the current change from one valve to another valve. So, that is why it is written here, the shift of current from one conducting valve to another conducting valve is not certain due to the certain problem like leakage or more leakage in the terms of the converter transformer and sometime your supply system weaker, supply system may also leads due to some other problems. So, the duration and current is shared by two conducting valve is called over lined angle u and it is known as commutation angle. To show it commutation here, again this that was the case.

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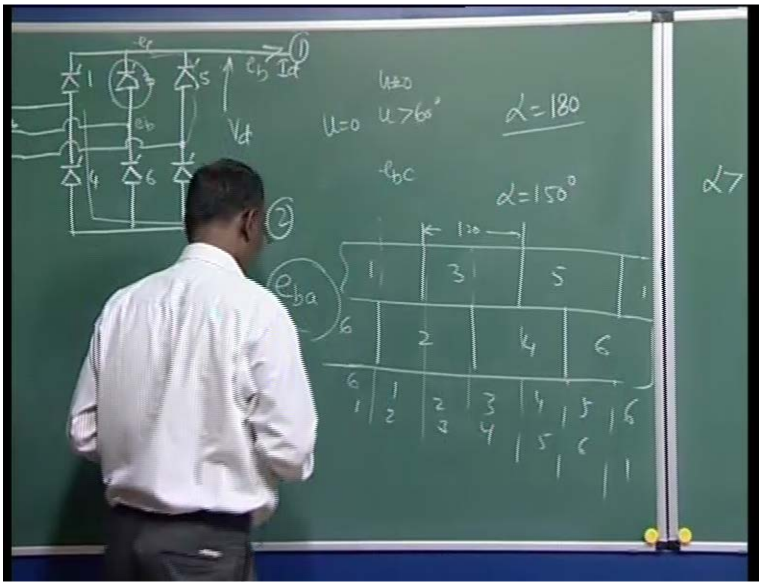

Now, I can say here we are having these two; Line upper I can say upper limb valves lower limb valves. Here I can say 1 here it was your 3 here it was your 5 and again it was 1 or.

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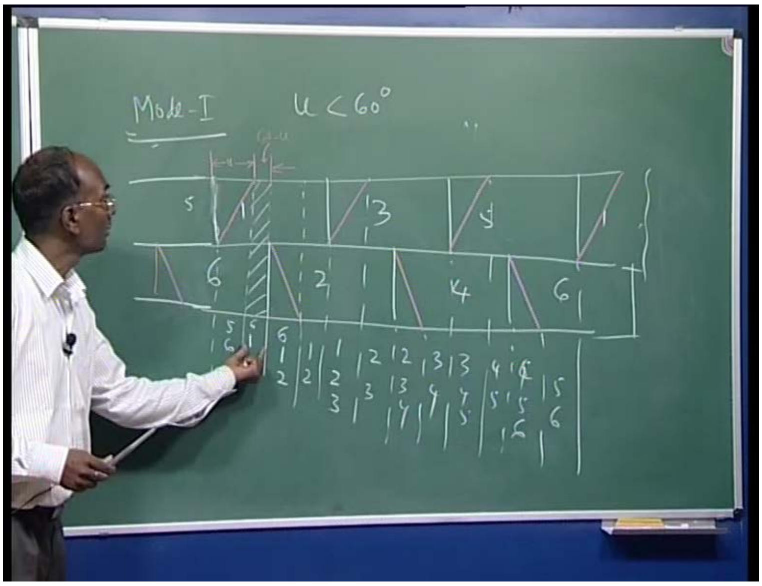

So, on and the conduction of each here it was your 120 degree. This 120 degree here this each valve in the, it is conducting for 120 degree. However, the pairs were conducting are the 60 degree.

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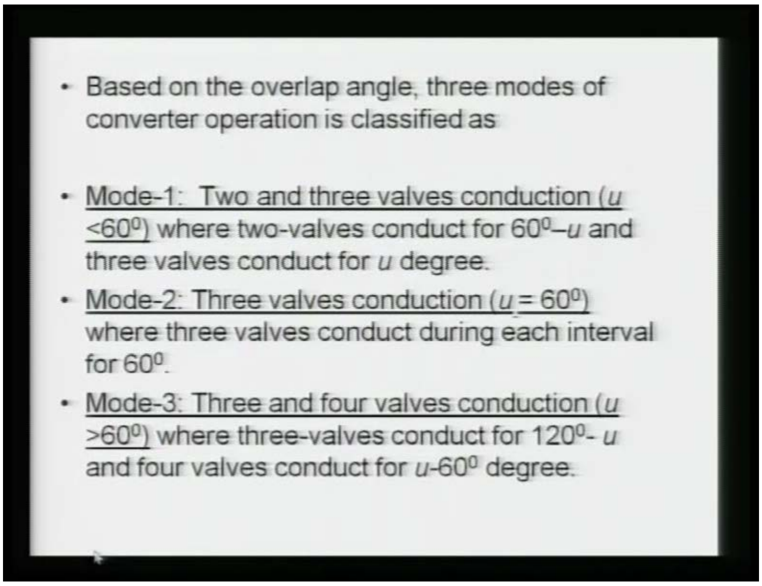

Now, here I can say this is half, this is half, this is your 2, here it is your 4, here it is 6 and again here is 6 so on and so forth. So, this was the ideal case you can see here your 6 1 was conducting than 1 2 was conducting here you can say you see this 3 and 2 in this zone. So, 2 3 here 3 and 4 and 4 5 and again 5 6 and then we have again restored same here. So, this was the 2 valve conduction case when u was 0.

But, when u is not 0 then what will happen? this There is a some period when the two valve will be conducting together and this depends how long they will be conducting. There is a possibility u will be less, u will be again you can vary from your 0 means it can be 0 and it can be more than your 120 degree. But, we are not going for this 1 u 120 degree is unrealistic case, but, normally it is very much possible that u can be more than 60 degree. Now, let us see if our u is less than 60 degree. Again we can have a different cases and thereby if we can have the different modes of operation and thus I can say mode one is u are the case when your u is less than 60 degree. This we can see from here again I will come back to this one here. I can say the mode work operation when the possibility of the sometime two valves, sometime three valves will be conducting and this is the case when u is less than 60 degree. There is a possibility this is the case or mode two is between mode three and mode one because this is a more than 60 degree it is less than 60 degree. So, mode two is the case when u is equal to 60 degree. Once here it is a 60 degree at all the time three valves are conducting and the three the two from one limb and one from the another one, all ways may be two from lower one from here or here, two from here and one from here. So, all the time in this mode two the three valves will be conducting. Now once here u is more than 60 degree. So, the conducting becomes the three valves and the four valves. Means the minimum valve will be conducting two and one and one here and, but, there is a possibility the four valve conduction two from here, two from here. It is not three here and one here. It will be two here and two here that will be four wall conducting. So, we are getting here four valve conducting and we will see there's the period of four valve duration as well as the three valve duration that depends upon and that can be very easily identified from this diagram.

No doubt this is very common is very common that happens because the u, is not u always it will take time because current from one valve to another valve will take some time it is not instantaneous. So, this mode one is very common, but, this mode two and mode two are not most common. But, they may happen when there is a some fall some problem in the ac system that we can land up in this condition when 2 and 3 valve or 3 valves are conducting. So, what we have to also analyze this case and what will be the problem in during this will see the how many component extra will be commensally high the jumps in the voltages of valves will be very high and we will also will see this case as well and first we have to take the case one here. Now, to see this what will be the pattern of the conducting in the mode one here; mode two and mode three and let us again try this bigger picture here and then it will be more clear. Here I can say here your valve 1, here valve 3, here your valve 5 and then we are again going for 1 and so on so forth.

Now, in the lower here this will be I can draw another line. This is your two here it will be 4 here it will be your six and again here your will be six. Now, two valve conduction case here the ideal case already have drawn here now let us see once we are going for the u is less than 60 now what will be the 60 you can see this duration this valve here it is the 60 period. This is one is conducting for 120 degree and u and this is your 60 degree, this is 120 degree and this is 60, this is 60. Now, we are assuming that this valve here you can see from this graph also here. Now, we are assuming that this is going to here. This slightly we get changing is not 60 degree, it is less than 60 degree. There is a some period it is set delayed means it is going to off here. This valve it is taking some degree here that is overlapped degree and this from here I can say this is your and the e u.

So, the remaining period here, this portion here will be your 60 minus u. This here will be 60 minus u. So, similarly, all the valve we are again assuming the symmetrical because the commutation that is a u is the same for all the valves which is taking place it is not that u is changing. It is assumed that u is fixed due to the certain certain condition and it is same for all the case. So, what will happen? This will be also going here I can just make it here and this will be this will be here, this will be here, this will be here and this will be here. Now, to know the, what will be conduction pattern and how it will be conducting let us start with this one. At this point we will draw the line you can see in this period one is there one is conducting from here to here. This one is the portion. So, we start here means one is there. So, I can write one, then your 6 is there I can write here 6 one is conducting. No two because 6 one is here 6 is conducting this portion. In this zone you can see here this is a one is there because one is conducting during this here. So, one is there and here you can say 6 is there. So, the 6 1 is conducting. Before that you can see here what was this 1? This 1 it was the 5. So, your 5 is conducting up to here means I can write the 5 than 6 and than 1. So, this was conducting here up to this portion. Now, here in this case now 1 2 and 6 because 2 is also conducting in this period here up to this portion, this period. This is your 1 this is your 2 and this is a 6 also conducting because here I shifted here. So, this 6 1 2.

So, this is also a symmetric conduction it is not that abrupt you can say here 5 6 1 before goes off because 1 is taking completely commutation is a over between 1 and 5. So, 6 1 is conducting are conducting. Now again now we are giving the pulse to two. So, this commutation between 6 and 2 is taking place for your u degree and than your 6 will off and then finally, you can see here it is your 1 and 2 are conducting. Similarly, you can see here. It is your 1 2 and 3 because the commutation between 1 and 3 is taking place. So, here the 3 is getting the pulse and 1 and 3 to means commutating. So, again you will find 2 3 and again I can keep on writing here 2 3 4 and here 3 4 here 3 4 5 and so on so forth. We can say find we are getting here 5 4 5 6 and so, on so forth. So, again we are getting the cyclic means here 5 6 will be remaining and then we are coming here again. So, this is the case of the 2 3 valve conduction means u period here the 3 valves are conducting and your remaining period that is 60 minus u is your that valve is conducting. That is a two valves are conducting. So, this is the case of mode one and here also it is just it is known to you it is given here. Now, we now we have to see if this u is your more than 60 degree. Means what does it mean?

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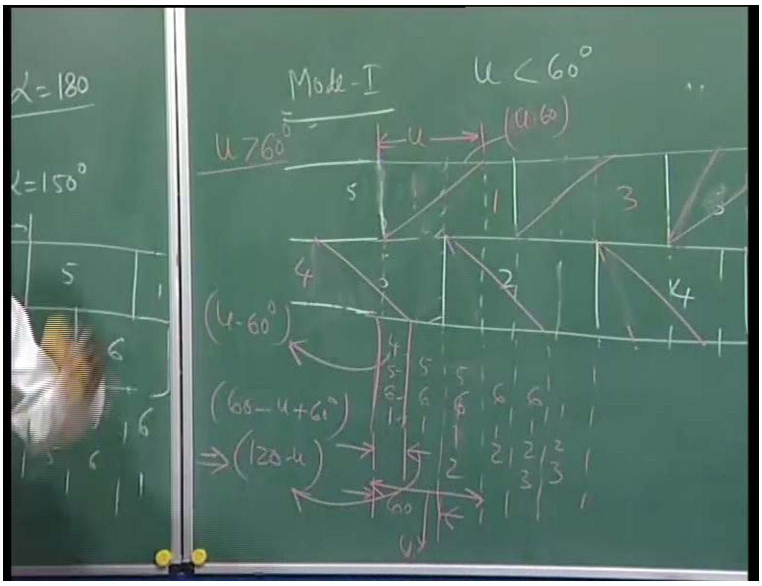

Means the once this is more then that now I have to remove here and let us draw the more commutation here and I can say this degree is going to be increasing from here. This is 60 degree. Now, I am drawing here. It is more than that because that is more than 60 this u here is less than 60 if it coming here it is a 60 if it is more than that it is more than 60. So, I am skipping more two because more two is a special case because if it is less than here will have here and the always we will find the three valves are conducting. So, similarly, we have to change this one also. This will be your, this is more than this 60 degree because this is 60. Here it is slightly more and this is also here if it is 60. So, it will be here. So, it is your 1 5 1 3 and now it is your 5.

Now, the lower portion also it will be change and here it will be your this your this your this and here will be this. So, this will be remote this red lines here this red line will not be there and now we have to draw this. What will be the various conduction pattern and the angle for those period? In this case, we are now going to draw u greater than 60. Now, we can take any portion here at this point here. Now, you can see at this portion between this your this phase 1 6 and this was 4. So, we are getting 4 5 6 and 1 are conducting. See it. This was your 4 four 6 2 like this 4 6 2 4 6 and again it is cycling. Here it is a 5 1 3 5 1 again. So, starting from here, you see in this period this portion and this portion because this is taken period when it is starting. This is you can say 5, here it is 1, here it is 6, here it is four. So, 4 valves conducting during this period. Now, I want to know what will be this degree when 4 valves will be conducting. You see this was your this is your u let us come further than it will be more clear what will be this degree.

Now, in this period here, your 5 1 and 6. So, we are having 5 6 and 1. No, doubt this total period here is 60 degree. This period here is 60 degree, this is another 60 degree. Now, I am going to write here again from here to here now you will find your 5. This is 1 right here, no problem 2 here 6. So, I can write here 6 and 1 two. So, it is 4 wall conduction. So, this sequence will follow you can see this is also symmetrical 4 5 6 4 will go 5 6 will retain here than again the 2 is 5 than 5 6 1 2 5 will go. Then we will find here 6 1 2 and so on so forth I can write here 6 1 2 3 here and then we can go for 1 2 3 and so on so forth. So, this will be conduction conduction pattern now we had to see how much which conducting you see which period. This period is your u means this period complete. This is your u because u is this period now as per now definition this is for voltage. So, this is your I can say u. Now what will be this period? this is 60. So, this period will be your u minus 60. So, you can see this period when the 4 valves are conducting; this is your u minus 60. This when 4 are conducting always when 4 are conducting it is u minus 60 degree. Now, I want to know what will be this your 3 valve conducting period? 120 minus u because the total is 120 as this is your already we have gone for this 60 this 60 minus this sixty. So, it is 120 minus u means 60 minus u minus 60 here means it is the 120 minus u. So, in the 3 4 valve conducting mode this is the period is 120 minus u and this period here this period is your u minus 60 degree and the pattern will follow and this is symmetrical component 3 than 4 than 3 than 4 than 3 and so on so forth. So, this is your mode two case which is this going to happen.

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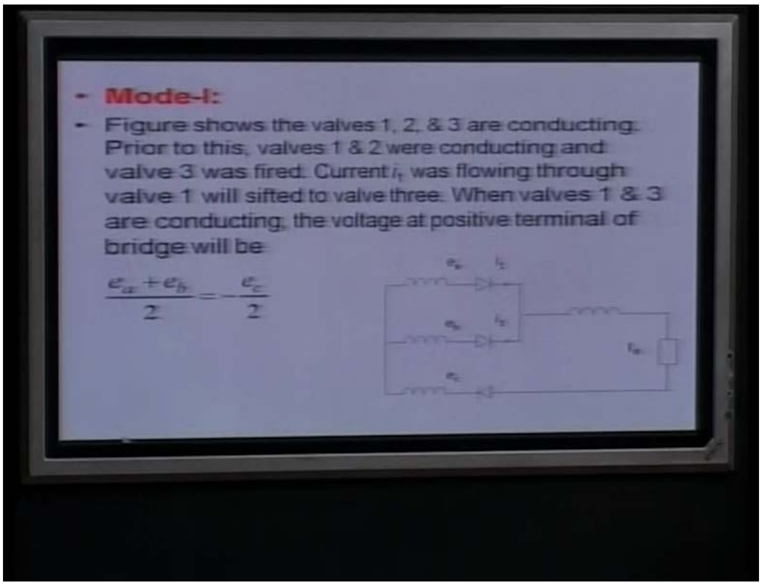

Now let us go for this when the valve 2 and valve 3 are conducting. Means now mode 1 where we are taking either 2 valves are conducting or 3 valves are conducting for the again repeated manner. So, this figure shows that valve 1 2 and 3 are conducting. You can see the 1 3 and here it is the 2 are conducting. Means before your 1 and 2 were conducting and 3 guard the pulse and it is now fired and, but, however, the current shift from 1 to 3 is taking some time and that is u degree and we are believing this u degree is less than 60 degree.

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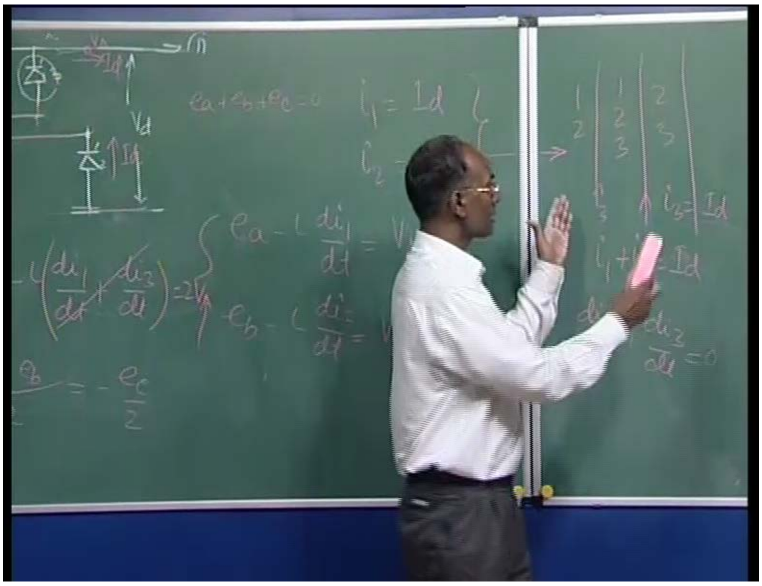

So, in this case we are going to have our as I said the conduction pattern here 1 and 2 are rare than 1 2 and 3 because here 3 guard the pulse and it is now the commutation between 1 and 3 is taking place. Means current which id here the current here in the, I can say I 1 was your id and you I 2 was your minus id during this period. Once here 3 is fired. So, in this period what happens? The current here I can say I 1 plus I 3 is going to be id because this current is going to decrease and this current going to increase and the finally, here once we are having 2 3, this is over at this period it is your I 3 is id only because 1 is off. So, in this period when the 3 valves are conducting, the current I 1 and I 3 because current shift from here because earlier this point was id. Now, it is going to be 0 here means I 1 and I 3 which was 0 here. Now, it is going to take complete current of the DC link that is the I d. So, that is why between this period it is always I 1 plus I 3 is equal to your I d because we assume DC current is the constant in this link. Now so, this is the case when this valve 3 before that here 1 and 2 were conducting and 3 guard the pulse and it is now conducting. Once it is conducting at that instant now, this will be the equal circuit of this here because 1 3 and the upper and the 2 were in the lower. You can see jus you can visualize or remove the other part you will find the zone. This simply here what I can do here I can remove this is the fifth link here and this is your 2 are conducting. So, I can remove this is and you can see we are finding this one.

So, this is you're here and now this this is the circuit we are having here you can see because this is your id which is flowing and here which is your I d is flowing. Here let us clear this id here. It is the positive I 1 because the direction here we are taking from positive to, but, this phase here it will be negative. So, this is there. Now, the first point once this two are conducting what will be the voltage at this point? Means I want to know what will be voltage here that I can say v a because once a and b phases are now you can say it is a line to line fact. This phase a is short circuit with b phase. Then what will be the voltage here? That voltage I can say this voltage will be nothing it will be the average voltage out there. Now question arises why let us see any voltage v a here and I am going to prove this v a will be nothing, but, it will be the average of this two voltages because then some inductances here. I can write here let suppose voltage a here. So, this voltage, I can write the v a means ea minus l d I one over dt is your let us suppose it is a va. I can write the current which is flowing here I one that will be this voltage minus the induction trap one di one because I one is showing here that voltage will be here.

Similarly, I can write for this circuit as well means here I can write e b minus a l d I 3 by d t will be your v a. We are assuming the l is constant in always there again this is a junction, but, one in the inductance afford by this transformer is the same in all this three phases. Now, simply added it. If you are adding here this two you are getting your ea plus e b minus l d I 1 over dt minus or I can say this is plus d I 3 over d t is equal to twice v a. Simply I add these two equations and I got it this we know this and this condition this I 1 plus I 3 is your id the DC current and it is assumed the DC current is constant and once you are going to derivate it will be 0. Means simply you can derivate here you are going to get d I 1 or d t plus d I 3 or d t will be equal to 0 because the DC current is differentiating with the time it will be 0. So, what happens this is 0, now you can see here v a will be your e a plus e b by 2 all the time. And this value is nothing, but, again we are assuming these three phases are the balance as again our resumption are there and then here I can write it is nothing, but, minus e c by 2 because we know we write here a plus e b plus e c equal to 0. So, from this equation we can write the ea plus e b is equal to e e c and this is the case. So, this voltage is known to you and then here it is conducting. So, this voltage is minus e c by 2. This voltage is e c. So, the voltage during this 2 3 valve conduction is your minus this minus e c yeah this is 3 by 2. So, we have to write this various voltage equation and now let us see here.

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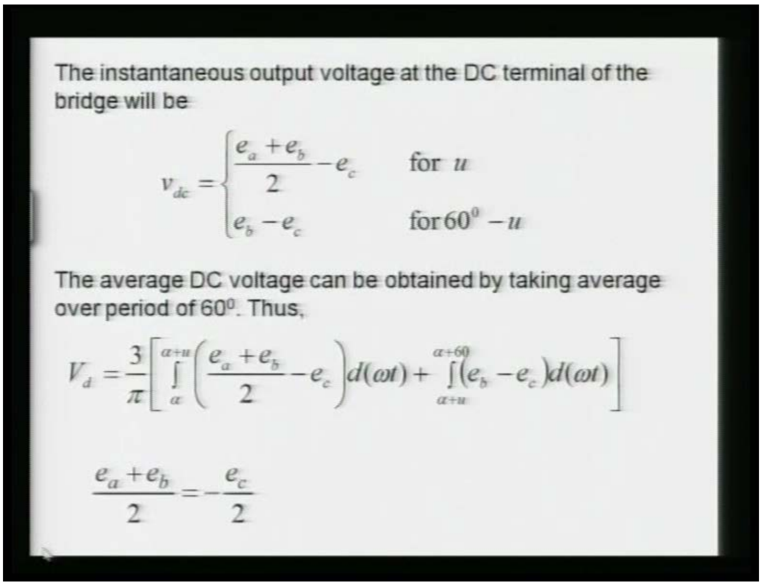

So, v DC here across this link here this is a small v DC means it is having the, again this is your 60 degree this is your 60 degree and then we can once again we are starting from here. This is total here the complete as I said this is your u period, this is your 60 minus u period means total is 60 period and again this pulse are symmetric and repetitive. So, we can just write here what will be the v DC for this period only.

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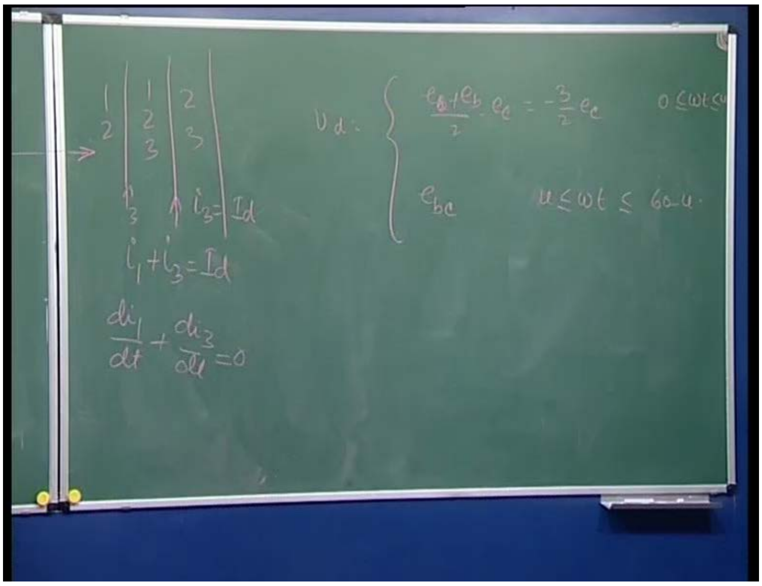

So, I can write here the v d will be the two cases when the three valve are conducting it was your nothing, but, e b ea plus e b by 2 minus e c or it is nothing, but, minus 3 by 2 e c because this value here it is nothing, but, minus e c by 2. So, it is minus 3 and that is for u period means here it is 0 to your omega t 2 u period means the 3 valves are conducting. If you are taking here instant is a 0 and then we are moving means here it is 0 than up to u degree this was the voltage then after here, once this is off it is again following us normal one. Means here this is off. Now, voltage here it is coming means I can say now this is a commutation is over. So, your voltage is coming here e b and here it is your e c means e b minus e c and as usual it was coming your e b c and this is your from starting from u omega t 2 here 60 minus u period. So, so this is the voltage thus we have written. Now, to take the average voltage I as I said this is for this period symmetrically we are getting further another period and here again 60, 60 degree. So, the our average voltage we can write as usual that for only our pi by 3 degree period and that will be giving our output voltage.

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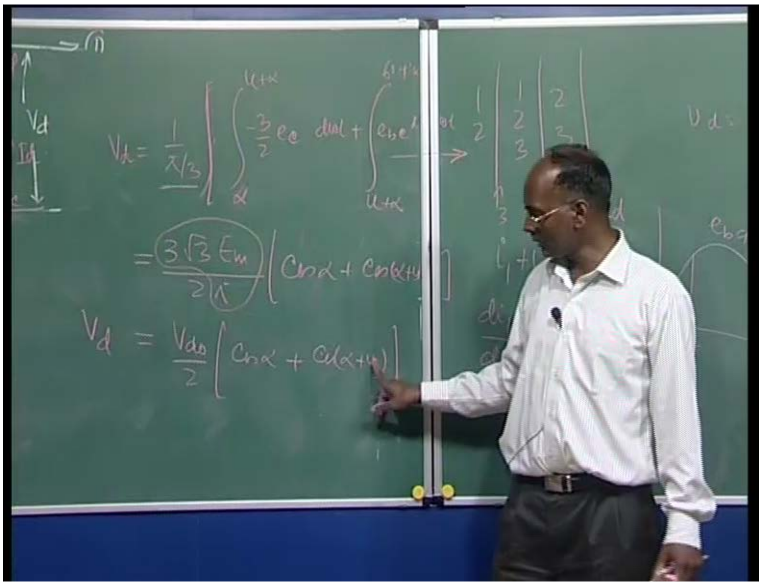

So, I can write here this v d the DC is 1 over here pi by 3. This is a for your written over pi by 3 means 3 upon pi and here we are integrating from this complete period. This is in square bracket this is from u a 0 to u, this is your minus 3 by 2 e c d omega t plus here u to what we are going to get 60 minus u e b c d omega t. One thing here we are starting this once 3 is taking place; at this point we are believing that there is no delay means u equal to zero. But, here as a commutation voltage once it is a starting as I said what about the voltage here e b a is a valve 3 you can start here or you can start something some alpha degree delay. So, once you are delaying here then your three is once fired, then it is going up to the two period that is your u period here. The commutation will occur and for the remaining period the u will be over. So, here instead of 0, I can start with the alpha degree and then it will be here alpha be added, here it will be alpha added, here it will be alpha added.

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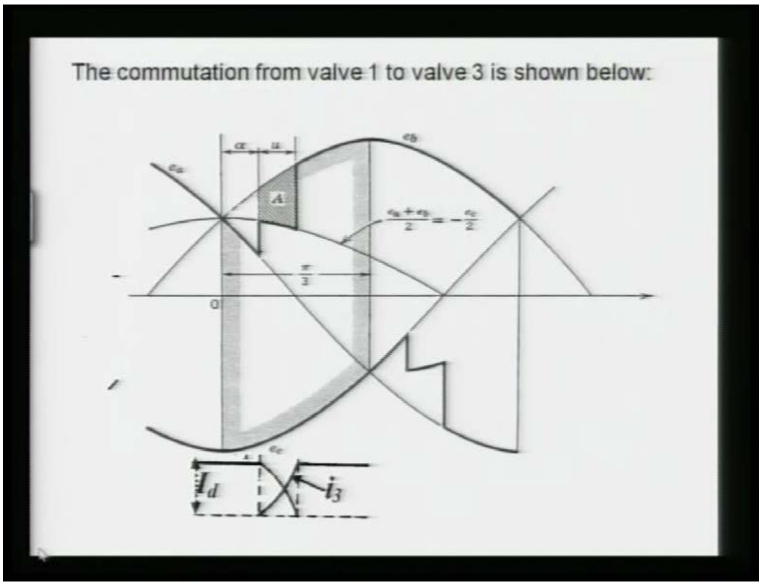

We will see again when we draw the voltages. So, this is your, even though you can see from this diagram. See here, this is the same case. You can see once your valve is fired here than your this period will be u, but, we are delaying it means once it is delayed here. Your e a continue to conduct means your 1 is continue to conduct here now once three will get pulse here at this point after alpha degree delay. Now, in this period u your you can see this is coming your upper limb ball it is a minus e c by 2 coming here lower here it is a e c is continuing. So, in this period here e u it is this minus this is the voltage and for the remaining period here this e b minus e c is the period and this is again the repeated one. So, here if you are staring from here then you have to take here phases accordingly, but, we took e b a as our reference mandate. So, e b a reference was 0 here because for I said this e b a which I am taking here is the reference here as our mega d equal to 0 and because this is our phasor voltages I took e b a as a reference. So, now, we are just delaying alpha degree as I said it was 0 here, but, I delayed here means your I d is continuing here in the valve 1 and then it is suddenly it is current sharing from 1 to here free during this u period and than 1 is off and 3 is continue to conduct and this is your upper voltage and it is your lower voltage here I was talking. This is upper, this the lower. So, I am just starting for this pulse here, this here, up to this portion this is again 60 degree. You can start from here also than you have to take this portion than you have to take this portion than you have to take this remaining portion here and that is again three different components which you are adding. But, if you are starting here, so, 1 is here you can say why I am taking 3 components because the voltages here is different during this period during this period is different. So, here I change from 0 here alpha here alpha plus u and then alpha plus u here it is again 60 minus u we are getting. We will see more detail about this even though the graph which I have shown here this also very tricky you can (()) current here from one, it is going to be it is like this and 3 is taking like this. It can be even though you can ask why not like this and why not this is going to be this one? We will see and derive this one all characteristic during this conduction period how the current is going to change from one valve to another valve and we will see later on in the in the same lecture.

So, now, here this is your DC output voltage as I said. Here this we have to write allready the d v we had the our expression for this we have the expression for this taking this as a reference. Already in the beginning I wrote and then you shall going to write here we can get this expression in here. Means you can say here what we have which I wrote here. Here, I think alpha plus u here yes 60 plus alpha will be there because we are just delaying for 60 degree we are talking only. Other period we are not talking because this will continue for remaining period, but, here alpha plus 60 degree only we are going because this is the 60 degree only we are concentrating because again it is a symmetric. So, here it is a alpha 2 u plus here and then here up to 60 plus alpha. Now, you can say total period here is 60 degree this upper limit minus the here lower limit means the 60 degree.

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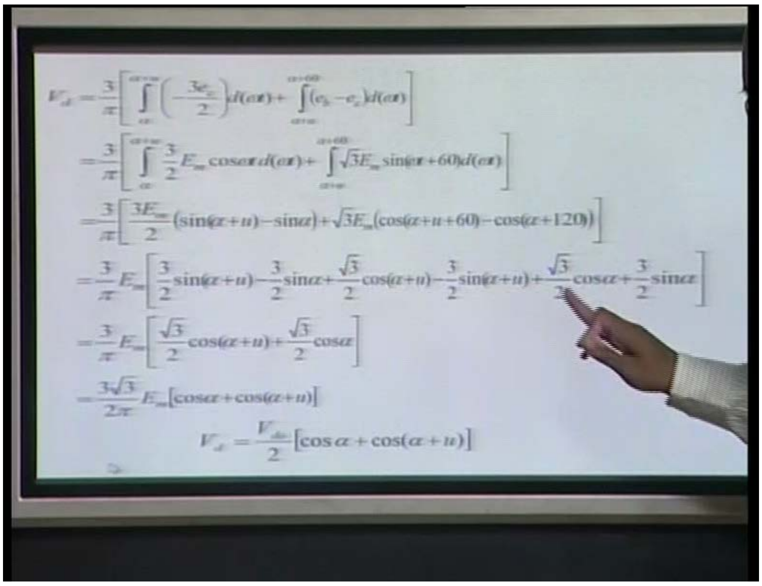

So, now, we are going to just integrate. Now, this is you can see the e c what was your e c it was in terms of sin sin omega t plus pi by 2 it was there. So, you can just here, you can write here from this e c equal to, this is the e c is the phase voltage. It is not line to line. So, this is a 3 by 2 I have written this e c now I have to write e c is nothing, but, minus e c here I am writing and minus e c is nothing, but, your cosine omega t at the same e b a is a reference. Similarly, here e b c here it was the 60 a degree here the sin already have written sin. Here, I change because the e c was in the sin component we wrote, but, it was e c was your omega t plus pi by 2 sin then it is minus cosine cosine omega t and this minus minus (()). So, this component is appearing here and this component and this is the line to line voltage e b c means it is under 3 e m this was your phase voltage. So, that is why it was e m here. Simply you will integrate it put the values you will get this value.

So, I am not going to integrate and put this value you can see in the steps they are written very well here this is a cosine become sine integration here. So, this is a integration of alpha plus alpha plus alpha 2 alpha plus u, say you got this term. Here is again we are getting this is a integrated, this is a cosine here and then we are putting this omega t equal to alpha plus u and another it is alpha plus alpha plus 60 and here you have to simplify and finally, you are getting this value. So, here we are getting the final expression I can write 3 under root 3 e m. e m is the peak value and it is a 2 pi and we are getting this cosine alpha plus cosine alpha plus u. Here this is DC voltage we are getting. This voltage you can see. Now, you can find this is a this components it was our V d o. So, I can write here it is v d o by 2 here. Cos alpha plus Cos alpha plus u this is our DC output voltage across this length in case of mode 1, that is your valve 1 and valve valve 2 and valve 3 are conducting simultaneously. Now, here you can see it will put alpha equal to 0; we are getting the same expression. This alpha is 0 means you are getting the two class alpha 2 2 will be cancelled and the v d is nothing, but, v d o cos alpha which we derive for the ideal case only valve were conducting.

So, this is the DC voltage; no doubt may be this expression may be the complex. There is another way that we can derive it and in that way here the simply just I will show and however, I will derive this in the next term. But, you will see here from I will see this graph what we can do only this area in this complete 60 degree this area is missing. So, what we can do already have out from here to here we had with our overlap, we had the

2 valve conducting very well and then this area can be subtracted. This area is nothing this minus this from this period and this is simply alpha plus alpha u and then you can subtract it you can again the DC voltage. We will see in the next class. So, in this we only derived up to the mode one electrification mode on the output voltage and the next term again will derive the current switch over and also this output voltage and we will see the valve voltages and DC output voltage have complete cycle in the next lecture. Thank you.