High Voltage DC Transmission

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Module No. #02
Lecture No. #06
Analysis of Converter Circuit (2-3 Valves Conduction Mode)

So, in this lecture also that is lecture number 6 of module 2, I will discuss again the two valve 2 and 3 valve conduction mode.

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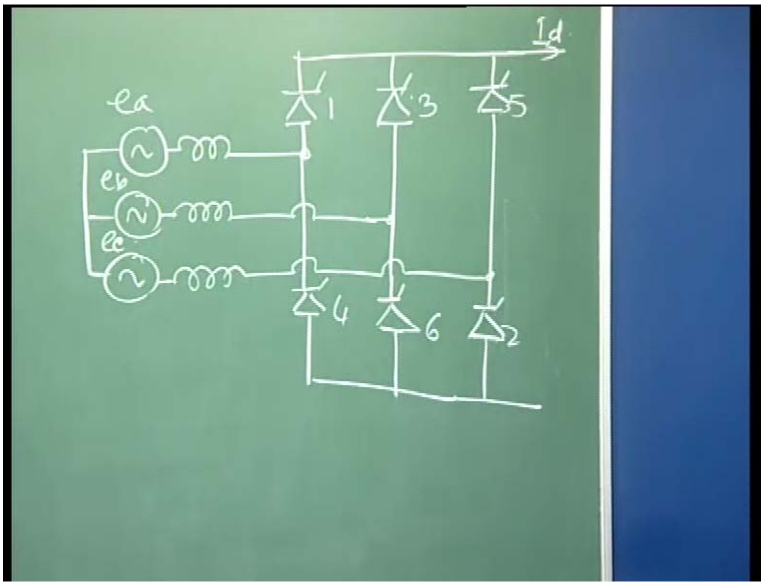

Last time our last lecture, lecture number 5 I explained about how to calculate the dc output voltage of the circuit when effect of this inductances are taken care. Means we are having the u is less than thirty degree u is less than 60 degree sorry.

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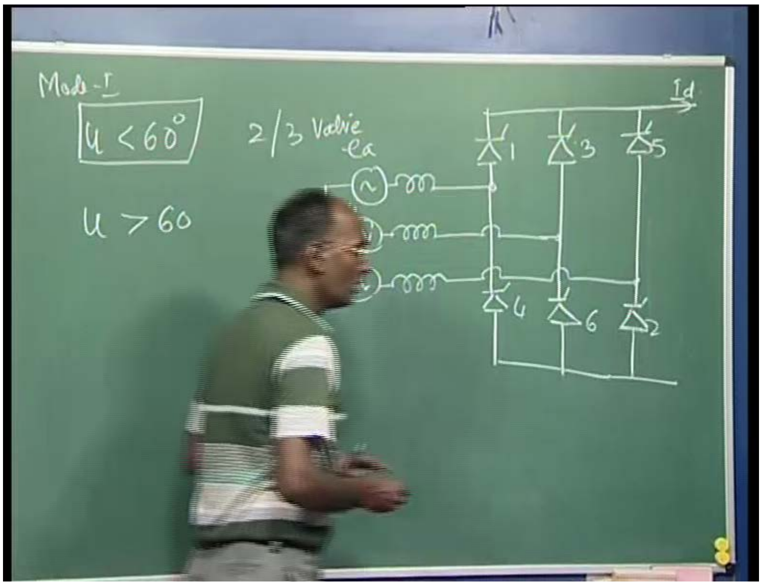

So, u is less than 60 degree and another mode we will see u is more than 60 degrees, but right now I am consulting this. Here thus called mode 1 and again I can say 2 and 3 valves conduction is the pattern. So, one straight forward that we can go for the 60 degree pulse the output voltage we saw and then we can take the average out for that 60 degree and that will be the DC output voltage.

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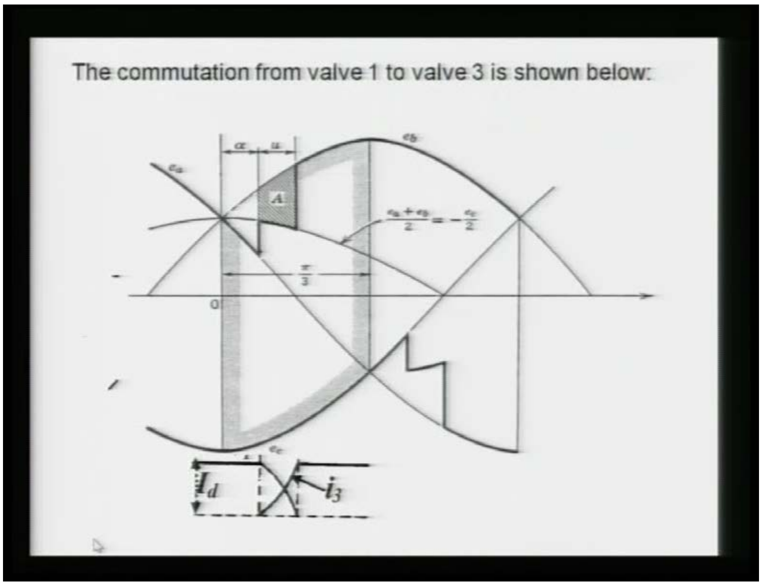

Another way that is a simple as well here, if we will see the conduction pattern here. This is again if we will see here, this is the e b voltage here e a means your commutation voltage of valve 3 start from this angle 0. Now, I have delayed here this angle alpha and now, you can see once alpha is here coming then your 2 the valve here that is before that your 1 and 2 were conducting now, 3 is given pulse. So, this 1 and 3 are commutating each other means, current from 1 is taken care by 3 means, earlier I d was following here. Now, this I d is shifting from here to here and that period is u period and in that case the voltage here because both are conducting. So, this voltage is nothing but your e b plus e a by 2 is happening and that is nothing but it is your minus you can see e c by 2.

So, during that u period the voltage here output voltage will be this upper part here is minus e c by 2 and the lower is e c because 2 is conducting. So, you can say lower here it is e c this is your e c I can say and upper here this for u period, u is conducting and once commutation is over means total current is taken care by the valve 3. This will be off and this will be full-fledged conducting means complete I d will be flowing here and that is a 2, 3 valve conduction. So, this period here now, this is a overlap angle now, you can say the voltage is reduced. So, due to the overlap your output voltage is going to reduce and finally, you can see this area in every 60 degree, this area is less before that if there is a u is 0.

If u is 0, what will happen? This will suddenly follow here and this will come here. If u is 0 means always we are getting here for this period, this e b c you can see this will be suddenly going here and this curve will be following and the e c will be there because 2 is conducting. So, this area a is the shortfall in every 60 degree due to the overlap so, output voltage is basically reduced due to this overlap. Now, to get this output already we have derived for this case when overlap is 0.

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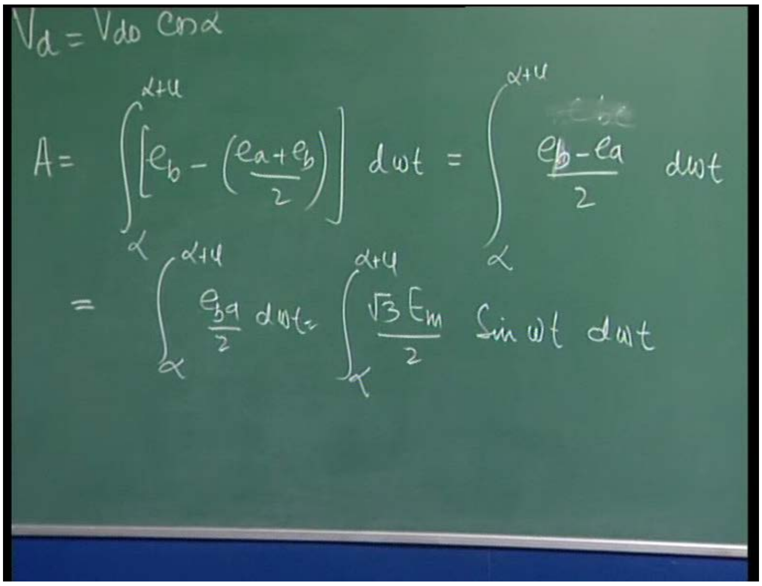

And remember here I just derived this V d it is nothing but your V d o cos alpha. Now, what I am going to do if we can calculate this area and I will show you this area is very simple to calculate. This area here it is this curve minus this curve and we have to integrate from here alpha to alpha plus u degree. So, the area a here it is nothing but it is your integration from alpha to alpha plus u and this is your e b minus, your e a plus e b by 2. And here it is going to be omega t because this axis is omega t so, this minus this between this period is your area a, this is nothing but is very simple expression. Here you will find this is your alpha here alpha plus u. And this is your nothing but e b sorry this e b minus e a by 2 and this is d omega t.

Now, this is nothing but e b a and e b a half of the e b a and e b a is the commutation voltage and it is our reference. So, I can simply write here it is alpha plus, here alpha plus u, e b a by 2 or I can say simply this is a d omega t here we are getting alpha, alpha plus u, under root 3 times. This is your line to line voltage that is your E m by 2 here sin omega t, d omega t. And just you integrate here and put this value you are going to get this area a and that is here only for we are talking here 30 degree, 60 degree interval.

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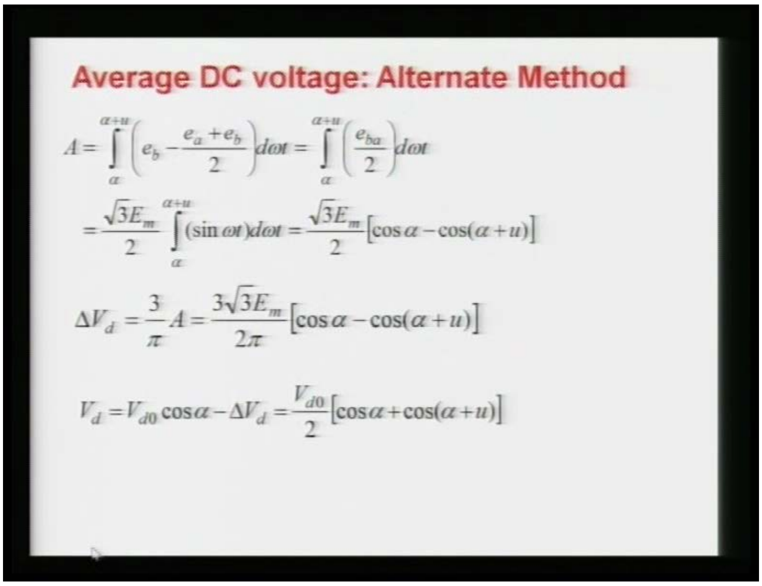

So, this expression here already I have derived and see from here we got the same expression and if you are integrating this sin omega t with respect to omega t. You are going to get cos and cos here it will be minus of this and then that is why here the alpha is coming first and this is coming here means.

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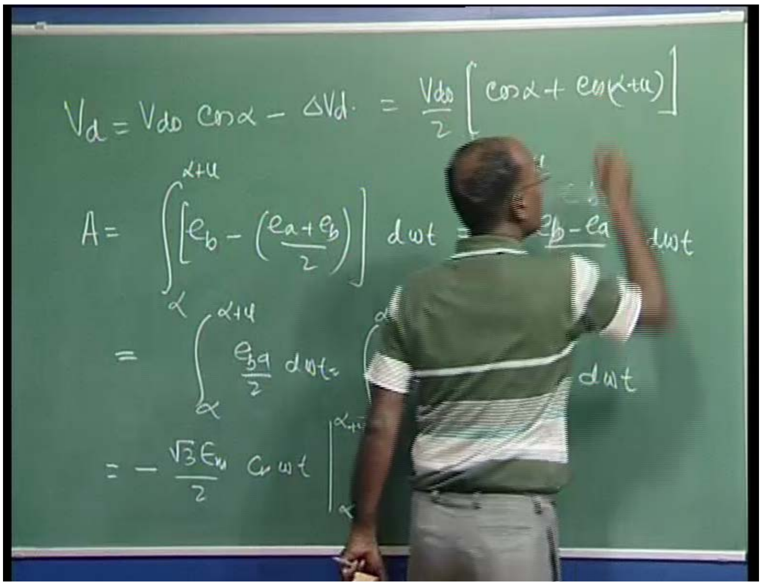

We are going to here this will minus under root 3 E m by 2 here cosine omega t and here your alpha, alpha plus u will be the limit. So put this value so alpha here this negative will go up, so we are getting cos alpha, here cos alpha, minus cos alpha plus u. So, this is your area A, if you are getting. Now, since this average is every 60 degree so, to take the average we have to average out for this a is in that what is the different. So, your this change in the voltage now, it is written it is nothing but 1 over pi by 3 A. Because this area was for this we are going to average out for the 60 degree and again it is repeated so this is your pi by 3 so this is nothing but your 3 upon pi A.

And if we are putting this value means now, V d here will be this V d minus your change in V d, and then you can put this value here you are getting the same expression. Now, you can see here it is the smaller derivation compared to the previous one because we were getting the 2 terms separately and then we are putting the value and simplifying it. So, we are getting here again the V d is equal to V d o by 2 here cos alpha plus, cos alpha plus u. You can also from expression you can see if alpha is not 0 what is going to have this value is going to reduce because this alpha is more than this u is more than 0 this value is greater than cos alpha value. So, this is going to reduce if alpha u is more than 6 0 degree. So, this average is going to reduce so the impact of this overlap is reducing your output voltage and more overlap period more output voltage reduction.

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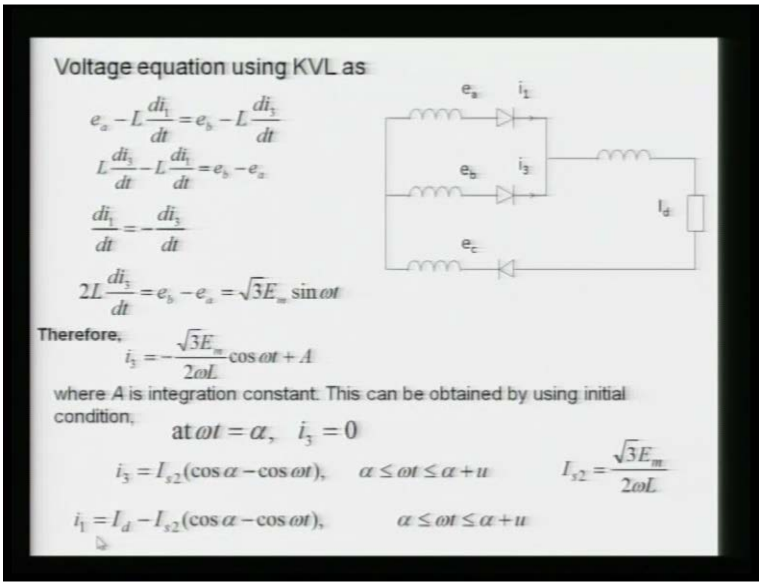

Now, we have to see what will be the pattern of current that is going to be taken care by here because earlier it was I d once 3 was fired then current is shifting from here to here. And this valve 3 is taking complete current just after the commutation period so here it was before this it was I d in the valve 1. And once during the overlap period the current is shifting from 1 to 3 and it is taking completely care, once this is taking complete I d current here this will be off and then we are having 2 3 valve conduction. To derive again the what will be the current in the I 3 once 3 is going to be fired, then we can write expression here again you can write the Kirchhoff voltage law is a simple in this circuit. This is nothing but from here I can write whatever the voltage here will be this voltage here, as usual. So, here I can write e a minus L d i by d t will be equal to e b and here d i is i 1, here e b minus L d i 3 by d t both will be equal and here it is written. Means this portion is the voltage corresponding to this and this portion is corresponding to this.

Now, we can simplify all this d i by d t in one side and here is e b a and this e b a is nothing but your commutation voltage of valve 3.

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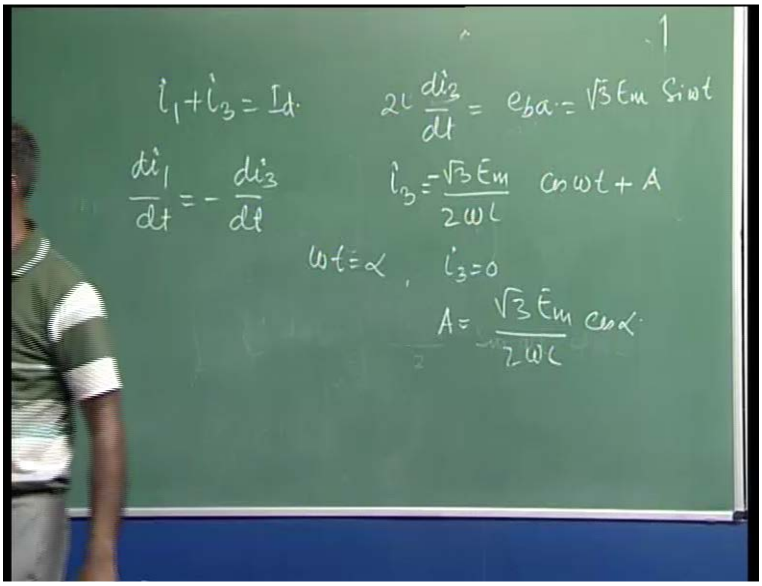

We also have another expression that is your i1 plus i 3 is I d all the time in that period. So, here if we are differentiating d i 1 over d i t will be minus d I 3 by d t, because the differentiation of the DC current will be 0. So, using this relation if you are putting here we are getting this expression means we are getting expression of i 3. I can say it is twice L d i 3 by d t and this is nothing but your e b a. So I can write here from this i 3 current just we can from here i 3 we can write the solution of this expression here with the some constant A that, constant A depends upon the initial condition that we can determine the A value.

So, here from this I can write this value is nothing but under root 3 E m sin omega t now, we are going to have under root 3 E m over twice omega L, if we are differentiating here is cos omega t plus A, here it will be minus sign. This omega is the integration here because this is we are going to integrate with the t not omega t. However in the DC output, we were taking is omega t because it was the axis was theta here it is the time domain the d t not d omega t. So, you are getting here this value and a is your integration constant and that can be determined that by the putting the initial condition means when your omega t was alpha just it was going to be fired then at that time your i 3 was 0.

Means just at that point your i 3 was 0 and i 1 was having the complete I d current, just put this value here and you will find this A is nothing but under root 3 E m over twice omega L cos alpha. Because here omega t is your alpha just put this value you will get A because this is 0 and we can have this and now, we can put this value we are getting the i 3 expression.

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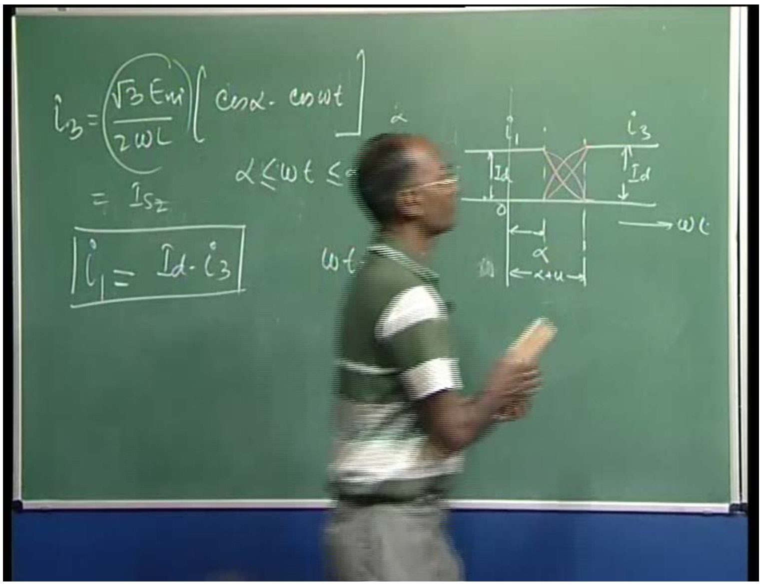

Means we can write our i 3 is nothing but under root 3 E m by twice omega L here cos alpha minus cos omega t. This is a 1 constant, it is in expression, it is so that it is I s 2. This is a some again notation I s 2 because in the figure again I will show what is the I s 2. So, this is i 3 now, we can determine i 1, i 1 is also we can from that expression it is your id minus i 3, will be i 1. Small quantities are basically it is a instantaneous currents so, I d is constant and i 3, if you are going to put it here you are getting your i 1 and that i

1 is written here in terms of this. And this expression here i 1 or this i 3, we are writing only from alpha to your omega t, here alpha plus u degree only, means during your commutation period.

Now, here let us see this how the current is behaving during the commutation period u. No doubt this current is rising it is taking care it is increasing from 0 value to I d and this current i 1 is decreasing from I d to 0. So, in this interval here we are going to have the characteristic similar to what is happening this was I can say this was your I d means it is your i 1 and this magnitude was your I d. At once it is going to fired here it is your alpha degree starting from here let us suppose this your axis just we are talking 0 and this is your omega t. So, this current is going to fall and here let us suppose this is i 3, this is going to take your I d current completely and this with the period when your here from alpha plus u period.

This is your alpha, this current is going to taken care and this current will be the 0 at this point. So, the pattern here will be whether it will be again I said whether it is going to be decreasing or increasing depending upon whether this current is going to rise here and this is decreasing here this pattern will follow. Or it is vice versa it is going to increase here and this is going to fall here.

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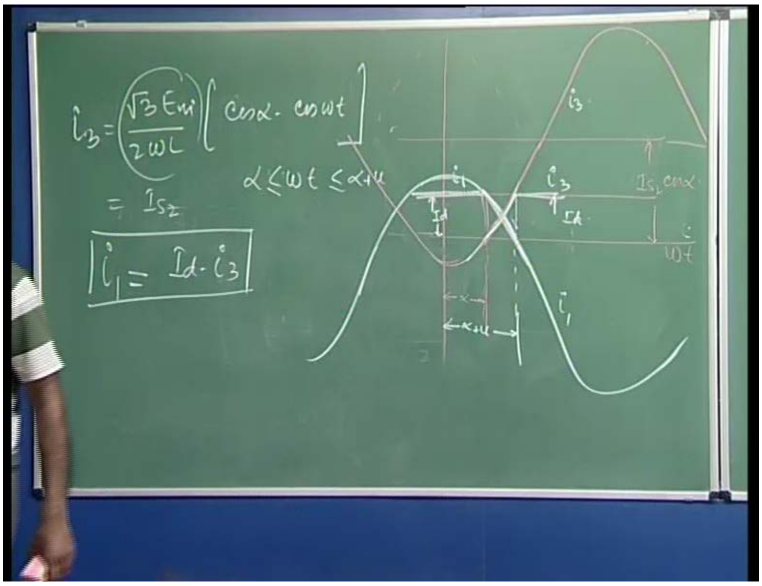

To see this, let us draw the diagram for i 3 and here your i1. Now, to have this we can have a axis this is your big axis omega t now, I am drawing the expression let us suppose this is a constant so, this value is constant. Means there is some positive value here I can say it is nothing but I s 2 cos alpha because in this i3 this value is added. After that here minus omega means if it is a positive that its shape was something means like this. This is a cosine term, but it is a reverse of this minus so, I can say here this is a cosine like this. Because now, your axis will be this for this cosine because this is added here this curve has shifted, means if you are drawing only this without adding this you will have this curve here. But now, this is adding this it is shifted here and now, we are having this one.

So, this is your basically the expression for here and this value you will see. Although this graph is not so accurate here it will be like this and this will be also said it will be the same shape here at this value let us see it is 0 current because this is we are writing the current axis. So, at this value this value is 0 and this will be only 0 when this alpha will be equal to your omega t. So, basically this is nothing but this is your alpha means at alpha what was happening this was your let us suppose I d current which was positive. So, at this value here your I d 1 was flowing means id 1 means your valve 1 current was there. So, this was up to this point your i 1 was flowing and once alpha is given pulse here to the 3 so, this is your I d.

Now, another expression for i 1 we can let us see, where it is going to happen so, then here basically this is a curve for your i 3. Now, we are going to draw the curve for this here this I d is this value now, you can see what I am doing? This is I d means now, axis is shifted here and then it is a minus of this. So, we are going to have a characteristic this is a minus here so, we are going to have like this a characteristic this is also cosine. So, what happens this is a axis is this and now, it is inverted minus i 3 because this is a minus. So, these curves will be inverted, but axis will be here because I d is coming and now, this here again it is going to be 0 because this is i 1.

This period is alpha plus u because this is a characteristic of i 1 and this becomes 0 after that it will be off and then this will be your here and this is i 3. So, this is your basically like this and this is basically like this, it is basically it is not drawn properly and this is a characteristic of this. So, during this period overlap this is here basically it is declining i 1 and i 3 is rising in this fashion. So, during this u period this is a characteristic before that it was i 1 here and after that it is i 3 which is again I d.

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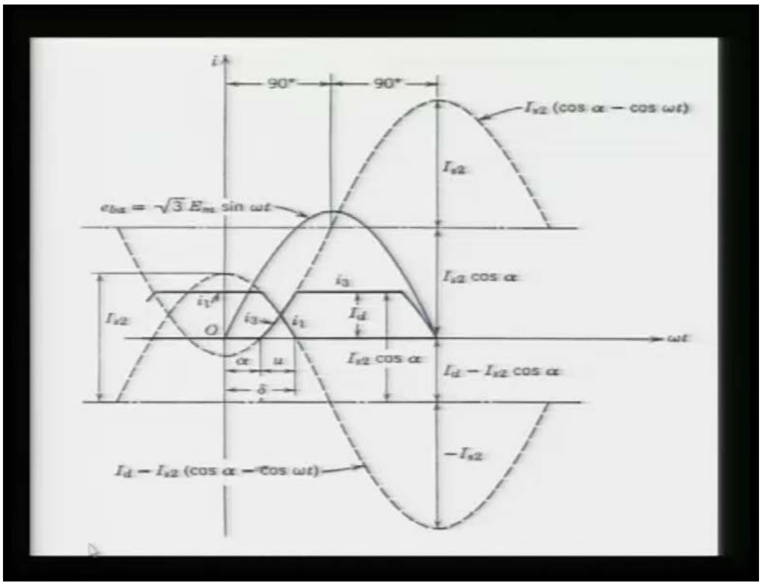

This can be seen again which I wrote. Here you can see the exact here in this curve this is the same curve now, you can see what I said here this is your omega t, this is magnitude I s 2 cos alpha. Means here this i3 is negative cosine which is going here so, this characteristic is I s 2 means this is your i 3 which I draw here. Now, at this point as I said it is 0 means here this is your alpha degree because at alpha i 3 was 0. Now, we are having this I d and this I d plus we are adding this value i 2 cos alpha.

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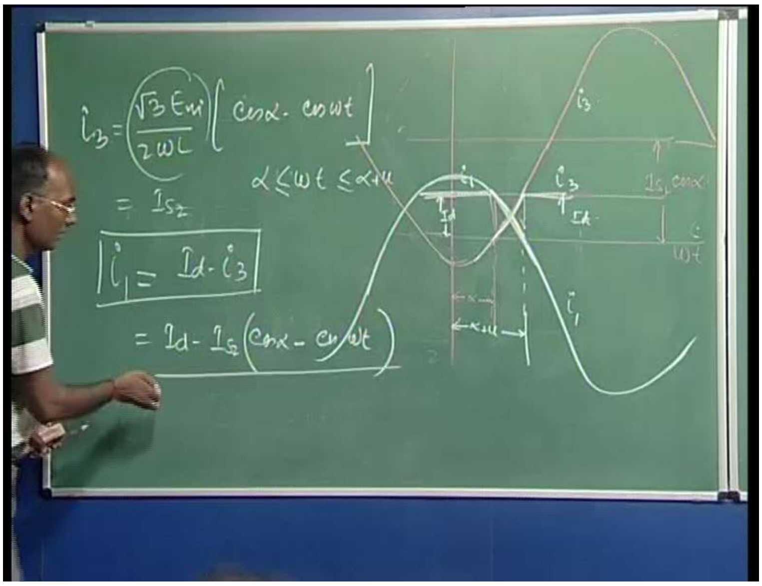

Because what happens here if we will going to put this value it is your I d minus I s 2 cos alpha here minus cos omega t here so, this minus case is again constant value and this will be positive. So, this what happens you can say this is cosine, but now axis become this because this I d minus this so, this has come down below one because this is more negative and this is your i 1. Now, at this point where i 1 is 0, means this is your commutation is over and this is your delta degree and delta is nothing but alpha plus u. So, you can see this characteristic is here is just at this shape and here it is going to this shape and this i 3 is taken.

Similarly, it is true for all the commutation of the valves whether it is 1 to 3 or 3 to 5 or here below 4 to here 2 to 4 or 4 to 6 or 6 to 2 it will be in the same pattern. So, this is during this period this shape will be there otherwise it will be conducting for I d current will be taken care of this.

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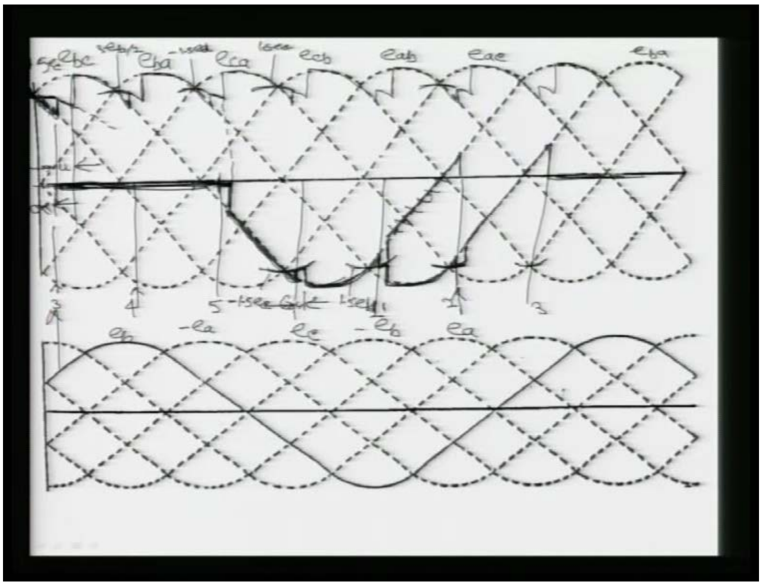

Now, let us draw the output voltage of the valve when the 2 and 3 valves are conducting. and this is I am going to draw here. This is your line to line voltage and we have to again to draw this we have to mark clearly the line to line voltages or if you are drawing your phase to phase voltage then this side this phase, this side this. So, the difference will be your output voltage. So, again since we are taking our e b a as a reference so, I can write here e b a as this voltage as usual. Once it is e b a then our next will be here e c d and another will be your a c now, I can write correctly this way. Now, intermediate you can see here this will be e c a, here this will be the reverse of this e a b and this will be your e b c.

See, it very simple how to write this I took this e b a now, every 20 degree here it is b becomes c and a becomes b. Similarly, at twenty degree here c becomes a and b becomes this. Now, from here you can see this is a reverse of this so, a c becomes c a here, you can say this is a reverse of a b so, it is b a similarly, here e c b so, you can write clearly for all the line to line voltages. Since e b a is the commutation voltage of valve 3 so, it can be fired from any degree here alpha from starting 0, here till here. Now, taking any degree here let us suppose I have taken very small u may be 5 degree then what happens now, I am taking your alpha here somewhere this value this is your alpha from here.

Now, before that 1 and 2 were conducting. So, your output voltage was e a c, and e a c was this, this voltage was e a c so up to here this was your output voltage. Do not know why it is not going. Now, once valve 3 receive the gate pulse at the alpha degree now, the voltage output voltage now, becomes here as I said both are conducting. So, this is your minus e c by 2 and this is c so, the difference is minus 3 by 2 e c now, here we have to see where will be the minus 3 a c by 2.

You know these points all these cross-sections this, this this, this this. Here they will correspond to 1.5 of the phase voltages you can see it these points have cross sections here they will correspond to 1.5 that is 3 by 2 after phase voltages. Now, what will be the phase voltages at that time that can be taken from somewhere else. You can see here this is your e b that is why I said here 0 and this was your e a means it is a b c and this is a. You can see just on top here this is a will be peak will be arising at these points just corresponding to this here also and here also you can see b will be here.

Now, how to know what will be the voltage at that time it basically depends what were there here. You can see what will be this one thing you can see it is what is e b here it will be means e b, means this value will be 1.5 of e b its magnitude will be changed. And to remember clearly this will be your nothing but e b 3 e b by 2. Now, here another point here what will be this, this is your e b, this is your e c, this is your e a. Here it will be minus e a, here it will be minus e b. Is it correctly I am writing? Why because it is very clear you can see this was your here is e b and if you are just this is your e b reverse of this is minus. So, it is minus here it was your e a and reverse of this is your minus here.

Now, you will see here it will be 1.5 e a, but with the negative and another way you can see there is some similarity on the line to line voltage as well. You can see the e a is appearing this a at the end, means here this here will be your 1.5 e a with the negative sign. Because before that you can see it is e b a, a is minus and after also it is e c a means a is there just we can have a similarity. You can see this is b and b was there at first time so, it was positive here a and a is there so, minus sign so, it is minus. So, it has a symmetricity here you will be get c positive 1.5 c here you will get the minus c b and so on so forth.

What will be here? It will be minus 1.5 e c. I think it is not eligible here so, this here it will be 1.5 e c. So, once we are going to fire here means our voltage suddenly is going to jump here from here. And this will be basically it will be like this, it will follow certain angle and once commutation is over now, our output voltage will become. Because during this period here it is your period u, here it is your u now. Means here valve 3 gets pulse again we are going to give the pulse to valve 4 and that will be here this is alpha degree. Now, another alpha will be this is 60 degree so, alpha will be here somewhere and where 4 will be getting your pulse. Once 4 is getting pulse now, there is a commutation between 2 and 4 valve because 4 is in the lower limb 2 was conducting. So, there is a current change from 2 to 4 once here it is coming now what will be the voltage here.

So, another pulse here it is getting here fourth valve is fired so, it was here this is conducting now, it is coming up to here and once you are giving a pulse to 4. Now, you can see this a this is c so, it is here a e a plus e c by 2, means it is minus e b by 2. Because a plus c is your minus e b and by 2 here it is this and this was 3 conducting so, e b so e b minus, minus here means 3 by 2 e b that is positive and we have the positive here as I said it is 3 by 2 e b. So, it will again follow and go up and now, here it will be suddenly going to this and it will follow up to u degree and then this commutation will be over. And then now, output voltage will be for 3 4 valve conduction, 3 will be your b, here it will be a and e b a will be the output voltage.

Then again after here we are going to get fifth valve here, we are going to get sixth valve and again here we are 1, here it is 2, here we are getting again 3. Similarly, you will see if we are going to now, at this point we are giving the pulse to valve 5 and now, the commutation between 3 and 5 will take place. Once here it is there now, we are getting the output voltage here at this length it is your e b plus e c, means minus e a by 2. This side the 4 was conducting so, it is your e a and just here this minus this will be minus 1.5 e a and again we are getting here this minus e b. So, you can see this we are it is a symmetrically we are getting this voltage.

So, here this will be it will be conducting here and once you are getting this so, output voltage now, this will be your pattern basically. And this will be continuously it will be the output voltage for we will find this is your output voltage that will be appearing. So, this is the output voltage across this d c link here and this is a symmetrical pattern. We are getting line to line voltage for the complete 2 3 valve conductions when 3 are conducting the voltage is reduced and once 2 is conducting the output voltage is fired and this is the average voltage that we can get as usual.

Now similarly, we can draw here once I want to remind you here this voltages concept must be very clear to draw the exact wave shape of the output. If this you are doing anything mistake, here you will not get you will get something different output. No doubt here you know the sequence pattern you know it will be coming, but if there is a some fault sometimes we will see in the inverter operation there is a commutation failure. And at that time we will find it is not a symmetrical and then if you are not knowing the voltage you cannot draw the output voltage.

Here we know that the output voltage will come like this even though you have done something mistake you can simply say it will be the output voltage. But I will always go for looking this voltages very carefully even though you are writing this and the voltage here you have written wrong means you do not know the concept. So, that is always I am going very slow that you should be very careful about line to line you should be very careful about this voltages. Because now, I am going very slow and you should understand properly.

Now, we have to see next one, that is for your valve voltage. Let us draw the valve 3 voltage and you know from this, is output. Now, we can draw on the same at here graph what will be the voltage across the valve 3 during complete cycle. So, you can see once we gave the pulse here this is alpha because 3 is fired so this will be your voltage till 3 will be conducting. You can see the fifth is getting here the pulse, means it will be conducting up to this portion till your fifth is getting pulse. Now, this is not only up to this point because due to the commutation.

Now, the conduction period of valve 3 is exceeding by u degree here from this to this point it is 120 degree because the alpha here we gave the pulse 2 3 it started conducting. then it was continuing here up to the fifth and we are giving the pulse to the valve 5 now, the commutation between 3 and 5 is starting and it will go up to u degree. So, this and the voltage across once it is conducting so the voltage across this will be going up to means this point here. So, this is your it will be the 0 voltage across valve 3. Now, here fifth is also conducting and 3 is also conducting so, what is voltage here? Here is a minus e a by 2, here it was e b.

Here it was now, what will be the voltage here once even though there is a commutation here that this is conducting. So, the voltage across this will be 0 because this is automatically it is going to take at this is conducting now, this is conducting so just. No doubt it will be the 0 once it is conducting as our assumption. So, this is conducting and this is also conducting so, the voltage will be here, but this across this it will be 0. Now, this is off and fifth is taking care so, the voltage here is coming your e c so, here it is e b means e b c will be the voltage. And let us see, where is a e b c here? Your e b c is just reverse of this, means this is your curve here, you can see we are coming here this line is your because e c b is on top so e b c will be down one, is clear? Because this it is minus of this if you are putting here minus so you are getting the reverse of this so this is your e c b so your e b c will be this.

So, here once we are getting this is off and fifth is only conducting on the upper limb and below is 4 we are getting this voltage. And it will follow now, it will follow till 6 now, we are coming up to this point here it is coming up to 6 voltage. Now, 6 is going to fire the 4 was conducting and 6 is getting here now, what will be the voltage here. Minus here it is minus a c by 2, this is conducting what is voltage here? It is this voltage will appear and other was your 5. So, the 5 here it was e c and now this so, we are going to have this minus this voltage means the voltage across this is minus 1.5 e g, means it is minus 3 by 2 e c during that here the commutation phase.

Because this is conducting so, this voltage will appear here and this voltage was already here and this was taking care so the voltage here now, we see where is that? As I said this voltage was your 1.5 e c positive because this voltage here c is positive. So, this will be your 1.5 e c positive and below here is a minus and we are going to have this so, once here it is conducting. So, this will be like this and means your minus here it will be like this means suddenly here we are going to have at this is going to follow. Now, during the 4 and 6 is conducting only for u degree this will be this follow and suddenly again it will come back because this is off.

And here we are getting your e b again because this is conducting and e b is again here and this was conducting here so for only this u period here it is just going it is following this is 1.5 minus of 1.5 e c. So, it came here and this commutation is over, suddenly it again follows the same. Now, again it will go up to your let us here this valve 1 now it is going to fire now this one is going to fired here now, we have to see what will be and your fifth is conducting. Now, this voltage is going to be minus e b by 2 and this is e b so, the voltage during that period it is 1.5 e b positive. Because this will be e b minus this it is 1.5 and then we have to see where we are?

Now, we can say this is minus so this will be positive e b so your output voltage means voltage which will be appearing here this your nothing but I can say it is 1.5 e b. So, what happens here the suddenly it will come here and it will follow up to u degree and then again it will go back when u is over. And then it will go up to here this valve 3 let us see and we will see here what will happen? Means your output voltage you can see it follows here, it is going here, this is going here. Again here it is coming up with this and then again it is going till here we are here. Now, 2 is now going to be fired here now, what happens? This is commutation between 6 and 2 is going to take place then again this voltage is going to change this.

What is this voltage? This is e b this is e c so, minus e a by 2 and this at before that what was conducting your 1 is conducting on the limb here 1. So, this is e a and you can say it is minus 1.5 e a where is this ea we can find ea, is this much your e a? It will be, here we will see the commutation between here once we are giving the pulse to 1. Now, there is a commutation between 1 and 5 is taking place because at that time during this period we saw this voltage across this valve will be h plus e b 1.5 e b. So, it will follow here once commutation is over now, what happens this one is completely taking the current and this now the voltage across this will be your nothing but e b a.

Because this is now full-fledged conducting and this is your e b, here e a so, e b minus e b minus e a is the output voltage. And it will not go here it will be coming here finally, and then it will follow till this point. So, this is not correct, it will be coming here and now, we are going to give the valve 2 and let us see what happens now, the valve 2 is getting the pulse now the commutation between 6 and 2 will be there. So, the voltage here it will be minus e a by 2 and then it will be here it will be minus e a by 2 and 1 is conducting here. So, it is minus e a by 2 minus e a, that is minus 1.5 and this is nothing but it is will be this value.

So, your this will be your, it will be coming here and then it will be up to u period and then it will be again commutation once will be over it will be going there. So, here this is nothing but I can say it is your e b a and it is going to follow here e b a and this is going to be here till we are having the 3 is going to be fired once 3 is going to be fire, this will be conducting and this will be your 0 which will again continue with this. So, output voltage will be now, you can see from starting from here. Once just we are talking the output valve voltage of 3 we are just drawing here, once 3 is getting pulse that is starting from here.

We are moving at this here because 3 is conducting up to here, the 5 is getting pulse, but there is a commutation between 3 and 5 it will be up to u degree. It will be 3 will be also conducting once 3 will be off and the fifth will be conducting the voltage across this will follow e b c and this will be your output it will be following this one. Now, at this point once the 6 is being given pulse. Now, there is a commutation between your 4 and 6 and your output voltage here is following this, this is nothing but minus e c 1.5 e c by 2. This is 1.5 e c, then it will follow up to u degree and again it will follow here till we are getting the pulse to 1. Again once we are giving the pulse to 1 now, the commutation between 1 and 5 is taking place and now the voltage because 1 and 5 here.

So, it is your 1 c it is minus here e b by 2 and this is e b so 1.5 e b and here we are getting this up to here and then again commutation is over. So, the voltage again across this is following one is conducting here and this is b so e b a, it will follow again here. Now, at this point again we are giving pulse to 2 now, thus here the commutation of the 6 and 2 is taking place and then the voltage here it will be minus e a by 2. And this voltage is here and one is conducting here so, it will be again we are following this voltage. Now, this is output voltage and again here 3 is fired means it will be 0 here. So, this is valve 3 voltage.

Now, you can see we are getting one dent here 1 rise here and another here overlap here. So, we are having the sudden jumps, whenever there is a 2 valves are conducting you will find there is a here dent because going in and this is output voltage here again we are following this, here it is here again and then finally, it is here. So, this is valve 3 voltage similarly, you can draw the valve voltage for other valves and you will completely for one cycle you can see. So, here it is looks very dirty now, you can see the valve voltage here.

We will see here this is the output voltage here again we draw this is output voltage across this link a valve voltage you can see once here is a conducting. you can see there is one dent then here this is again overlap, here again this is here and then finally, it is coming 0 so, it is similar to that what we opted. It is for all the valve, it will be the same shape only it will be shifted by 120 degree also. So, the pattern will be same if it is a symmetrical firing and we have assumed it is a symmetrical gate pulses are given to the valves. Similarly, you can see the current change over here from, you can see this is your axis. here we are taking this is axis because the commutation voltage we have taken for this one, here is e ba.

So, this is axis here also omega. Now, you can say i 3 was there up to u and then i 1 is here up to because alpha we are giving the pulse to 3. So, i 1 was I d now, there is a commutation between 1 and 3 is taking place.

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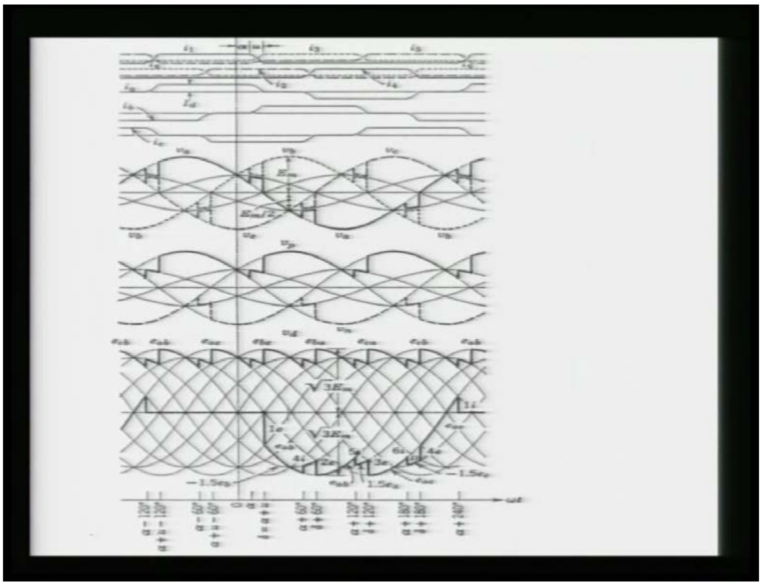

So, here the current is decreasing of i 1, i 3 is peaking up again it is going so, this is upper limb current and the lower is the lower limb current. So, it is basically taking care of all the things so, this is a current also the second graph shows the upper and lower limb voltages. Here from you can see this is upper and the lower you can just subtract you will get this pulses and 6 pulses as well. So, either whether you are going to draw line to line or phase to phase means from this phase and the this side and this side you can draw only from this minus this will be your output voltage. So, you can clearly draw and you can also mark the conduction valves when they are going to conduct.

So, that is very important in the drawing the output voltage you have to mark the line voltage, you have to mark the firing angle of the valves when it is going to get the pulse. And then sequentially you can write it and then you have to find what the voltage will be appearing across.

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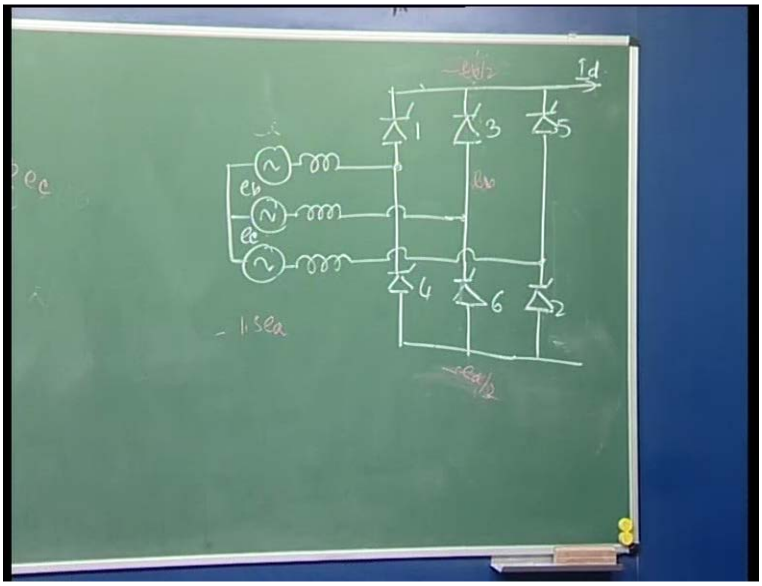

Either if you are drawing the output voltage, you have to shift the output voltage. If you are going to see what will be the valve voltage then you have to see what will be the valve voltage at that time. And then you have to find that curve and then you can make it and it will be symmetrical all the time you can see.

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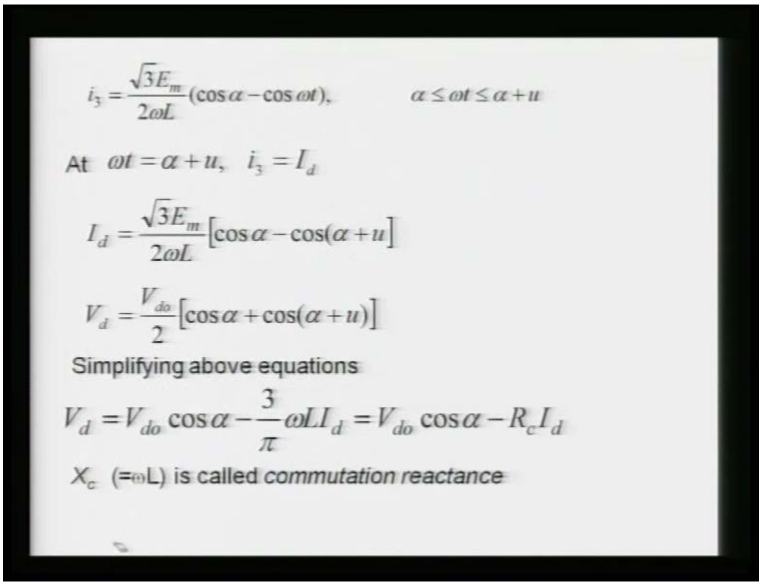

Now, let us we can relate our output voltage this is a power electronic circuit now, I am going to represent this in terms of your electrical circuit. And we can visualize because we have the electrical equations the voltage in terms of current we had the equation and then we can simplify it. Now, you can see we had this our this i 3 expression this, this was for your from alpha to omega t alpha plus u degree and this was your I d because this I d once you are putting here.

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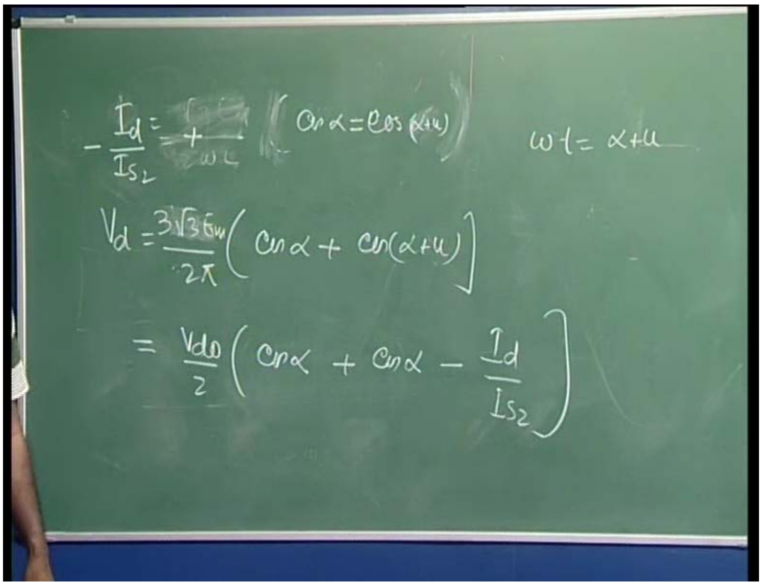

As I said it is i 3 it is under root 3 E m by twice omega L cos alpha minus cos omega t this is your i 3. You know once commutation is over means your omega t is equal to your alpha plus u, then your current here becomes I d. So, this will becomes your I d and this angle becomes your alpha plus u t**.** Why I want to express this is in electrical circuit because the measurement of u is very very difficult. This alpha is in your control the current in the limb is in your control because the some controllers are taking care of the current to maintain in that. So, the d c current is controlled your alpha is controlled, but this u depends upon your different circuit, here what will be the L? What will be the source here? And this depends upon this.

So, that is not in your control so, I want to eliminate this you at all and we can write expression in terms of v and V d this is a DC current and I also want to write in the DC output voltage. So, we have this is V d that is your V d o by 2 cos alpha plus, cos alpha plus u, from these two expressions we can eliminate this u means we can eliminate this two terms. And what we can do here from directly we can write what is this value this value is 3 under root 3 E m by pi. Now, our intention is to eliminate u, means we can directly eliminate alpha plus u here we have the alpha plus u directly so, we can put this site means I can write this value is your I s 2 barabar this.

Means I can write here this is a minus, this is your plus, this will be equal, means I can write this cos alpha plus u will be your I d upon I s 2 here minus and the cos alpha put this value here. If you are putting this value here, means now I can write here V d o by 2 later on we will remove here this is your cos alpha and now we are going to put here value this is a cos alpha inside and your minus I d by I s 2.

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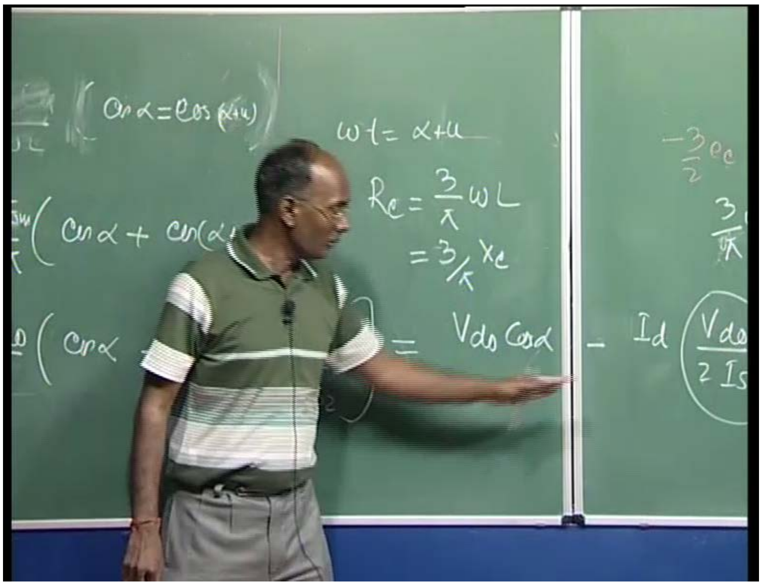

Now, what happens? This is a 2 cos alpha. So, I can write here it is your V d o cos alpha minus now, we can just simplify this to this means it is I s 2 here, means we are getting I d. I d is one variable now, this is we are having this V d o by 2 I s 2 and this is nothing but it is your equal to 3 upon omega 3 upon pi omega L. Just you can see here we are getting this value and this complete value is represented as R C and that is called equivalent commutation resistance. This R c arise due to this L value of this winding, this omega L is known as the commutation reactance, but resistance is 3 upon pi x e.

So, I can write here your R c is I can write here 3 upon pi omega L and that is equivalent to 3 over pi x e, this is equivalent commutation resistance. And here this unit is resistance because omega L is there so, this is in ohm, this is a commutation reactance. Now, this is your simple we can represent as a very variable source because your alpha is changing so, your the V d is changing. If your I d is constant, your output voltage can be varied only by alpha or you can vary some of the parameters here, means you can change your magnitude of phase voltage if possible.

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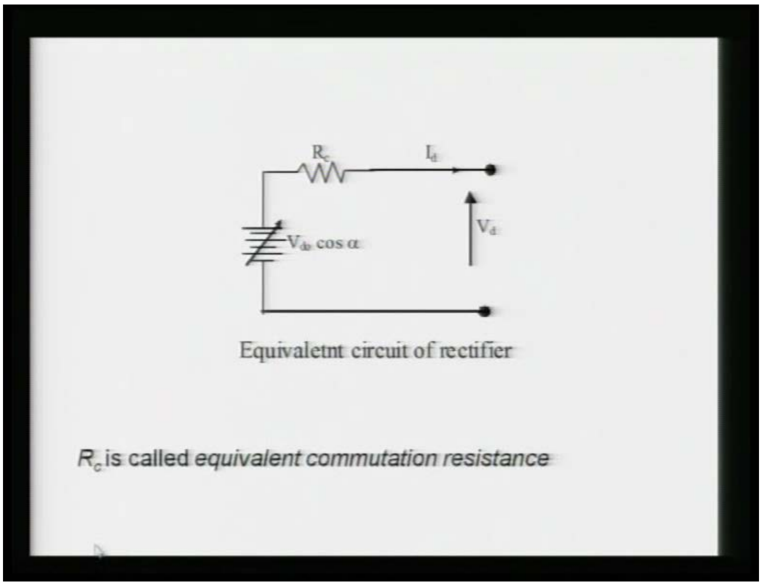

We will see that is also done in the practice and here I can draw this is the equivalent circuit of what we got here in terms of V d. So, your V d is your V d o cos alpha why I have written here the variable because alpha is changing. So, we can change your DC output voltage is changing minus the drop due to the commutation reactance, resistance here now. So, we can write this V d in terms of V d o cos alpha minus I d into R 3 and here this is expression so, whole your rectifier this is a one end rectification circuit. Now, we are talking only rectifier till now and the rectifier can be replaced by a equivalent electrical circuit. Similarly we will can also do it for your inverter circuit and then, but for that we have to see the inversion operation of this converter circuit.

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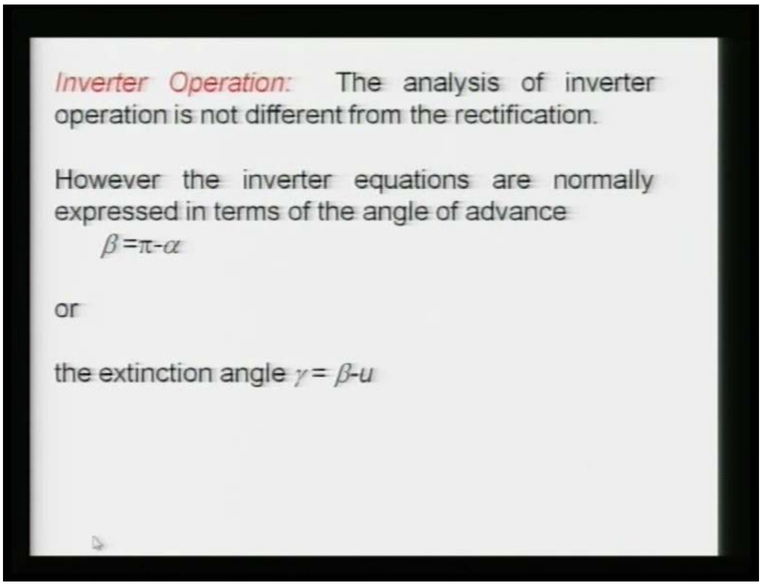

Now let us see the difference in the converter and inversion operation is not big. It is here the analysis is almost same only this your advance angle, it means alpha that is a delay angle is more than 90 degree.

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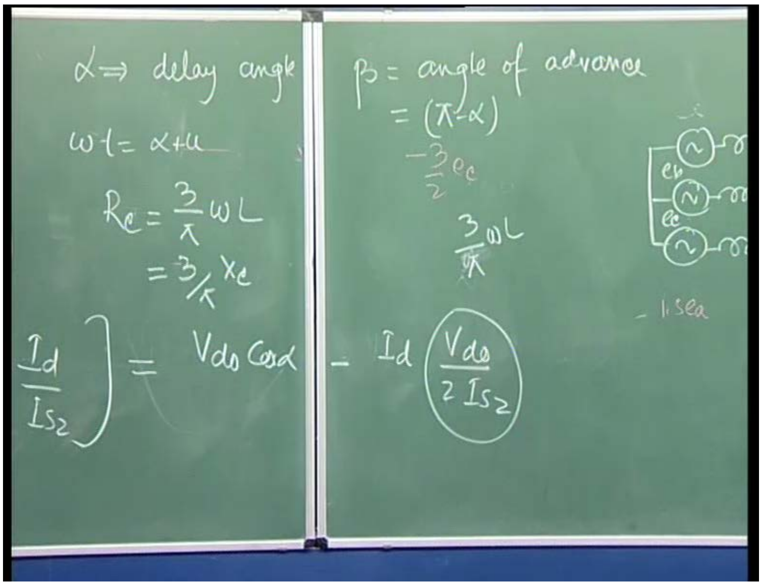

So, we have a two terms now, in the inverter operation which normally define one is called the angle of advance. You know alpha, here it is delay angle normally it is called. And your beta is your called angle of advance, advance angle is also true and it has relation because this your beta is nothing but your pi minus alpha.

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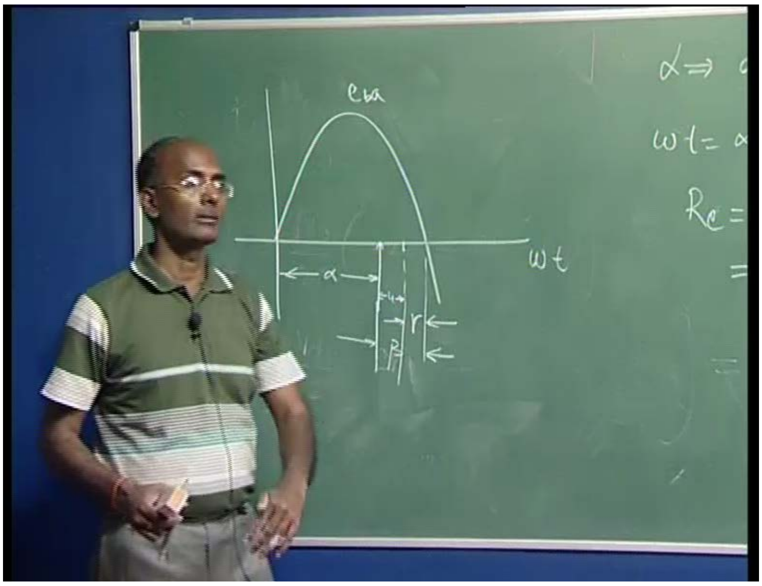

To see, it let us draw a commutation voltage of valve 3 and then it will be more clear, what is alpha? What is gamma? And what is the u that is going to correspond? In this axis this is your omega t now, this is your e b a. Now this alpha is delayed more than 90 degree let us suppose this is your alpha degree, that is delay. So, the beta is measured the pi minus this, means your beta here it is your this angle so, the beta is measured from this side to this side. If your beta is increasing means you are coming here means alpha is decreasing beta increase, means alpha decrease or this increase means beta decrease because your beta is measured from this angle from 180 degree.

Now, once the pulse is given here, again there will be commutation because once here you are giving 3. So, there is a commutation between 1 and 3 and it will go up to here let us suppose u degree this is your u degree. So, this difference is called your here extinction angle gamma so, this angle here it is called your extinction angle gamma. This angle is very important because this must be maintained some minimum value otherwise what will happen if it is exceeding here. There is a possibility the commutation is not successful because the current here it is i 1 is decreasing i 3 is increasing, but the possibility that because the voltage reversal. Again i 1 can picked up and i 3 can again decrease so it is a commutation failure.

So that is this angle is very important, that is called your this extinction angle. So, we will see in the next term next lecture that how this inverter operation and the voltage of valve etcetera. We will see and then we will again model the equivalent circuit of this inverter operation then we will connect by the d c line and then see whole rectifier. And the inverter can be represented by the equivalent electrical circuit and that will be used for your control algorithm design. So, with this now I can stop here and next lecture we will see the complete inverter operation again for the mode 1 when the 2 and 3 valves are conducting. Then we will go for your mode 2 mode 3 basically when the 3 and 4 valve will be conducting and then we will analyze and we will see. So, with this I should stop and we will see in the next lecture about the inversion operation thank you.