High Voltage DC Transmission

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Module No. # 02

Lecture No. # 04

Analysis of Converter Circuit

Today, just I will discuss about the converter circuit analysis and we will take the ideal case when there is no overlap and if you remember, this we discussed. The various assumptions here the assumptions are same for this analysis with these four assumptions and it is also another one just here. It is said the valve can only be fired if the voltage appearing across it is positive and gate signal is available.

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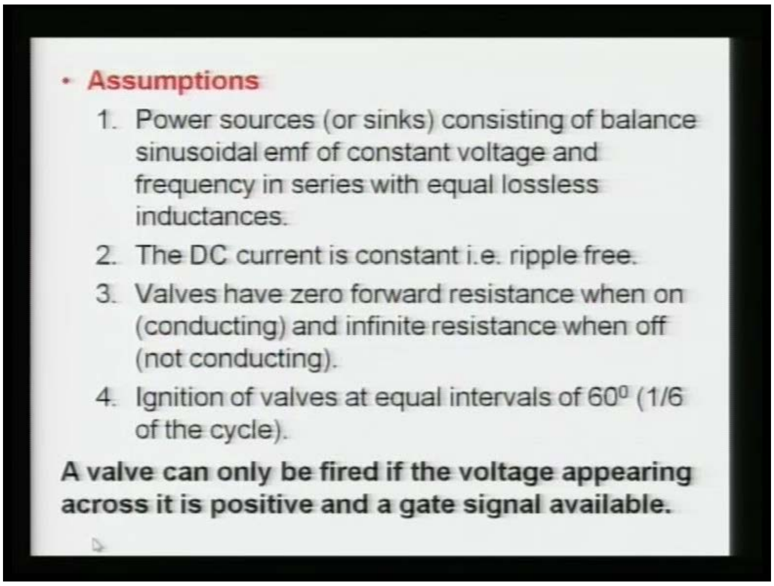

So, we are giving this gate pulses every 60 degree and if the voltage is positive then, that valve will be fired otherwise it will be not.

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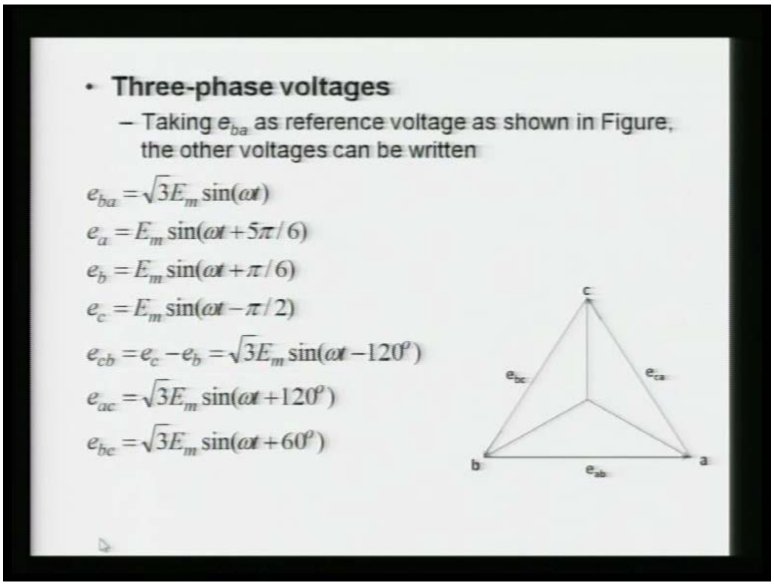

So, we also discuss here the 3 phase voltages and I took the e b a as a reference. The reason for that we are going to take this valve 3 commutation voltage here the e b a we will see the commutation voltage for valve 3 will be e b a and I am taking this as a reference and other phase voltages. These phase voltages as well as the line voltages are written here because, those will be used when we are going to plot the valve voltages. We are going to plot your output voltage and also we are going to calculate the output DC voltage across the valve.

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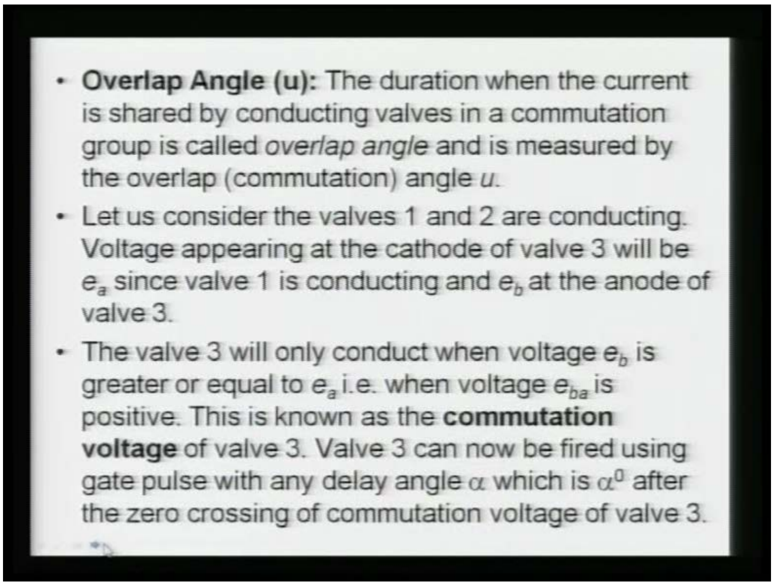

Today, I will be discussing when the overlap Angle is 0 overlap angle is defined as the duration when the current shared by. The 2 valve in the same commutation group means there is a 2 commutation group here.

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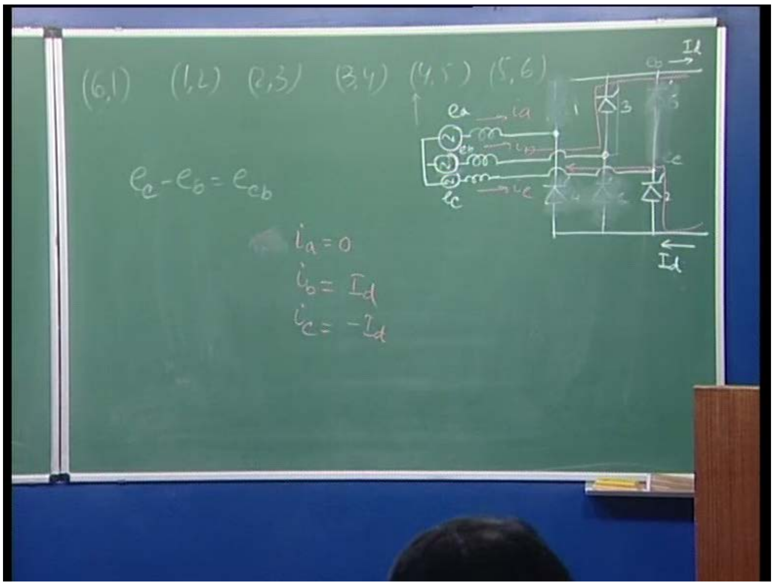

As I said here, this is an upper commutation group and this is a lower commutation group. So, when the valve current here 1 and 3 this from 1 and 3, it is going to share that duration is called the overlap angle and we are assuming the overlap angle here is 0. It means, whenever this is going to get the fire impulse, suddenly the current from here it is shifting here. So, this is an instantaneous change. Also, in this analysis we all assume the valve 1 2 are conducting and then 3 is getting the pulse and then thereby we are starting. So, we are analyzing our circuit when your 3 and 2 are going to conduct to know.

The commutation voltage as here if 1 and 2 are conducting, you can see the voltage this is conducting; this is a short circuit and here the voltage is appearing e a and this is your e b always positive. e b here across the positive of this wall it is not always positive. This is a positive across this, the positive terminal of this. So, e b a if it is positive then firing pulse is available here valve 3 will be fired and that is why e b a is known as the commutation voltage of valve 3. Similarly, we can calculate the commutation voltage of other valves as well. For example, if we want to calculate the commutation voltage of valve 5 what will be this before this 5 your there and 4 were conducting because, always we are assuming the conduction pattern is a 6 1. Here, 1 2 then it is 2 3 here 3 4 and your

4 5 here 5 6 and then, we again we are going to 6 1. So, for knowing the commutation voltage of 5 you have to see when the 5 is going to appear. So, 5 is going to appear here at this instant means, before 3 and 4 were conducting. So, once 3 and 4 were conducting now you can see here this voltage is coming here means it is e b and this valve is c here c. So, means your e c b e c minus e b or you can say e c b is the commutation voltage of valve 5. Similarly, you can calculate for others as well.

Now, let us see when the valve 1 and 2 were conducting and now 3 is just getting a fire impulse means your 2 and 3 are conducting. So, your circuit becomes here from here again we can draw. Our circuit can be seen here; already you can see this is our circuit means, here your b phase is giving here the valve it is your 3 here it is a 2 the lower 1. So, this is a current flowing and a is open circuit means there is no current in phase A current you can also analyze from here means, once 2 and 3 are conducting means this is your off.

I can open this is off means, this switch is off and now this is your 3 this is a 5 is also off because, it is not conducting and 6 is also off and 4 is also off. So, you can see this is your, this is a current which is flowing and then finally, it is going back here means we can write the instantaneous values for all the Valves as well as all the phase current we can write here now you can see here e a we can say i i a means phase A current means it is 0 because here that is it is open circuit.

It is also open it is hanging also you can see in that circuit now we want to write i b and i c i b here it is nothing, but your Id we are assuming this Id current the DC current repeal frequently flowing in the DC link. So, this current will be your Id. What is your i c? it is minus because we are taking our this direction is your i a here i b here it is your i c. So, i c is your minus Id. Similarly, we can write the instantaneous values at this instant when 2 and 3 are conducting.

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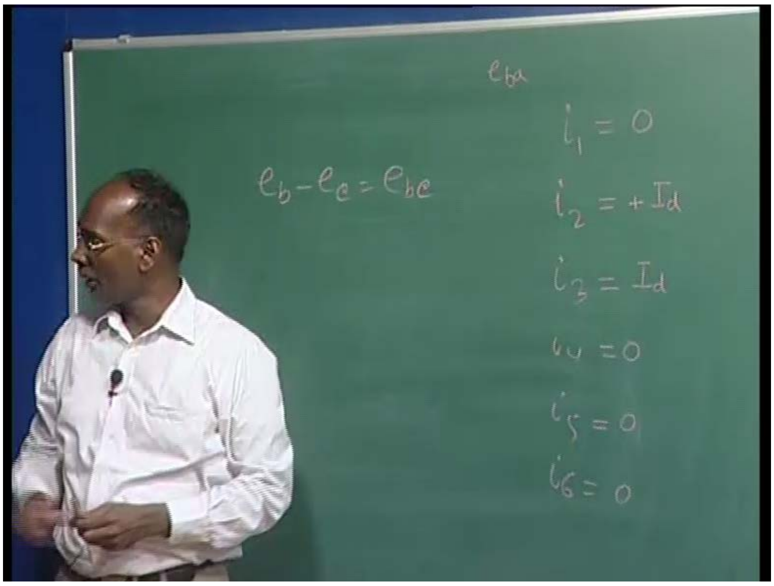

We can write the current across valve 1 valve 2 valve 3 valve 4 valve 5 and valve 6. So, you can see this valve 1 is 0 because, is open it is not conducting your valve 2 is conducting your valve.

There is also conducting valve 4 is not conducting 5, is also not conducting this is also not conducting. So, i 3 here is your positive Id here this is your Id positive because the current which is flowing here from this positive to here and we are assuming this is a current direction of here i 2 means we are assuming the current direction from positive terminal to negative terminal. So, this is also Id; it is not minus Id but, here it was the direction which we are assuming all the 3 currents are flowing. Here, this was going in the reverse direction that is why I wrote here it is your negative. So, these are basically already you can see all the here the currents are written here. Now, your output voltage here as usual this e b is appearing here because this is conducting and this is your this is phase c e c means output voltage will be your e b minus e c and that is nothing, but your e b c. So, during that 60 degree when 2 and 3 are conducting your output voltage will be the line to line voltage and it will be e b c which will be appearing now you can see the commutation voltage of there was your e b a, but output voltage is not e b a it is a differently the e b c. So, both are different always you should be very careful that what is a commutation voltage, what is the output voltage.

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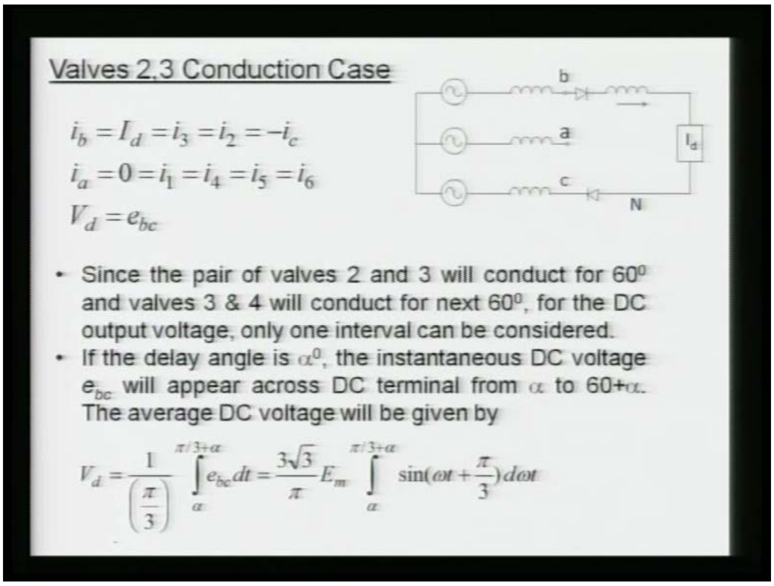

This voltage is appearing across this and that will be the instantaneous voltage now we have to write what will be the output voltage If we are having some delay. So, to know this delay we can let us suppose the alpha degree is delayed and that delay here will lead to you can see the DC voltage the e b c where output appearing now we are delaying it is not from starting from 0 we are delaying by alpha degree. So, it will be delayed by here 60 plus alpha. So, output voltage here the V d will be now we are talking about pi by there because this is always we are assuming we are having the symmetrical patters which is appearing to the DC link and it is a 6th pulse. So, we can take the average of one pulse and then it will be the same for other pulses as well. So, your V d will be only taken by here pi by 3 degree means 60 degree. So, only for this one we are integrating and this output voltage is e b c d t and then you can get this value again from this derivation.

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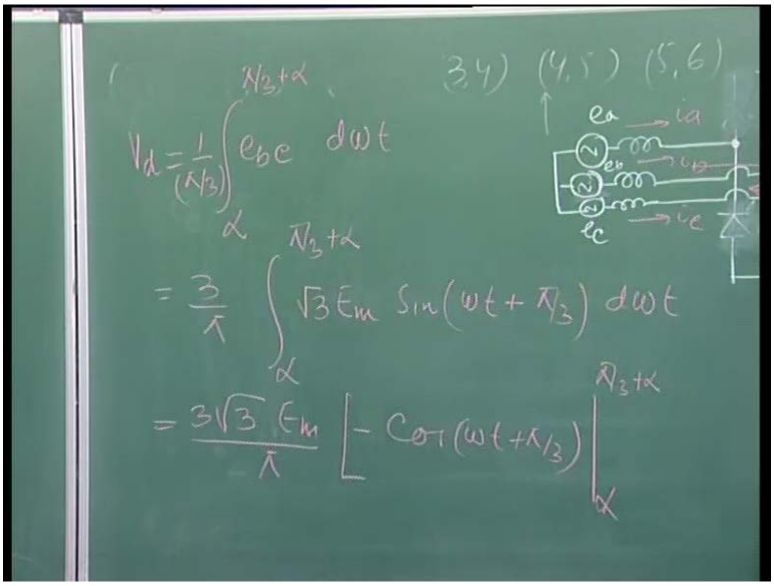

You can see our this V d which it is written it is your nothing, but integration e b c d omega t here from alpha to your pi by 3 plus alpha here we are writing pi by 3 here always you should be very careful here d omega t it is not omega d t because we are here to cos omega t we are taking means this is a theta. So, now, I can say it is 3 over pi this value e b c if you will see from our the phase diagram we wrote here it is your under root 3 E m sin omega t plus pi by 3 here d omega t this is your alpha pi by 3 plus alpha now we can take it out and then we can differentiate we will find that this is your 3 under root 3 E m divided by pi and if you are differentiating this sin omega t plus pi by 3 it will be minus cos omega t plus pi by 3 here it will be your alpha here pi by 3 plus alpha.

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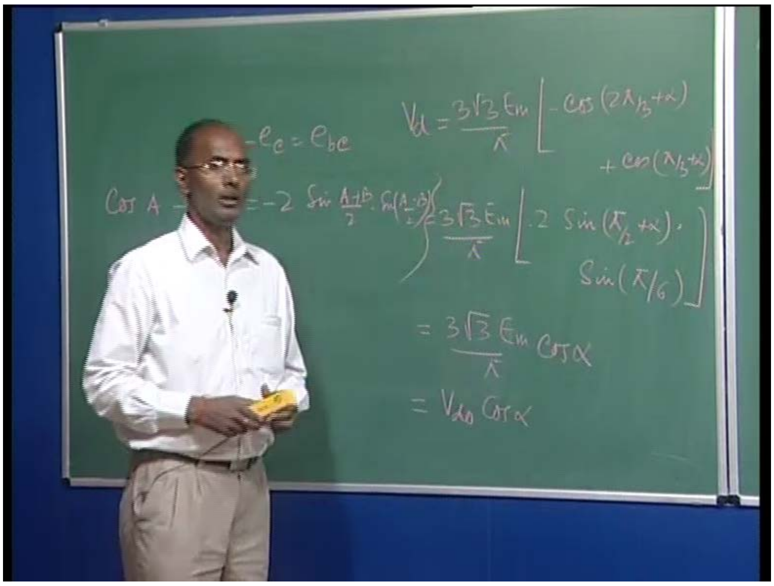

Then, if you are going to simplify this you are getting your value means your V d will be your 3 under root 3 E m over pi this value is minus cos twice pi upon 3 alpha plus cos it is pi by 3 plus alpha here we are having you can say cos A minus cos b then finally, here you are going to have 3 under root 3 E m over pi this value we can write twice sin pi by 2 plus alpha into sin pi by 6 and finally, here we are getting 3 under root 3 E m over pi cos alpha because here.

The sin pi by 2 alpha is a cos alpha this will be 1 upon half will be cancelled and we are getting this negative will be at will be taken care here we are adding means you know this is a formula very well this cos A minus cos b it is nothing, but minus 2 sin A plus B by 2 into sin a minus b by 2 in this formula you can just find it now we know that this value it is your our V d o when alpha is 0 and we can write it this is a cos alpha. So, this is your DC output voltage the average DC output voltage which is appearing across your DC link and this will be average because we have here we have took the average for 1 pulse and similarly the all the pulses are same symmetrical and then it will be the average voltage for whole cycle as well.

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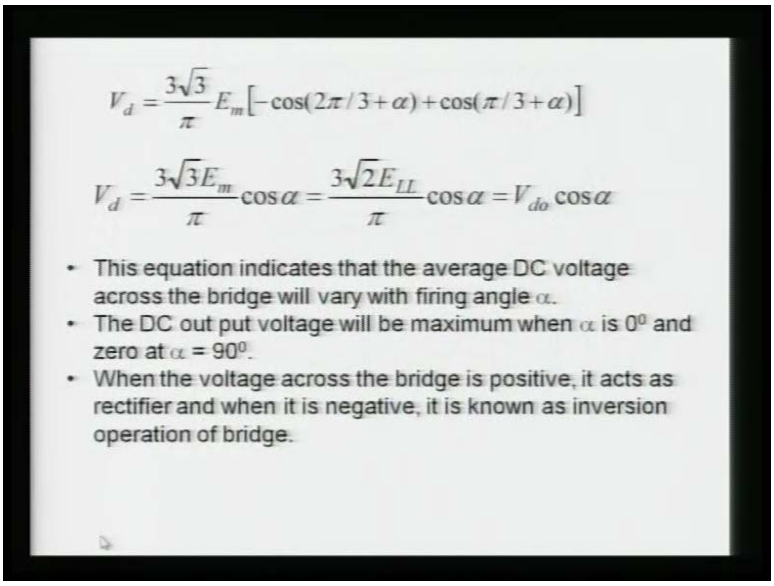

Now, we can see here this value V d this alpha once it is 0. So, we are getting the highest voltage as usual in rectifier circuit and if you are delaying this alpha up to let us suppose 90 degree.

This value become 0 means output volt is 0 and if it is again further delayed then this voltage becomes negative. So, you know from 0 to 90 degree in ideal case when there is no overlap the output voltage will be positive or up to 0 if you are delaying from 90 degree onwards it becomes Inverter operation voltage becomes negative for this case

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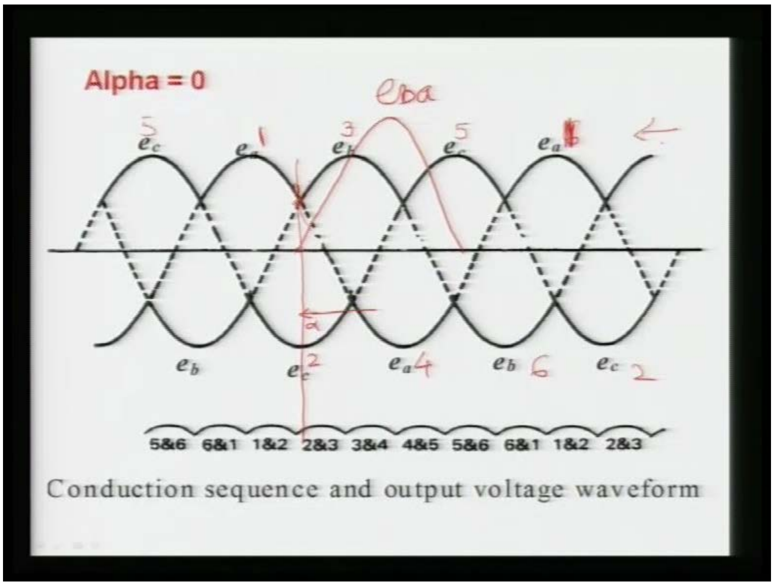

Now we have to now draw the output voltages for all the complete cycle because always we have to see this what will voltage well it is conducting now if we will start let us suppose your again 1 and 2 are conducting what will be the voltage output here you can see here I have written a b c phases upper limb and the lower limbs also here this is basically the phase voltages phase voltages this portions shows your upper limb voltages this is your lower limb voltage it is not line to line line to line to get line to line you have to subtract the upper limb voltage minus lower you will get line to line. So, this is the way shape wave form of your the phase voltages now as I said let us suppose 1 and 2 are conducting where we are 1 2 or this are conducting you are here somewhere you can say 1 and 2 here. So, this is here at this point before that your 1 and 2 were conducting now you are giving a pulse to 3 it will conduct because this is a voltage e b a will be positive here because e a is going to be negative and this is going to positive means you'll find your e b a will be here this is your e b a and that is the commutation voltage of your valve 3 means even though you can fire here this your alpha can start from this value here alpha. So, you can delay alpha till 180 degree if it is up to 90 degree it will be the Rectifier and after that it becomes Inverter.

So, now we can write this e b a is here you can see now I can see your valve this b means your 3 is conducting then after it is your 5 this will be a 6 here again sorry it will be over run here it is 1 and here again 5.

So, it is 1 3 5 similarly you can see here the c you can say it is your 2 than it is your 4 6 again 2 and. So, on. So, far. So, you can see here even though in this diagram also when your 3 is conducting your e b is appearing before that it was not e b. So, e b is just going to appear at this point when the commutation voltage of 3 is going to be positive. So, this upper limb here the upper phases voltage are showing this is your positive means upper side voltage and this is your lower side voltage. So, the voltage which is going to appear across the DC link it will be the difference of this minus this will be the DC voltage to know it this in line to line

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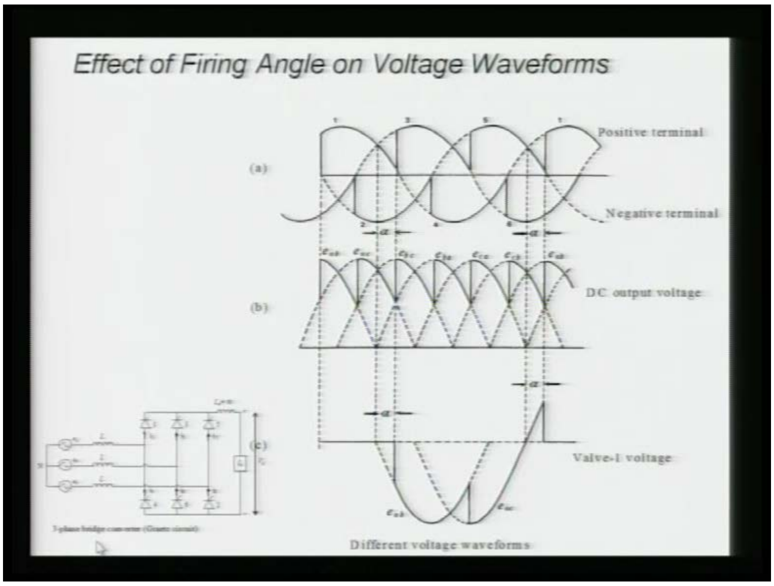

We can come here to let us see line to line voltage. you can see the line to line voltage here the alpha here this e b a if you can see this is your e b a and here we are measuring the alpha from here because we are just assuming our cycle just start from here when 3 is going to be fired before that 1 and 2 were conducting. So, you can see this is this voltage is your e b a now here if alpha is delayed than here you can see the voltage is now e b c suddenly is coming here because before that it was e a c and similarly it will be the pulses it is now it is your 2 3 than 3 4 than your 4 5 here 5 6 and. So, on they are just conducting now it is here to draw this wave shape excreta is very simple, but actually how to draw how to know the phase voltage here and there how to even though draw this write all these values it is also complex

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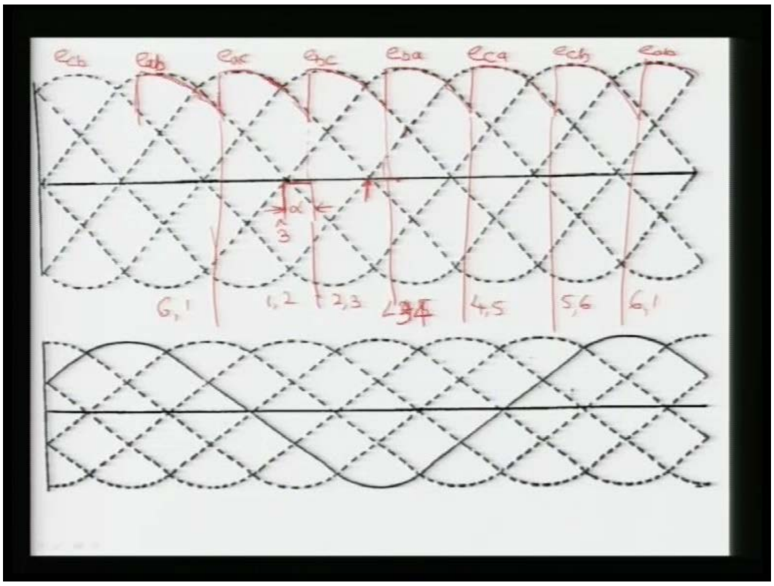

If your concept is not clear than you cannot write for example, see I have given a blank sheet to you and I am saying that this voltage is I am writing e a b.

I have given this is a voltage h not e b a it is e a b now is a line to line voltage now we want to know what will be the line to line voltages for this. So, here what you can do here this is e a b you can go for the cyclic 1 means here a b than you can go for b c and you know what happens this is a complete cycle after 120 this will be your e b c than again after 120 here this will be your e c a and it will be repeated you can say this is again coming here it will be e a b means why I said here you can see this is your complete 1 cycle 80 degree half of the cycle and this is repeating here now after 20 degree this portion is your 60 degree this is a 60 degree another here it will be 120 degree also in the line to line voltage. So, here I have written b c because a becomes b b become c similarly again here the 120 degree here b becomes c it becomes a because this is a cyclic a b c and then it is written now what will be your where is your e b a e b a will be you can see this is e a b it will be reverse of this. So, to write this I can simply write here this will be your e b a and this is the commutation voltage of your valve 3. So, you have to find out the e b a and then you can start now this is your I can say if your 2 3 going to be there. So, e b a here your 3 can be fired similarly what will be this value this is your e a c why because this is your e c a this is a reverse of this. So, you have to write all the voltages here I can write e c b and now I can say you can see I have written each and everything e c b. So, line to line voltages now I have written based on 1 voltage information I have written all these line to line voltages here in this 1 both a b and b a means here you can say a b b a f e c a b c c b and. So, on.

So, far now I want that we can see I want to know what will be the output voltage in terms of line to line when alpha is not more than 90 degree some alpha degree we are delaying what will be the output voltage you know before this your a c was conducting the advent 3 are going to 5. So, here it was conducting your this value was your e a c was there now once we are delaying here this is delayed here.

Let’s suppose alpha degree means we are delaying we can fire here at this because this is a commutation voltage, but we are delaying by alpha degree now this voltage will be up to this portion here once you have given the pulse to valve 3 suddenly the voltage will become e b c and it will follow this now every 60 degree here again now we are alpha degree delayed now it will conduct for your 60 degree plus it will be going up to here this point and again it is delayed this is your how much this is your 60 degree and this we are going to have a here 60 degree again. So, what will happen it will come and then again it will go here and it will be this because this is your 60 degree just see here this is 60 degree. So, again alpha here it is shifted and then finally, here this is we are getting here alpha you can see at this portion your 2 and 3 are conducting because once 2 and 3 are conducting means

We are getting the voltage e b and e c here e b c across this now after that here thee c a is basically the commutation voltage of valve 4 and the valve 4 can be here fired means it can be fired here only at this point it can be fired, but again alpha degree here also means all the Valves are delayed by alpha degree because the conduction there all the Valves are getting the pulses after 60 degree if 1 valve is delayed alpha then everyone getting alpha degree delay means 60 60 again continuous interval. So, here your 4 is coming means we are going to have our 4 5 valve conduction and it means 4 5 are conducting means what this is your this is your e a and 5 here your c c a is your 4 and 5 e c a will be conducting sorry here 4 is going to be there. So, it is your 3 and 4 will be conducting because your 2 and 3 were conducting now we are giving the pulse 4. So, 3 will continue to conduct. So, here it will be this your b and a. So, e b a will be there similarly you can see it will be again delayed by here then.

It is your valve 4 and 5 are conducting. So, it will be going up to here again this alpha degree and then and. So, on. So, far. So, it is 4 5 here it is a 5 6 and here again 6 1 and. So, on. So, far. So, you have to draw the complete cycle. So, if it is not complete cycle this side. So, you can go back side as well. So, here it will be your 1 and 2 are conducting. So, it was your output voltage here up to here 1 and 2 then it will be your what is 6 and 1 and it is repeated. So, this is output voltage that is appearing across though at the DC link with alpha degree firing and this alpha degree we are talking that alpha is less than 90 degree. So, and you see the voltage across this is this is magnitude which is appearing this is a 0 reference from here this value and this is if you'll take the average already we calculated the average value here with alpha degree so.

We are going to get a DC average voltage across the converter circuit similarly you can draft out the again I showed your previous graph that you can draw from our limb voltage here limb voltage also separately that can be also asked. So, always here I want to emphasize that you must find out whatever the voltages are given you have write if you cannot draw this voltage and write this line to line voltages then your pattern will be certainly totally different here it is very simple because you know this is a systematically should come, but once we will go for the overlap and we will go for the 3 and 4 valve conduction the patter will be totally different and if you are not drawing you will not get the output voltage at all you will get something else. So, this is very important you have to just write this for given any voltage if it is not given than you can choose here simply e b a because valve 3 commutation voltage and continuously you can write accordingly. So, so going back here here just

I want to emphasize about this alpha degree this alpha degree as I said it can be from 0 to any value between 0 to 180 degree, but normally this alpha we never go to 0 normally we keep this alpha minimum the alpha minimum is basically required because you are having series of Valves if there be any delay any of those series of valve. So, it may (0) the valve will not conduct.

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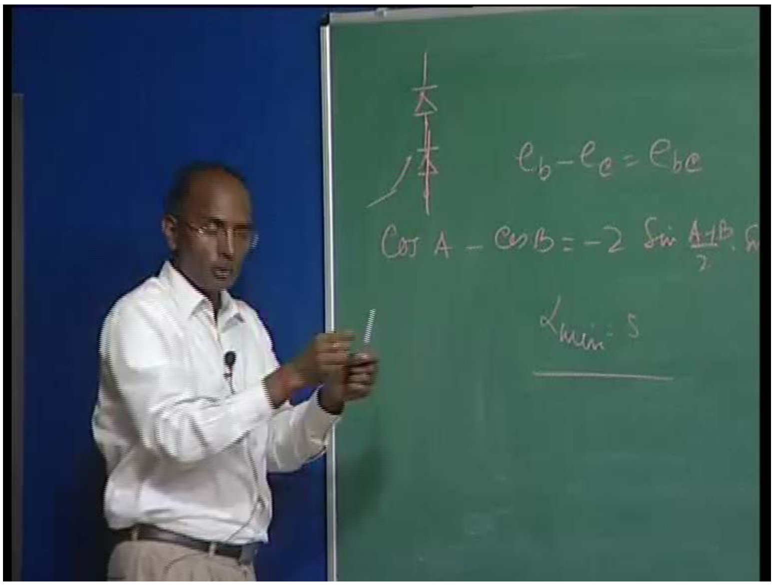

So, what we do we fix this alpha normally it is called alpha minimum and this alpha minimum is normally kept 5 degree because the voltage across any of the valve may not be suddenly positive because 1 will conduct then voltage will appearing across this for example

Let’s suppose here we are having the various Valves in the series now if you are conduct giving the pulse here the voltage may be appearing across this. So, the voltage across this may not be positive because it is not conducting once this will conduct than voltage will come here and. So, on. So, far. So, we just there are. So, many Valves are in series. So, we give some margin. So, it is not even the 0 we give some margin and that is why it is called normally it is a 5 degree we keep it for h V DC links similarly if you are going for alpha near to 180 degree it is also we always maintain some degree.

That is called the extension angle because here at this alpha we will see Inverter operation this is a very very critical for the Valves because in the Rectifier board the voltage across the Valves are mostly negative means if you’ll see the valve voltages you will find it is mostly negative very few portion it will be positive, but in the Inverter operation the valve voltages is mostly positive valve voltage I am talking positive and very less for the negative side. So, if it is slightly deviation certain problem occurs then positive voltage is there it will continue to conduct it will not off.

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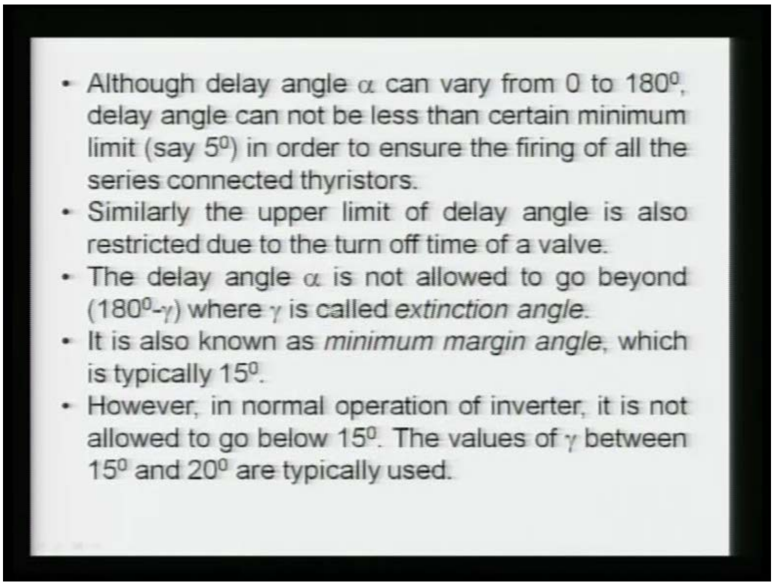

Here, as I already I had said here the delay angle alpha is not is a we maintain the alpha minimum and also the delay angle alpha is not allowed to go beyond 180 180 minus alpha that is a gamma that is gamma is called a extinction angle this is also called the minimum margin angle

We will see later on when this margin angle and extinction are both are different later stage we will define when we will go for the overlap excreta. So, how were in the normal operation of the Inverter it is not allowed to go beyond below the fifteen degree even though sometimes ten degree also allowed for this proper commutation of Inverter operation

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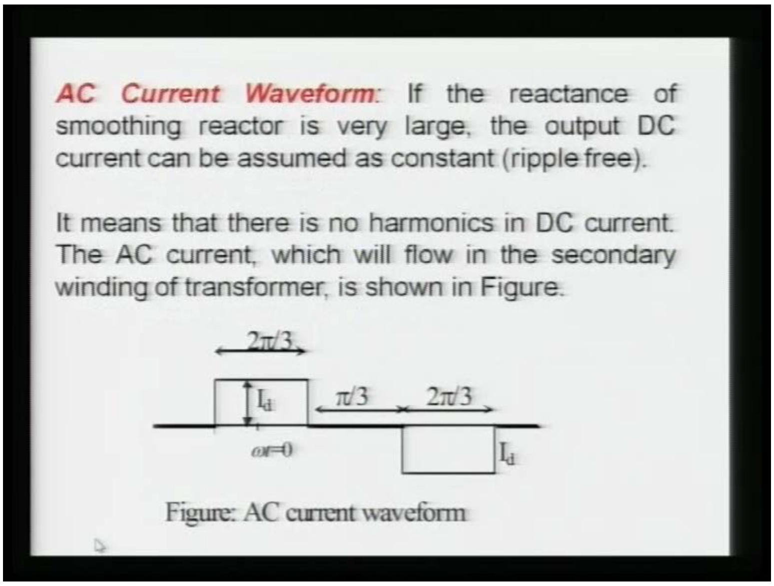

Now let us see what will be the fundamental current in this again valve here means it is our I can go for this 1 again and now once your we are starting when valve 3 is getting pulse means we are trying to draw the phase A current

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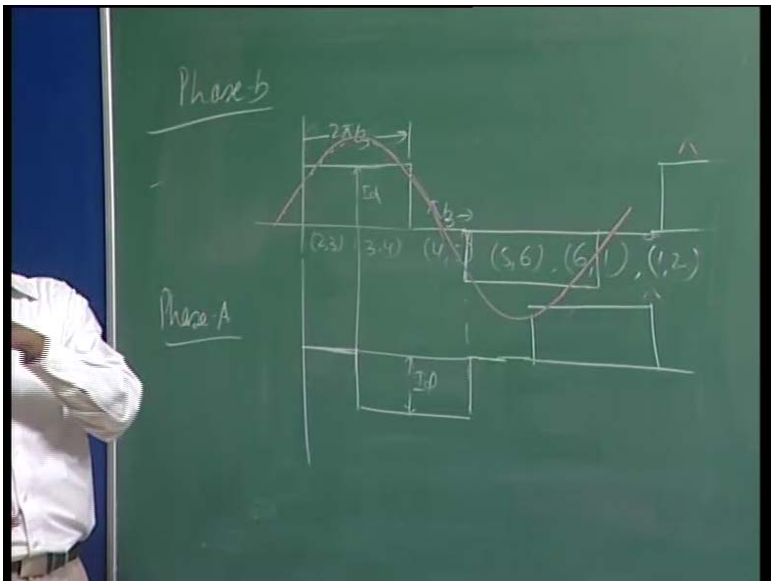

In this circuit the phase let us draw the phase b current this phase b current and. we are starting when this 3 is going to be fired. So, what happen if this is going to fire at that instant the current Id will be totally coming here and that is a full phase current means I can here I can say it is your Id and till the 3 will be conducting means here half the portion it is your 2 3 and then again here 3 4 are conducting till here the current will be your Id in the phase A phase b now once after that if we are going to 4 5 now we can say the V phase is off and no here neither 3 nor 6 are conducting. So, it will be off and there will be current 0. So, here that portion here this.

This is your 2 pi by 3 means 120 degree here it will be 0 for pi by 3 degree now here now another sequence is 5 6 6 1 and again we can go for your 1 2 now once the 5 6 is coming 6 is again the b phase and now you can see the current pattern that is here it is going to be here means negative of your phase b. So, here it will be coming Id and this will be till your 120 degree because this is 6 is involved in that and than again here 1 2 no phase either 3 and 6 are conducting. So, it will be 0 again and then it will be again. So, this is your phase b current similarly you can find the phase A current phase c current again based on these conduction pattern now.

You can say simply c what will your phase A phase A current here 1 2 and 3 are conducting means 1 is off either neither 1 nor your 4 are conducting. So, here it will be 0 up to this this is 0 now 3 and 4 means 4 is conducting means it will be negative and till here. So, it will be your Id and here 5 6 again your it is off. So, it will be 0 and then again here it will be 1 once 1 is coming then it will be positive similarly you can draw for phase c as well now i want to calculate what will be the fundamental component of this means r m f value of this since it is not a perfect sinusoidal, but it looks like a some pulsating and we can see this here.

It is your this fundamental component will be like your for this like this is your current just huge fundamental component; however, some other harmonics component will also appear, but that will be less now to know what will be your the fundamental component and you know it is basically calculated by few rear series analysis and therefore, this it has some symmetricity you can see this is a either 2 symmetricity here is a half of this and also this is rotated some of the 2 symmetricity we will discuss again later on, but for

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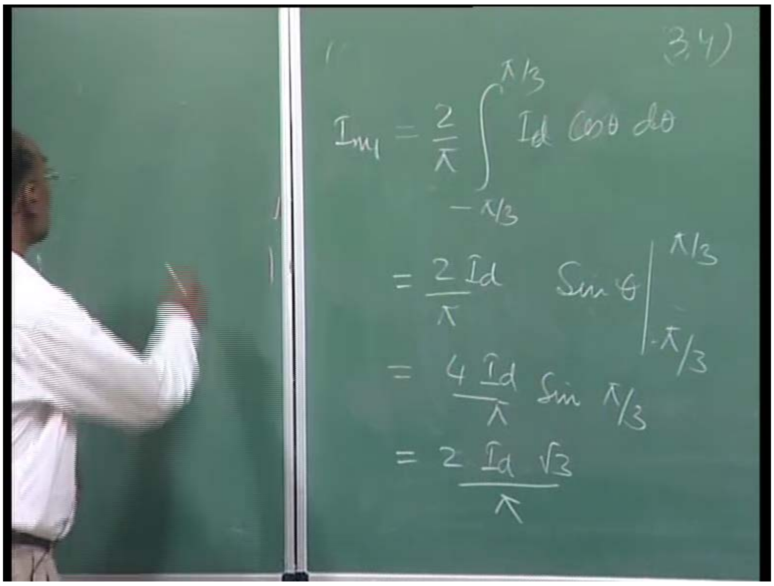

I can say this I I m 1 here I am writing the fundamental component peak value m is peak value I am calculating this is can we retain twice upon pi here we can write for this component as well from this to this here. So, this side it is 0 this side it is 0. So, we can simply integrate from minus we are taking this is a axis here. So, this will be your minus pi by 3. So, I can write here pi by 3 here pi by 3 it is your Id I d here d theta or d omega t theta is nothing, but your omega t. So, into here.

For the cosine component we are taking. So, here cosine theta d theta we have to write this is a cosine component because we are taking here both side it is a symmetricity. So, this will be component at this axis here we can just take it because this you can say it is a cosine component we will again later on we will see all the harmonics later on, but here only take the fundamental component. So, now, if I going to calculate here what value you are going to get it here now put this value. So, we are going to get 2 over pi this is Id this is your sin sin theta minus pi by 3 to pi by 3 and this value will be your how much this will be twice means

We are going to 4 Id over pi sin pi by 3 because sin pi by 3 minus minus pi by 3 here both will be added. So, the twice I have taken here it is a pi by 3 means this value we are getting 2 Id into under root 3 by pi because this value is pi under root 3 by 2 this is your peak value

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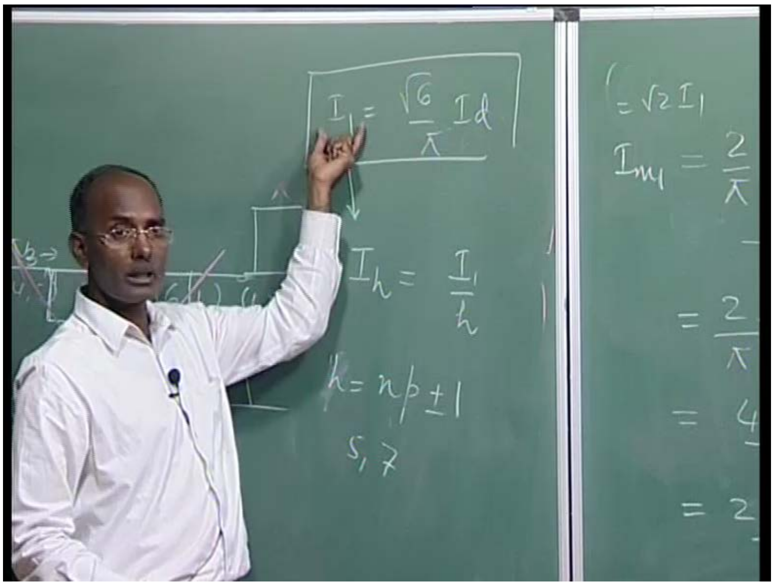

If i want to calculate this r m s value I 1 it will be here I can write this will be equal to under 2 i 1. So, I 1 I can write it is your under root 6 divided pi into Id this is basically the r m s value of the fundamental component of this phase current this is the r m s value why we are talking because always the our power this active power we are talking we are talking the fundamental component that is flowing through

This phase current there will be some harmonics we are avoiding this we want to calculate what will be the a c power we will see later on and also we will see later on this I h will be your I 1 upon h is the harmonics components if you are having as I said it is a 6 pulse converter your this it is a P your sorry your h is your n P plus minus 1. So, this h is the harmonics component that will appear in this output of the current will be related with this. So, for 6 pulse we are going to have fifth and 7th. So, this h value here is your 7th and 5th components as well. So, whatever the fundamental here r m s value we are getting divided by that it will be keep on coming. So, for all you can see here the larger harmonics here you are getting the lesser magnitude of that harmonics current component.

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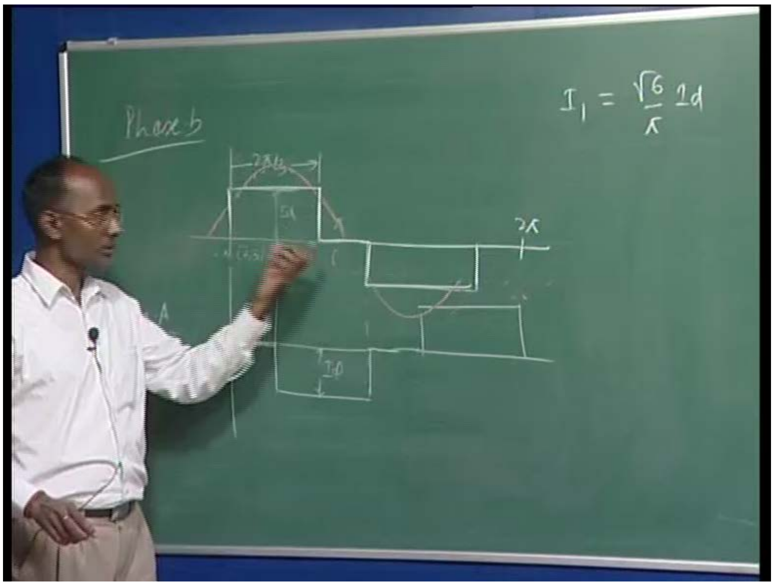

So, now, let us see the total r m s component here of this current including your harmonics here i wrote this your I 1 it is your nothing, but your under root 6 by pi I d it was the fundamental component, but we are having. So, many other harmonics component as well

Now, i want to write what will be this r m s valve of this current total r m s not only the fundamental is a total r m s value and that you know again this is your r m s value is here

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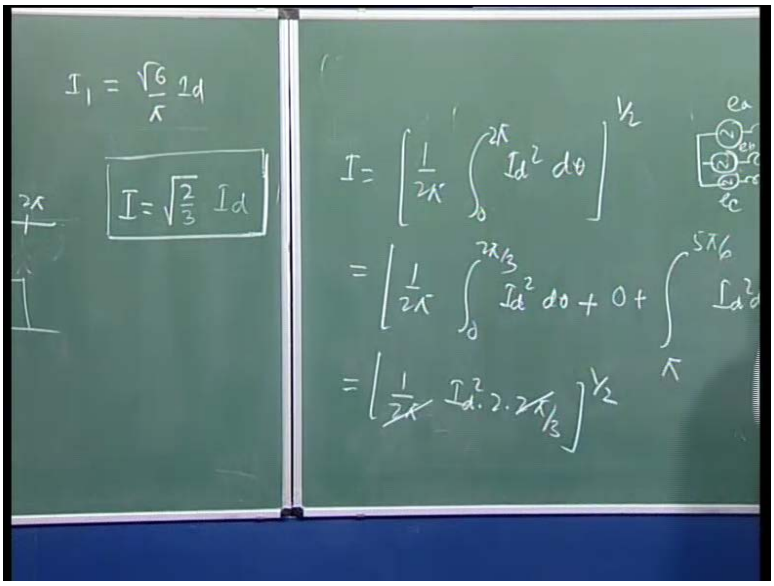

We can write in this way means your I will be over 2 pis means we have to talk for the complete cycle here this is this and up to here it is going to be a twice pi this is 120 degree 60 degree means 180 and here 120 degree and 60 degree. So, it will be complete cycle and then here from 0 to pi this is your Id square d theta and it should be 1 upon half means square root now

You can see here it is we can again try in the 2 parts now it will be I can write 1 over twice pi. So, here sorry it is 2 pi here. So, we can write here 0 to 2 pi by 3 Id square d theta plus second term is 0 plus here I can write the remaining portion that is here from pi to your this is your 5 pi by 6 Id square d theta again this is 1 over 2 this value is same equal to this value because this is Id is negative, but square it will become positive and this is for 120 degree here this is 120 degree here. So, this will be same and finally, we can get here this is your 1 over twice pi and this is your Id square into twice into 2 pi by 3 and of course.

It will be 1 by this 2. So, this is going to be cancelled here and you can see we are getting this i means total r m s current value of this it is under root 2 by 3 I d. So, as written here expression we can also calculate systematically. So, this is the r m s current the phase current here the r m s value that is of including your harmonics as well as your fundamental component you will always find this value will be lesser than this value because this is including all your harmonics you can also put the value you can check it now let us draw the valve voltages again here the conduction pattern I will just come again at this where we were here.

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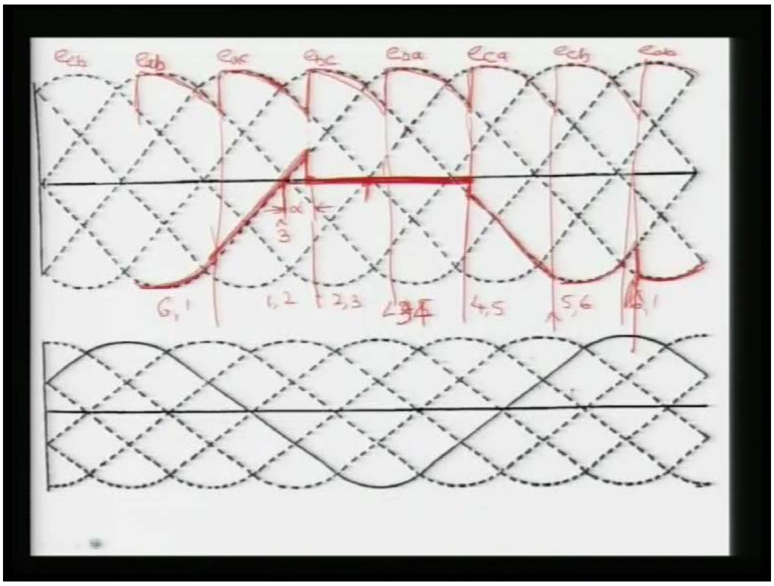

I want to draw the valve voltages again because you know just i derived the output voltage is here starting from our here the 3 is going to be 5 it is a delayed by alpha degree now once it is a 3 is going to conduct i want to draw let us suppose valve voltage sorry once 3 is conducting means the voltage across.

This will be 0 means here from this point to it will be conducting up to this point it will be 0 up to here it is 0 because valve 3 is conduction means the voltage across this is 0 as we assume this is ideal valve from here now now 4 and 5 are conducting now from here you can see this is a 4 and 5 for conducting means once a 5 is conducting here the voltage across this is your e c the voltage here is a e b all the time. So, e b minus e c will appear now see where is e b c is there e b c we will see where is e b c this is your e b c this is a downward. So, it will be it will be coming down and this value is here and then it will be coming here. So, once this 4 is going to be fired means the voltage across this valve it is your this your 5 is going to be fired here. So, then it is coming here your e c and this is your e b. So, e b c will appear across this. So, it will be suddenly it will be coming here and it will follow till this your valve will be conducting this your 4 5 will be conducting it will follow your e b c now here once 6 is given a pulse now you can see where the 6 this 6 is now conducting. So, this will be this and after that your valve this is your fifth is no here it is 6 is getting a pulse and now we are your 5 and 6 is conducting again this is your e c. So, it will be continue again and it will go up to here again now we are giving a pulse to 1 now 1 is conducting now you can say 1 is appearing here. So, it is a e b a is coming and now you can see where the e b a basically this will be coming here your e b a is here now it is here and then it will be continue.

So, again it will be coming back here you can see we have started here at this point now you can see again if your 1 and 2 are conducting this voltage will continue and it will be going here till this value and then finally, here it is 0. So, this is a complete valve voltage as I said here once your 3 is given pulse means 2 and 3 are conducting. So, 3 once 3 will be there the voltage across this will be 0 now here valve 4 gets pulse means your 4 and 5 are conducting and you can see 5 is c. So, it is c and 4 is there. So, e b c is appearing and till here than because 5 is there. So, 5 basically corresponding you can see the 5 is coming the voltage here it is coming e c all the time.

So, it will follow the c component and here e b c which will follow means for this 2 cycle means 4 5 and 5 6 it will be conduct your the valve 3 voltage will be your e b c now once here you can see your 1 is going to be fired at this point where 1 we are firing. So, a is coming here and the b. So, e b a it is suddenly it is coming to e b a and you can say here you are following e b a and then again 1 till 1 will be there it will be here e a and this will be a. So, this is your valve voltage similarly you can draw the valve voltage for other Valves as well because

We are having 6 Valves any valve can be asked for you thus you have to draw the valve voltage. So, again that depends upon what you have taken this references and then you have to follow that where it is going to be fired what will the voltage. So, this circuit to analyze this you should be very careful about this number then you have to see which patterns are coming and then what will be the output voltage what will the voltage across any of the valve and then you can draw on the same graph here. So, this is your Rectifier circuit now you can see in this Rectification circuit the voltage across the valve most of the time here it is negative it is always negative. So, even though you are getting the pulse it will not conduct.

So, Rectifier circuit that is why is very stable circuit even though there is spurious signals in the gate this will not conduct you can see only the positive voltage appearing here in this 1 for valve 3 and then you can give the false here or anywhere it will be conducting. So, in this whole Rectification operation it is very stable; however, you will see in the Inverter operation this is a very difficult because these whole scenario is changed because this voltage will come down this will go up. So, you can see most of the time.

If it is coming up voltage across the Valves are very positive and any spurious signals in the gates excreta even though rate of change here also may sometimes leave without the gate pulse it can come you can the Inverter can that valve can fire and that is that is why the commutation failure another things are coming to the picture in the Inverter operation now.

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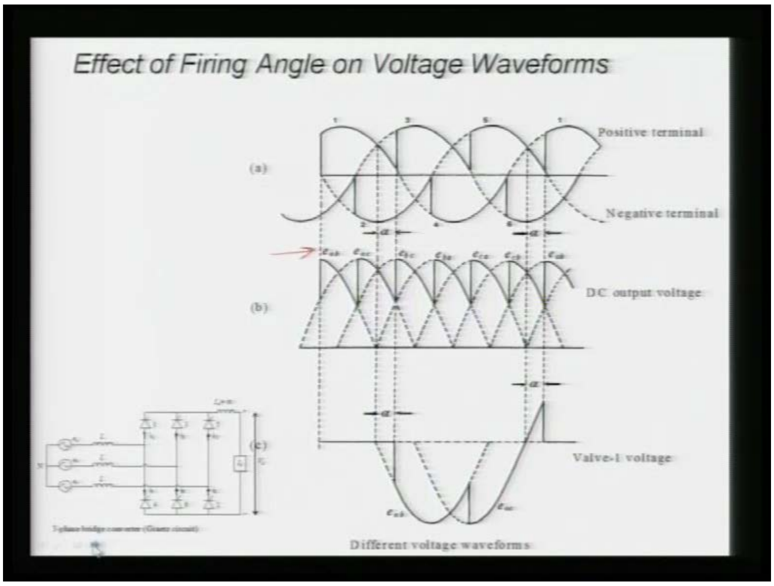

So, that is why here it is shown the valve 1 voltage you can see the valve 1 voltage here this is coming the symmetrical pattern

You can see here and then finally, it is conducting here. So, here also it is conducting. So, this is output voltage valve 1 voltage similarly as i saw i draw for valve 3 voltage

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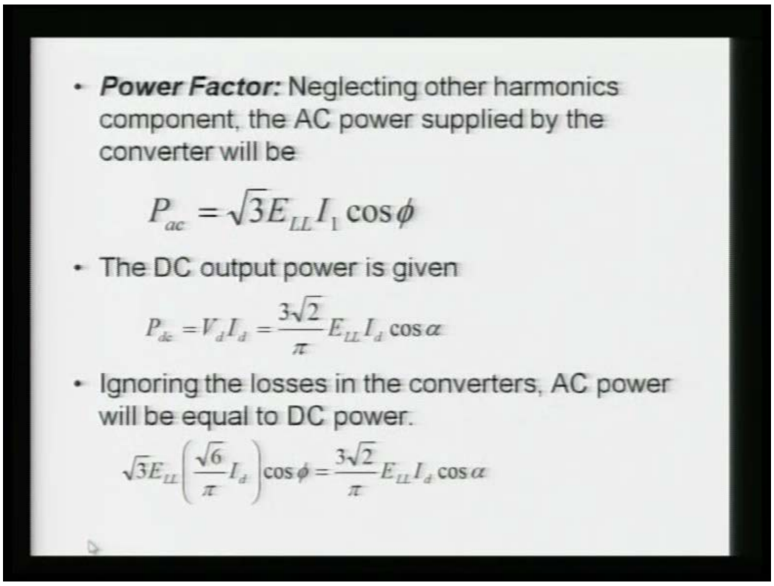

Now let us see the Power Factor as I said the Power Factor is very important in this thruster control h V d c link and we will proof that the Power Factor will be equal to your the cosine of the delay means whenever you are delaying means your Power Factor is worsening means is going to be deteriorate vary badly means if your alpha is delayed much the Power Factor is very poor means you require more reactive power support to flow the power over the DC link now see the first here the what will be the a c power a c power here because we are talking the a c power if that is a fundamental component power

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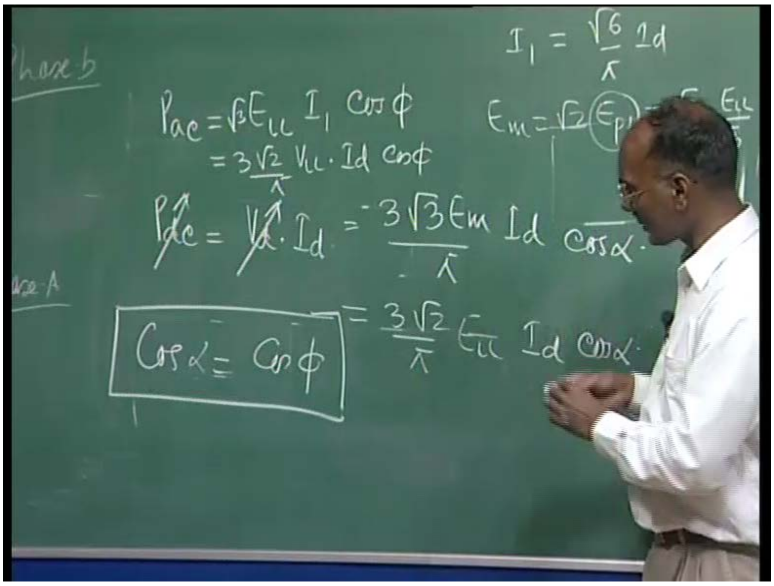

And this P a c is your a c that we are talking that is your e this r m s voltage I can write l l into under root 3 because we are writing in terms of line to line voltage and here it is your I 1 cosine of phi phi is the Power Factor angle this is 1 I am writing here is the r m s component of the fundamental 50 hertz cycle we are ignoring the harmonics component. So, this is your a c power now our DC power as our definition it is nothing bur your V d into your Id now if you are going to put this value here the V d we already define under root 3 E m over pi Id cos alpha because here the V d i put 3 under root 3 E m divided by pi cosine alpha this E m we know.

This E m is nothing, but under root 2 e phase value the phase voltage here will be this peak values under root 2 into r m s value here I am writing or I can write here under root here this phase value we can write in terms of under root 2 here e l l over under root 3 this is line to line. So, you must know always this your V phase will be your V line by under root 3. So, if you are putting this value here E m and you will find it is 3 under root 2 divided by pi e l l Id cos alpha this is your DC power if it is a lossless converter as we assume this there's no loss means a c power will be equal to your DC power now we are going to put here I 1 as well from here and if you are going to put here we are going to get 3 under root 2 V l l into Id divided by pi cos phi because this under root 6 here this under root 3 here it will becomes 3 under root 2 is coming out here pi V l l. now, you can compare these two; you will find we are getting the cosine alpha will be equal to your cosine phi. So, this shows that your delay the cosine of the delay angle is directly related to your Power Factor.

So, if you are going to reduce your the voltage of the output terminal the Power Factor of the a c here becomes very worsen. So, that is why also we put some limit on alpha. Also, we do not want to delay alpha too much now the question why we are delaying this alpha delayed is to control the DC power because in the DC link the current is always constant we maintain the current constant and your voltage is changed. So, that our P DC here can be changed by changing your this V d. So, this can be changed. So, to change this you have to control the V d means you have to control the alpha.

So, alpha has a lower limit as alpha minimum alpha here also we cannot go out certain beyond here alpha because the reactive power requirement will be very excessive means the a c system require huge reactive power. We also limit alpha maximum value in the Rectifier operation as well and. That is why our controller will see how complex it is because we have. So, many limits we cannot operate means up to our desired feature because we have some limitations alpha; we have certain limitation on even though extension angle if alpha is operating Inverter side. So, this will create the problem and that is why we have to have a very sophisticated control system to take care of all this.

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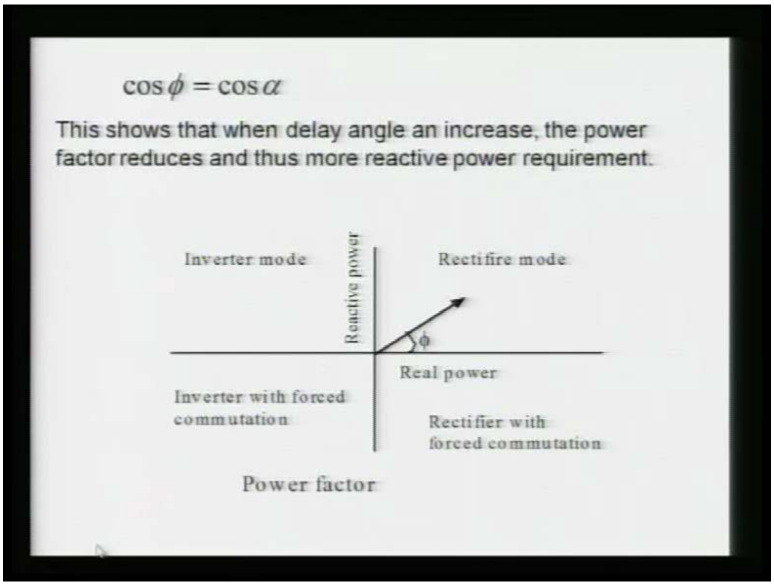

Now, to see this reactive power requirement it is not only in the case of Rectification operation it is equally valid for your another operation as well now here now you can say alpha becomes more than 90 degree, this value will be still positive and is lacking only, what happens? The voltage becomes negative the DC becomes the current power will be the Real power will be then negative direction now you can see this is your Rectifier operation mode in this quadrant first because in this case if you are assuming the power is coming out from the Rectifier. So, it will require some reactive power as 1 here. Now, if you are coming in the Inverter side this Real power becomes negative but, reactive power again it require from a c side.

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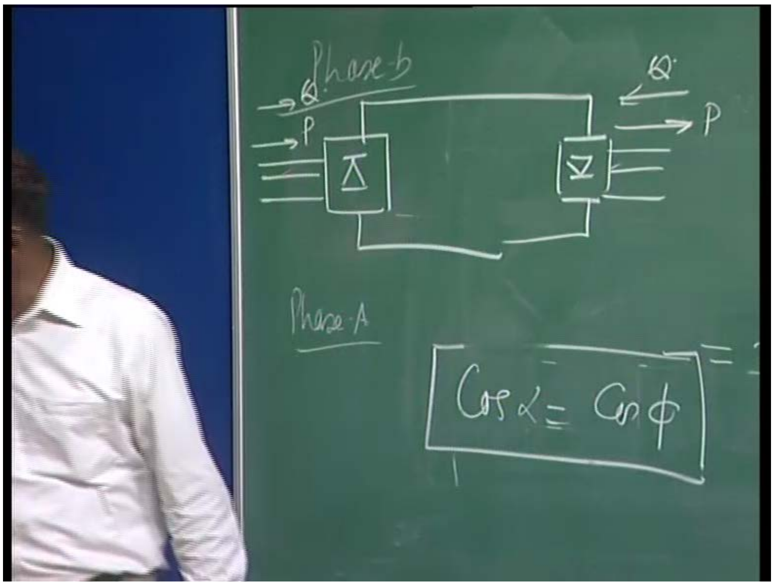

The power here as I said, this is your let us suppose Rectifier this is here this P is going here and the Q is also going here, means, it requires reactive power at this converter circuit. Similarly, if you are talking about the inverter, this P direction is changed; here I can say this is your link this is going to be here and we are having your inverter operation here. Now, this P is going to be this side, but your Q here it is going to be this because the V d becomes negative. So, you can see here this is also reactive power consumption. So, in the normal case Rectifier and Inverters consume excessive reactive power. Due to this factor this is tactically it is not hundred percent correct because, here we have assumed there is no overlap angle. We will see later on this value is going to be changed; if we are assuming there is some overlap again overlap means, once the 2 valve the currents here by here it is shifting here.

It will take some time. Therefore, here it is going to be change but, in ideal case it will be approximately this. So, we will see how it is going to change now to even though there is some options are there that we can have a forced commutation circuit. Then, we can this requirements reactive power can be changed even though can be your leading Power Factor means, it can provide reactive power support. Then, for that you should go for the different type of valves as well as we require from some extra commutation circuit as well but, that is possible and then, lot of people are doing some research in this area. So, with this here, I am not going to draw the output voltage for the Inverter operation. We will see in the next lecture here, we in this lecture we saw how the Power Factor is related to the delay angle; we saw the currents, the fundamental components of current. We also saw this rms value, total rms value of the current of the phase phases and here, we saw the reactive power requirement for both Rectifier and the Inverter mode operation. With this, thank you very much.