DC Power Transmission Systems
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Lecture – 22
2 and 3 valve conduction mode of 6 pulse LCC

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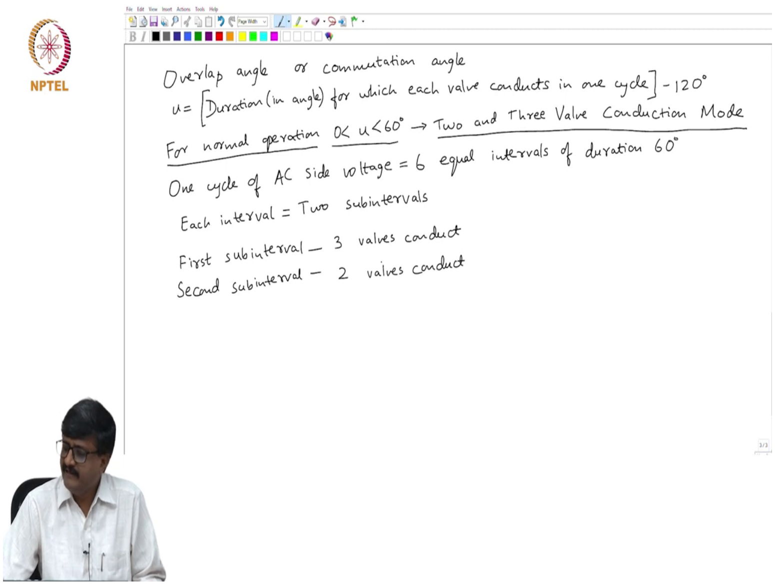

Now, this u can take in fact a any value, but we will consider some special cases. So, if I take normal operation for normal operation u is between 0 and 60 degrees. Now, what is so special about 60 degrees. See 60 degree is actually the duration of one interval. See we have defined what is known as interval each cycle of the AC side is divided into 6 equal intervals. So, one interval is 60 degrees. So, a pair of thyristor valves conduct for each of these intervals. So, u is less than 60 for normal operation we will also consider abnormal operation where u can go beyond 60.

So, let us first to concentrate on the normal operation where u is between 0 and 60 degrees. So, if I take one cycle of the AC side voltage one cycle of AC side voltage any voltage the 3 voltage sources 3 single phase voltage sources any voltage it is equal to 6 equal intervals ok. So, each of these are of duration 60 degrees. Now, what I do is I divide this interval into 2 sub intervals. So, each interval of duration 60 degrees is said to be equal to 2 sub intervals.

So, there are 2 sub intervals. There is a first sub interval and a second sub interval in each interval. Now, by definition the first sub interval is the one where there are 3 valves that are conducting and the second sub interval is the one were 2 valves conducting. See my assumption is normal operation and hence u is less than 60 degrees ok. So, I up to some angle there are 3 valves that are conducting that correspond to overlap angle or a commutation angle and once that is over the current has completely shifted say.

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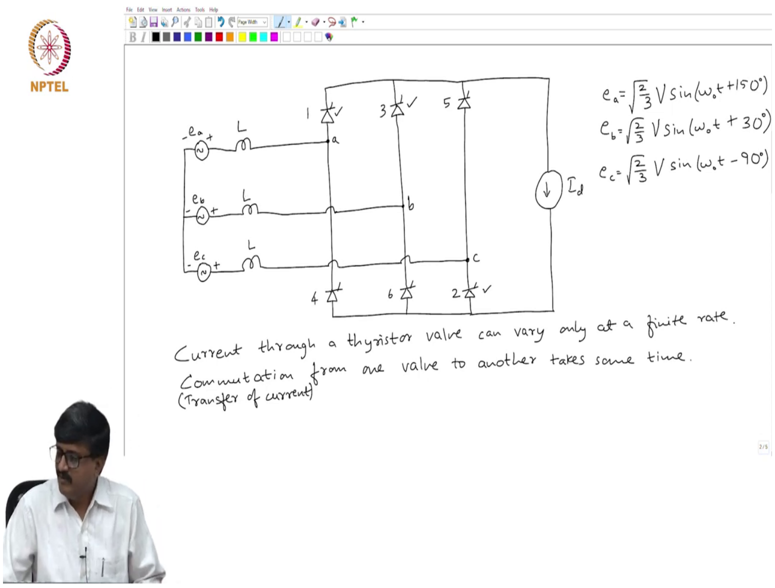

If you look at the previous figure, there is a certain duration for which 1 and 3 both are conducting after certain time one stops conducting in the same interval only 3 is conducting. So, I am dividing the interval into 2 sub intervals. The first sub interval is the one where 3 valves conduct; 3 valves conduct and in the second sub interval 2 valves conduct. So, since you take any instant either 3 valves are conducting or 2 valves are conducting that is why this case is known as 2 and 3 valve conduction mode 2 and 3 valve conduction mode.

So, there are other possible modes corresponding to other possible range or other possible values of u. So, far u between 0 and 60 degrees we have 2 and 3 valve conduction mode. So, if I want to analyze I will take a one interval and we will see that it is sufficient to analyze one interval we can in fact, get the entire waveform of any quantity either on the DC side or the AC side. So, let me take one particular interval and analyze it in detail.

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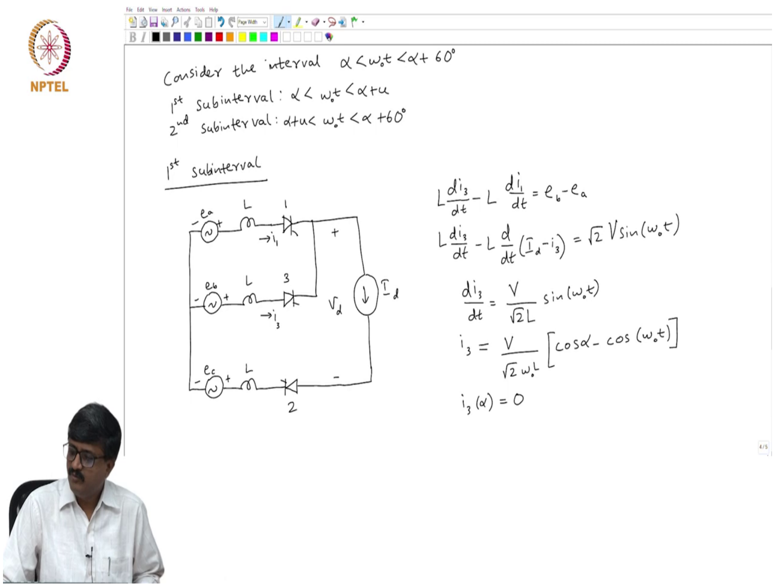

So, consider the interval. Can you suggest what interval we can take? See one interval is 60 degrees what interval can be taken. Any suggestion. Suppose I take the interval the starting point of which corresponds to turning on off for valve 3 at what instant valve 3 is turned on alpha. Suppose I take the interval between alpha and alpha plus 60 degrees. This is one interval ok.

So, again this in this interval has 2 sub intervals. There is a first sub interval and a second sub interval. So, what is the first sub interval? What valve what are the values of omega o t? What is the range of omega o t in the first sub interval?

Student: (Refer time: 05:29) alpha to alpha plus minus.

Alpha to alpha plus minus. If I take the second sub interval it is omega o t taking values between alpha plus u and alpha plus.

Student: 60 degrees.

60 degrees ok.

Now, I want to analyze the circuit for the 2 sub intervals. Let me take the first sub interval. So, what do I will try to do is I take the first sub interval that is alpha 2 alpha plus u and try to draw the circuit which is only relevant for the first sub interval. See the circuit is. In fact, drawn here already ok. Now, when I say a first sub interval there are 3 valves that are conducting 1, 2 and 3. Now there is a valve 5. There is a valve 4. There is a valve 6 which do not conduct. So, there is no current flow through valves 4, 5 and 6. In the second sub interval when only in the second sub interval which valves conduct.

Student: 3 (Refer time: 06:43).

2 and 3. So, when only 2 and 3 conduct ea does not carry current only eb and ec. So, what I will do is I will just draw a simplified diagram where I only show those components which

carry current. So, when something is not carrying a current I can just remove it is a I say open so, open circuit. So, I will just draw a circuit diagram showing only those components of the circuit which carry a current of course, all the 3 voltage sources carry current. So, I will show all the three.

So; that means, all the 3 inductances carry current. See when all these inductances are connected in series with the voltage source. So, this is ea, eb, ec. Now, I draw the remaining part of the circuit in a slightly different way. If u look at the original circuit thyristor valve 1 for this first sub interval alpha 2 alpha plus u is as good as being connected in series with ea and L. Similarly thyristor valve 3 you please refer to the original circuit.

So, the in the if you look at the original circuit 1 is connected in series with ea, 3 is connected in series with eb and there is one more thyristor is conducting 2 that is connected in series with ec. But only thing is now the direction as far as 2 is concerned the direction is in the opposite direction. So, the current flow is in entering the current is entering the.

Student: Voltage source.

Voltage source ok. So, this is 2. Now from the circuit we know that the cathode of 1 and 3 are at the same potential. They are shorted cathode of 1 and 3 are shorted. So, I will short this and the cathode of 1 and 3 is nothing, but the positive terminal of the DC side voltage and the anode of 2 is the negative side of the DC side voltage. So, on the DC side I have a current source Id. So, this is positive terminal of V d this is negative terminal of V d fine.

Now, let me take the current through valve 1 say i1, i1 is the current through valve 1. So, I will always show the current through a valve as the one which is flowing from anode to cathode. Similarly I will also show i3. What about i2? I2 is Id. Please note i2 the current flowing through I valve 2 is Id ok. So, that I need not give a separate notation for that ok.

Now for the analyzing this I will apply Kirchhoff's voltage law this to this loop consisting of voltage source ea voltage source, eb the 2 inductances, l valve one and valve 3 just apply Kirchhoff's voltage law nothing more ok. So, if I do that Ld i1 by dt minus L. I will do one thing. I will try to go in a different direction I will say L d i3 by dt minus L d i1 by dt. So, by Kirchhoff's voltage law this is equal to eb minus ea. Is that ok?

So, what is eb minus ea? See we have the expression for eb and ea, eb and ea the expression is given here ok. It is root 2 v sin omega ot. So, I will make one further assumption I mean no one further I use of further relation. So, d i3 by dt into L minus l. Of course, i1 is i1 and i 3 are not independent. See if Id is the current on the DC side i1 and i3 are related to Id. So, I can write i1 as Id minus i3, i1 is I d minus i3 by Kirchhoff's current law this node.

So, this is d by dt of I d minus i3 equal to eb minus ea is root 2 v sin omega ot. So, I can or try to solve this these are differential equation in i3. So, solve this differential equation for i3 that is all ok. So, this can be simplified Id is a constant please note our representation of the DC side is a constant current source. So, Id is a constant. So, derivative is 0. So, what we get here is d i3 by dt is equal to v by root 2 L sin omega ot, is that ok?

So, left hand side there is a 2 L d i3 by dt. So, the 2 L I have taken to the right hand side root 2 gets canceled with this root 2 on the right hand side. So, this is the expression. So, can I get; can I get an expression for i3. So, i3 as a function of omega ot. So, it is v by root 2 omega oL. You want to integrate with respect to see then if you look at the left hand side the derivative with respect to time. See for most of the waveforms our independent variable is omega ot, but the derivative here that is involved is with respect to time ok. So, that is why there is omega ol coming there. Then what.

Student: 1 minus cos of cos.

Student: 1 minus cos of omega.

1 minus cos. How did you get that 1?

Student: (Refer time: 13:52) initial condition.

Plus cos alpha. So, it is cos alpha minus cos omega ot. See what you can do is take the there is a constant of integration I mean how do we get that constant of integration.

Student: (Refer time: 14:08).

How do we get that?

Student: (Refer time: 14:12).

You use one condition that is i3 at.

Student: I3 equal to 0 at t equal to alpha.

So, at omega ot equal to alpha i3 is 0. So, using this condition you get the expression for i3 ok. Now, let me take this expression for i3 and see what happens to i3 at alpha plus u. See alpha is the alpha is at one end of the first sub internal alpha plus u is at the other end. So, what is the value of see please not this expression is applicable for any value of omega ot between alpha and alpha plus u that is all. Not any value I mean it is not applicable for less than alpha or greater than alpha plus e. So, at i3 of alpha is 0, what is i3 of alpha plus u?

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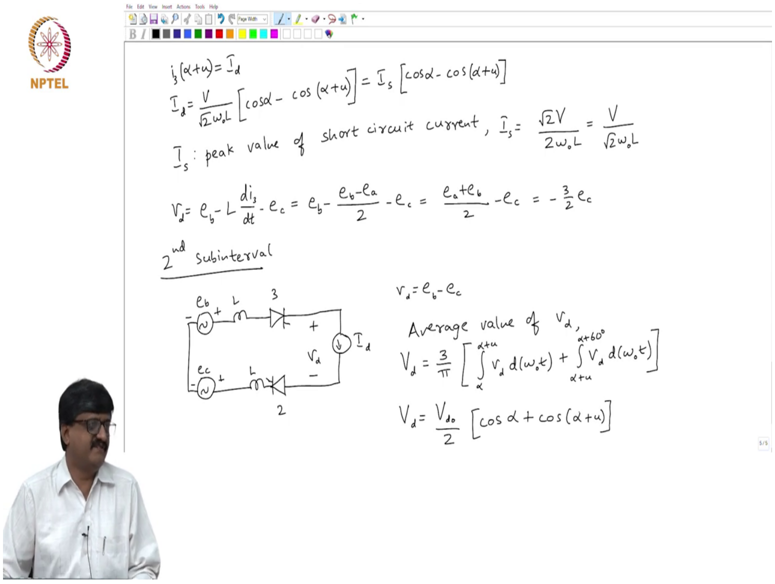

I can use that expression, but what is the value of i 3 at alpha plus u that is the definition of.

Student: Id.

A first sub interval. So, it is equal to Id; that means, the current should have got completely transferred from valve 1 to valve 3. So, valve 3 current i3 at alpha plus u at the end of first sub interval is equal to Id. So, if you use the expression what do you get? So, this gives Id equal to. So, the expression is v by root 2 omega oL into cos alpha minus cos.

Student: Alpha plus u.

Alpha plus u ok. Now we normally write this in terms of current which is obtained as the peak value of short circuit current. See if u just go back to the circuit the original circuit. See there are AC side terminals of the converter suppose there is a short circuit between any 2 AC side terminals, what will be the short circuit current through the source or inductance. See suppose I call this a point a, point b c. There is a short circuit between a and b rb and c rc and a, what will be the current flow through the voltage source or inductance when if there is a short circuit.

It is as good as saying I apply a line voltage. There are 2 phase voltages I apply a line voltage to an equivalent inductance of 2 L. So I can easily get the RMS value of the short circuit current by taking the RMS value of voltage divided by reactants. So, the reactants will be 2 times omega oL ok. So, what I do is I define what is known as the peak value of short circuit current. We use a notation I subscript s, s for short circuit.

So, suppose Is is the peak value of short circuit current then Is is related to the RMS value v the frequent angular frequency omega o inductance L of course, I forgot to close this bracket. So, how is Is related to v omega o and L. See if you look at the RMS value of the short circuit current it is equal to the RMS value of the voltage which is sorry. RMS value of the line voltage is just v RMS values is v line voltage divided by the total impedance or reactance which is 2 omega oL.

So, that is RMS value. If I multiply this by root 2, I get the peak value. So, that is nothing, but v by root 2 omega oL. So, I can write Id in terms of Is that is what I am saying. So, I can write this previous expression as Is into cos alpha minus cos alpha plus u. So, this just for the sake of simplifying the notation instead of every time writing v by root 2 omega oL I just say Is and Is has some meaning.

Now, let us see what happens to the instantaneous value of the voltage on the DC side. So, if I take the first sub interval what is V d. So, if you go to the equivalent circuit see what we have here is the equivalent circuit were only the elements which do not which carry current are shown. So, what is V d? I can get an expression for V d from this circuit and the expression for i3 which I have just derived ok.

So, can I get an expression for V d by applying Kirchhoff's voltage law to this lower loop. See if 2 and 3 are conducting obviously, that happens in the first sub interval. They are short circuit idlth (Refer time: 19:52) they are short circuit. What about the voltage across L in which is in series with ec. What is the voltage across the inductance which is in series with ec or valve 2. It is 0 because the constant current is flowing. D Id by see rate of change of current is 0 because current is constant through this inductance L which is in series with ec.

So, Vd can be related to eb, ec and the drop across this L which is in series with eb ok. So, by applying Kirchhoff's voltage law I can write Vd as eb minus L d i3 by dt minus what. See I am referring to the circuit. I am applying Kirchhoff's voltage law to this lower loop. So, it is.

Student: Minus ec.

Minus ec. So, what is this L d i3 by dt. You have an expression for l d i3 by dt. Just go back to the previous page L d i3 by dt is nothing but.

Student: (Refer time: 21:13).

Can I relate that to eb and ea.

Student: (Refer time: 21:17).

See L d i3 by dt is nothing, but eb minus ea by 2 by 2 from the first equation because L d i1 by dt with the negative sign is nothing, but plus L d i3 by dt ok. So, it is eb minus ea by 2. So, I have eb minus L d i3 by dt is eb minus ea divided by 2 minus ec.

Student: 2 plus ec by (Refer time: 21:47).

So, eb minus eb by 2 is eb by 2. So, I have ea plus eb by 2 minus ec. Now ea eb and ec are balanced so; that means, ea plus eb plus ec is.

Student: 0.

0. So, ea plus eb is minus ec. So, this is equal to.

Student: Minus 3.

Minus 3 by 2 ec ok. So, this is the expression for V d in the first sub interval. Now, if you take the second sub interval second sub interval is very straightforward of course, it is much easier. In the second sub interval I have only 2 valves conducting 2 and 3. So, if I want to draw a equivalent circuit showing only those elements which conduct current then it is the same circuit which I got earlier.

But now a few elements can be removed because i1 will be the current through valve one will be in second sub interval i1 is 0. So, I can just remove this ea L and valve 1. So, the remaining elements which are shown are eb ec L. So, there is a valve 3 which is shown and a valve 2 which is shown Id and the voltage across this current source Id is V d. Now of course, there is a showing L in this case is a redundant because the current through the inductance is.

Student: Constant.

Constant both inductance is constant as current is constant. So, there is no drop across the inductances ok. So, what is V d in the second sub interval.

Student: Eb minus ec.

Eb minus ec because there is no drop across the inductance ok. So, if I want the average value of V d can I get the average value of V d from the expression for V d in the first sub interval and second sub interval. See first sub interval and second sub interval constitute one interval of 60 degrees. Now is one interval sufficient for computing the average value of V d see on the DC side what is the minimum period.

Student: It is 60 degrees.

60 degrees on the DC side the minimum period is 60 degrees.

Student: Yes.

So, we whatever happens for 60 degrees the same thing repeats after every for every I mean subsequent 60 degrees. So, the 60 degree period consisting of first and second sub interval is sufficient enough to compute the average value of V d. So, I can say the average value of V d. So, we will use this notation uppercase V with the subscript d. So, this can be obtained from the expression for the instantaneous value in the first interval of duration 60 degrees.

So, it is 3 by pi which is nothing, but the reciprocal of pi by 3 60 degrees is pi by 3 radian into integral of V d with respect to omega ot from alpha to alpha plus u plus integral of V d with respect to omega ot from alpha plus u to alpha plus 60 degrees. So, you have to substitute 2 different expressions for V d in the 2 integrals. In the first integral V d is minus 3 by 2 ec in the second in integral it is eb minus ec and we have expressions for ei eb ec.

So, if I substitute those expressions I get the. So, I will leave it to you to derive that this V d can be shown to be equal to V do by 2 into cos alpha plus; cos alpha plus u. So, please derive this after substituting the expression for V d and then afterwards substituting the expressions for ei eb ec ok. Of course, V do is the notation which you have been very familiar with what is V do.

Student: Maximum of DC voltage maximum.

Is it the maximum sorry?

Student: (Refer time: 26:55).

Maximum average value of the DC voltage for which case?

Student: (Refer time: 27:03).

That we for the case of u equal to 0 or L equal to 0. Is it true even for this case? For any non-zero value of u is it still applicable?

Student: It is only a number (Refer time: 27:18).

It is just a number. We have the I mean we have the notation V do. What was the definition of V do? V do is the maximum value of the.

Student: Average DC voltage.

Average DC voltage with L equal to 0.

Student: Yes.

But can we still say that it is the maximum average value with the a non-zero L. Anyway there is no need to even I mean generalize the definition of V do. Once you have define the V do we will just use it as V do being the maximum average value with L equal to 0.

Student: Yes.

So that same notation we are using here ok. So, we will just relate V d to V do fine. Now what was the expression for V d with L equal to 0. See L equal to 0 is equivalent to u equal to 0. So, if L is 0 or u is 0 V d is V do.

Student: V do cos (Refer time: 28:14).

V do cos alpha.

Student: Cos alpha.

We derived that V do cos alpha. So, you can get that you just put u equal to 0. If u is equal to 0 we get V d as V do cos alpha. Now due to u or L, is there a reduction in V d or is there an increase in V d.

Student: (Refer time: 28:35).

Is there is a.

Student: Reduction.

There is a reduction ok. So, we what we can do is we can actually a quantify that reduction. So, what we will do is we will just use this relation to see how much reduction is there.

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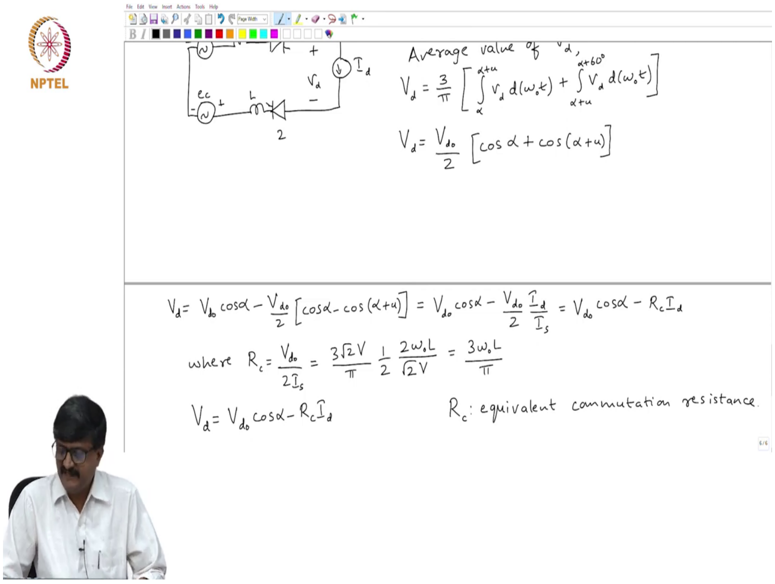

So, since I am just going to the next page I will use this. So, I use this expression V d equal to V do by 2 cos alpha plus cos alpha plus u. So, I will write this as V d equal to. So, without inductance that is when L is 0 or u is 0 the expression is V do cos alpha. So, now, I can write with inductance or with non-zero u V d is V do cos alpha minus V do by 2 cos alpha minus cos alpha plus u. Is that ok? This is same as the previous expression

Student: Minus (Refer time: 28:48).

Student: The change.

Sorry.

Student: (Refer time: 29:54) change in the.

No I am just rewriting the previous expression. Instead of writing Vdo by 2 cos alpha I am saying V do cos alpha minus V do by 2 cos alpha that is all. I am just rewriting the previous expression nothing more than that. Now, why I do this way is the first term is the expression for V d for the special case of u equal to 0 ok. So, this can be written as V do cos alpha minus V do by 2 into cos alpha minus cos alpha minus u. Now, just go to the previous page look at the expression for Id, Id is given by Is into cos alpha minus cos alpha plus u.

So, cos alpha minus cos alpha plus u is Id by Is. See from this equation cos alpha minus cos alpha plus u is Id by Is. So, I will write cos alpha minus cos alpha plus u is Id by Is. That is what I have here cos alpha minus cos alpha plus u is Id by Is. So, we write this as V do cos alpha minus R c into Id were R c is defined as V do by 2 Is. So, one can put the expression for V do. See V do is 3 root 2 V by pi. V do is 3 root 2 V by pi and 2 Is, what is 2 Is?

So, 1 by 2 is 1 by 2 e into of the reciprocal of Is. So, by definition Is is the peak value of the short circuit current. So, it is root 2 V in the denominator in the numerator it is 2 omega oL. So, if you do all the cancellations what you get is 3 omega oL by pi ok. So, the point to note is if you just look at the previous line what we have got is V d is equal to V do cos alpha minus R c Id. So, the second term is due to L because R c is equal to 3 omega oL. If L is 0 we do not get the second term ok. So, that is why this R c has a name. R c is called commutation resistance. In fact, equivalent commutation resistance.

Now, it is just an equivalent resistance, but it does not result in any loss. See this resistance is not causing any loss say there is no resistance in the original circuit. So, it is just a name ok. So, R c is just a notation it is not a physical resistor which is present there which is causing any loss ok. So, one has to just look at that as an equivalent commutation resistance ok.