DC Power Transmission Systems
Prof. Krishna S
Department of Electrical Engineering
Indian Institute of Technology, Madras

Lecture – 44
Capacitor commutated converter: Part 1

So, today we will actually consider converter which is actually different from the other circuits we have seen so far. See, the converter is just a consisting of 6 valves, the ones which you have studied 6 pulse converters. But what is different in the circuits is the model of the AC side and the DC side ok.

Now, we will consider actually a different converter where the circuit of the converter itself is different. So, in addition to the 6 valves we will have what is known as a capacitors on the AC side. So, what we get is a capacitor commutated converter. So, a capacitor commutated converter is same as the line commutated converter with some addition.

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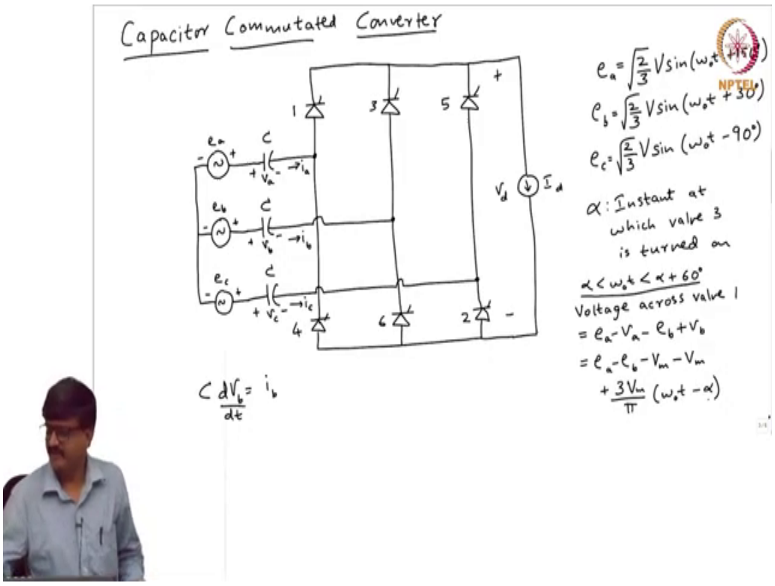

So, I how 3 legs corresponding to the three phases of the AC side and in each leg there are 2 thyristor valves. So, there is an addition of a capacitor in each phase on the AC side. So, there is a series capacitor on the AC side. So, we will call these valves as 1, 3, 5, 4, 6, 2.

So, there are two terminals on the DC side the DC side terminals and three terminals on the AC side. So, this is the circuit of a capacitor commutated converter. So, in addition to the 6 thyristor valves we have the 3 thyristor 3 capacitors.

So, again if I want to explain what is the necessity of having a capacitor. What we will do is we will try to take a circuit that is a model of the AC side and the DC side. The simplest model on the AC side is just a three phase voltage source the simplest model on the DC side is a constant current source.

So, first we will consider the simplest model. Of course, we will not be going into any detail model, but one can easily extend this to any other model of the AC side or DC side. So, I have a constant current I d on the DC side the voltage the instantaneous voltage on the DC side is v d and the AC side is represented by a three phase balanced sinusoidal voltage source.

So, the capacitance of all these capacitors is c. So, they are identical capacitors. So, e a, e b and e c are three balance voltages. So, we will use the same expression for e a, e b, e c that we have been using root 2 by 3 V sin omega o t plus 150 degrees. e b is root 2 by 3 V sin omega o t plus 30 degrees and e c is root 2 by 3 V sin omega o t minus 90 degrees. So, we already have a notation for the currents that are flowing on the AC side i a, i b, i c.

We use some notations for the voltages across these capacitors v a, v b, v c. So, I call this as v a; the instantaneous voltage across this capacitor in phase a similarly, this is v b and this is v c. So, we will analyse this circuit. So, in the process of course, we will see what is the purpose of having a capacitor on there on the AC side.

So, we know that a when there is no inductance on the AC side, the current can be changing suddenly. So, at any instant only two valves are conducting, either 1 and 2, 2 and 3, 3 and 4, 4 and 5, 5 and 6 or 6 and 1 ok. So, there are 6 intervals and in each interval we need two I mean one valve from the upper commutation group and one from the lower commutation group is conducted.

So, for the sake of explanation; we will try to look at one of the capacitor voltages. So, we have been using this notation alpha. So, what is alpha?

Student: P is (Refer Time: 06:40).

So, it is instant at which valve three is turned on. So, instant is see though I say instant I mean it is angle ok, because our most of the times our independent variable is angle instant at which valve 3 is turned on.

So, let us try to plot the voltage across the capacitor in one of the phases say b phase. So, suppose I want the plot of v b ok. So, if I want plot of v b, what should I do? How can I get plot of v b? v b is the voltage across the capacitor in b phase. So, how to get the capacitor voltage waveform?

Student: We write the KVL equation.

Why should I write KVL equation? I mean why?

Student: (Refer Time: 07:40).

What is the voltage see if I want the voltage across the capacitor can I not find the voltage by knowing the current, capacitance is known. So, can I not get the expression for v b if i b is known. Now what is i b? So, have we already seen the waveform of i b?

See, suppose the capacitors are not there we know i b, now will anything change as far as the currents i a i b are concerned if these will these currents change due to the presence of capacitor is a question. See we said it is still 2 valve conduction mode.

Student: yeah (Refer Time: 08:20).

So, it is still 2 valve conduction mode. So, as long as it is 2 valve conduction mode let us assume 2 valve conduction mode than say it is allowed actually, 2 valve conduction mode is allowed here. So, that is the only thing 2 and 3 will not happen, because we will see that there is no inductance on the AC side. So, if these 2 valve conduction mode then we know the waveforms of i a, i b, i c. So, what are the possible values of i a, i b or i c?

Student: It is id or minus id.

Its id or minus id or.

Student: 0 0.

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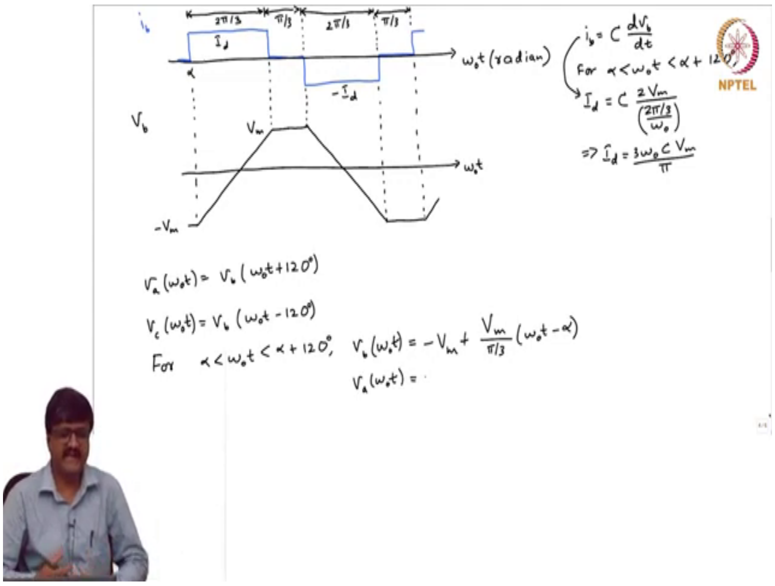

0 ok. So, suppose I take the waveform of i b. So, let me plot i b first. So, from i b, I can get the other waveforms ok. What I will do is (Refer Time: 09:06). So, this is omega o t suppose I plot i b. I start plotting from alpha ok. So, at alpha, what is what is i b?

Student: id id (Refer Time: 09:37).

It actually goes from 0 to Id, it goes from 0 to I d. So, it it is 0 at alpha till alpha and it goes to Id and it remains at Id for.

Student: 120.

For how many degrees?

Student: 120.

120 degrees, then it goes to.

Student: 0.

0, for how long it remains at 0?

Student: 60 degrees.

60 degrees. Then after 60 degrees it again goes to.

Student: Minus Id.

Minus id and it remains at minus Id for 120 degrees, then again it goes to 0. It remains at 0 for 60 degrees and then it becomes again I d and the cycle repeats ok. So, I have i b equal to Id or minus Id or 0. And this is alpha and this duration is. So, this duration is 120 degrees in radian it is 2 pi by 3. So, I will show this in radian. So, let me show these distances in radian.

So, this is pi by 3, this is 2 pi by 3 and this is pi by 3. So, if this is i b, what is v b? So, go back to the circuit see if you look at the circuit what is v b? V b can be related to ib.

Student: 1 by c (Refer Time: 11:50).

How v b and i b are related?

Student: 1 by c integral (Refer Time: 11:56).

1 by c.

Student: Integral ib.

Integral ib. So, I can write ib as C d v b by dt. So, I have to take a waveform for vb such that it is derivative is similar to ib. Of course, except for that constant C. C is a constant. So, except for C, the derivative of vb it should be similar to ib. So that means; if I want vb ok, let me use a different colour suppose I want vb ok. So, how will vb vary from alpha to alpha plus 120 degrees.

Student: (Refer Time: 12:39) alpha minus alpha.

It is a, it increases linearly.

Student: (Refer Time: 12:44) transfer function.

It is a linear function right it is ramp then from alpha plus 120 to alpha plus 180.

Student: decrease (Refer Time: 12:52) constant.

Decrease.

Student: Constant, constant (Refer Time: 12:54).

Constant, it is constant. Then when ib is minus Id negative then it decreases linearly then again for another sixty degrees it remains constant. Now the question is if I plot vb it is like this let me so, it increases linearly then it remains constant for 60 degrees then for the next 120 degrees it decreases linearly then again it remains constant.

Then the cycle repeats it again starts increasing. So, before alpha it would have remained constant ok. So, let me just now what should be the average value of v b? What do you expect the average value of vb to be ok? So, I forgot to use the what should be the average value.

Student: (Refer Time: 14:22).

Ha?

Student: Looks like it will be 0.

Looks like?

Student: It will be 0.

Looks like it will be 0. Why, why it should be 0? And that to are not certain.

Student: (Refer Time: 14:37).

Yeah, I am asking you to just guess ok. Why it should be 0?

Student: Because, ib is like symmetry across (Refer Time: 14:50) so.

Sorry.

Student: vd got average of voltage across thyristor to minus thyristor valves.

No. I see when I know current through the capacitor I need not worry about anything else in the circuit, say ib is known to me ib is known to me. So, when I know the ib is the current through a capacitor. So, from ib I am trying to plot vb, but the only question that cant be answered using this ib is what is the.

Student: Average value.

What is the average value? So, average value I mean; it should depend on the initial value. Now the question is even if initial value is not known can we plot vb is the question.

Student: (Refer Time: 15:36).

Ha?

Student: (Refer Time: 15:39).

Sorry.

Student: Access.

What access?

Student: (Refer Time: 15:43).

I have not drawn because I do not know average. If I knew the average I would have drawn, I would deliberately not drawn the access omega ot access that because I do not know the average.

Student: (Refer Time: 15:55).

So, what is the average?

Student: (Refer Time: 15:58).

Ha.

Student: t times (Refer Time: 16:01) steady state (Refer Time: 16:04).

T tends to.

Student: (Refer Time: 16:08).

See when in steady state what should be the average.

Student: Actually average will be 0.

Why?

Student: Because q is equal to 0 and the charge is current into time. So, we see that the same amount of charge is getting into the capacitor and the same amount is coming out so.

Yeah see.

Student: And also there is no charge.

Answer is; it depends on the initial charge of the capacitor, but what happens in practice is something different. See we have taken an ideal case if you look at the circuit that we have considered on the AC side, just a voltage source, that is an ideal case in practice it is an voltage source in series with inductor in series with.

Student: Resistor.

Resistor. So, whenever there is a resistor, you will see that there will be always decaying. So, any DC value will decay to 0. See the resistor will ensure that on the flow of the AC side any

DC value will decay to 0, because of the resistor. Now this resistor is something which is always present of course, we have not modelled it. So, we have ignored that ok. So, assuming that there is a very small negligible resistance we can always say that the steady state waveform.

So, I am always trying to plot only steady state waveforms no transient no transient analysis done here. So, steady state waveform will have a average value of 0 ok. So, that cannot be inferred from the circuit that I have drawn. So, that can be inferred only by the fact that there is always a resistance only thing is we ignore that resistance that is all. So, the plot is something like this where the average value happens to be 0.

Student: Sir that argument is not valid.

Which one?

Student: The same charge is going in and out (Refer Time: 17:58).

See if when you just take a circuit without resistor it is only dependent with their initial charge is say 0 ok. So, it can have a nonzero average value. It can have a nonzero ok. Let me just slightly deviate let me slightly deviate.

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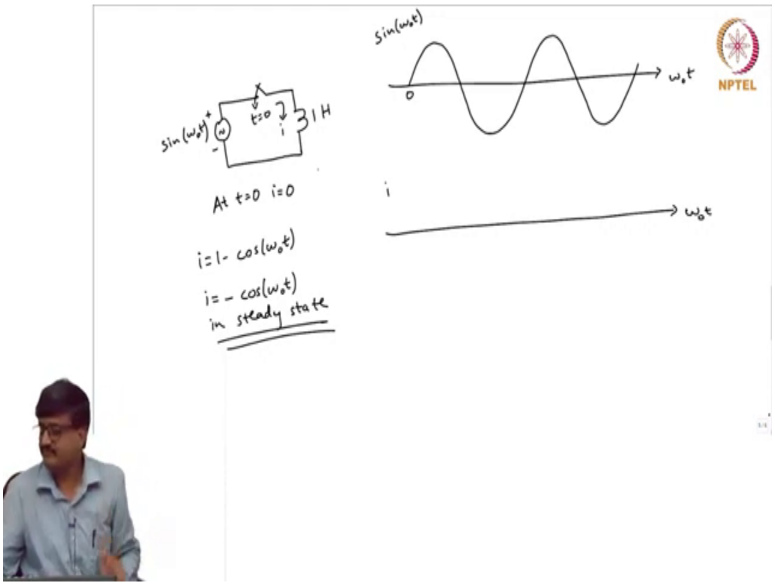

I have this circuit ok. I have an inductor suppose, this is sin omega o t suppose this is 1 henry, the switch is close to t equal to 0 then the current flows after closing the switch. So, if I plot the sin omega ot, I know sin omega ot it is like this this is sin omega o t this is 0. Now, what will be the plot of current?

Student: Minus cos omega (Refer Time: 19:16) 0.

Ha minus?

Student: Minus cos omega ot.

Minus, do you get minus cos omega ot if you solve this circuit. See the circuit as a solution say at t equal to 0, I is equal to 0, that should be satisfied. Because switch is closed only at t equal to 0. So, there is no current before closing the switch. So, if you take cos omega ot r minus cos omega ot s is expression for I there is a problem.

Student: (Refer Time: 19:43) minus.

So, it is.

Student: 1 minus.

1 minus, 1 minus cos omega ot. So, if I is 1 minus cos omega ot, what is the average value?

Student: Average value.

Average value of I is 1. Now, if this goes against what I mean does it go against what we have learned already. See AC circuit the current should just lag the voltage by 90 degrees.

Student: Yes.

But it is not just lagging, it is lagging and getting shifted vertically upwards.

Student: Yes (Refer Time: 20:20).

Now, that is because this is a I mean there is no resistance. So, the DC value is not decaying. See if there is a very small resistance steady state would have been the one the waveform which we expect. Now this is actually an ideal circuit we have ignored the resistance it is not that resistance is 0, we have ignored it. So, in any circuit that we study in engineering when we say a resistance is not there it means that it is not that, it is not there it is ignored it is a small value that is all. So, when we plot the waveform, we still say that it I mean I is minus cos omega ot in steady state.

So, what I want is in steady state ok. So, so it is because if I just look at this circuit the solution is 1 minus cos omega ot, but if this circuit represents some physical circuit in practice then it is an approximation. So, yeah we are not worried say to start with in a I mean study some circuits which are by itself, but as we go on we are only considering circuits which represent some physical system.

So, when you are considering a circuits with represent some physical system resistance equal to 0 does not mean there is no resistance, it just means resistance is negligible, that is all ok. So, the steady state waveform will be equal to minus cos omega ot because resistance is ignored that is all. I hope it is clear, please note that. There is a difference between studying the this circuit as a circuit by itself and studying the circuit as a representation on of some physical arrangement that is all.

So, what we are considering is a physical arrangement. Please note we are not considering some imaginary circuit, it is a what we are studying is representations of some actual circuits which are there in practice. So, by that argument v b is a waveform which has a 0 average value ok. Now the question is can we get a v a, v c. What is va? Can I get va, vc I mean in terms of vb. So, v a can be set to be identical to vb except that there is a phase shift phase shift of.

Student: (Refer Time: 22:51).

120 degrees. So, can I say that va is vb of to be very precise what I should do is I should write va of omega ot is equal to vb of omega o t.

Student: Minus sir no sir plus.

Plus or minus?

Student: (Refer Time: 23:15).

Plus or minus?

Student: Plus.

Plus. Similarly, vc of omega ot is vb. Now, why I write in terms of vb so I have shown vb we have got vb that is all is omega ot minus 120 degrees. So, just take vb and shift it by 120 to the right you get vc to the left you shift it you get ve that is all ok.

So, now let us come back to this. Now the question is what is the purpose of capacitor. So, can you guess why I have put a capacitor. And there is a purpose. So, which is actually hinted by the name itself capacitor commutated converter.

Student: (Refer Time: 24:02).

Sorry,

Student: To remove any DC (Refer Time: 24:05).

To remove any?

Student: DC from the voltage source.

Dc from where.

Student: Voltage sources.

Voltage source is perfectly sinusoidal. No if you are familiar with this term of commutation what is commutation?

Student: (Refer Time: 24:22) current from.

A current gets transferred from one valve to another. Now to get that current transfer one valve should turn off actually. So, the turning off is also I mean you would have studied commutation to be the word used even for turning off of a valve. Only when it turns off the current that was flowing in that valve would go which shift to the another valve.

So, capacitor is seen to help that commutation process. Now when is commutation a problem. So, inverter operation is actually the operation for which the commutation margin angle will be small. So, we will see that for inverter operation this having a capacitor on the AC side will help ok.

So, let us see how it helps. So, alpha is the instant at which valve 3 is turned on. Now if I take the duration alpha to alpha plus 60 degrees ok. Now, for this duration valve 1 would have just been turned off ok. So, what is the voltage across valve 1? It should be negative for a long duration that is what we want. So, what is the voltage across valve one in this interval alpha to alpha plus 60.

So, we can try to get a get the expression for voltage across valve 1 from this circuit. So, alpha to alpha plus 60 means; valve 3 is conducting. So, it is irrelevant whether valve 2 conducts or not, valve 3 is conducting. So, by Kirchhoff's voltage law valve 1 is not conducting it has stopped conducting. So, the voltage across valve 1 is ea minus.

Student: ea minus va.

ea minus va.

Student: Minus eb.

Minus eb.

Student: Minus.

Plus.

Student: Plus.

Plus vb ok. So, let us plot let us try to get the expression for va and vb. So, it is ea minus eb what is va what is the expression for va say we already have the waveform of vb ok. So, let me try to get the expression for vb for alpha to alpha plus 120 degrees.

What is vb? Ok. So, what I will do is, I will try to denote this minimum value as minus V m, m for maximum value maximum value is plus V m, V m is positive. Of course, we can get an expression for V m itself in terms of id c and omega o what is the what is the relationship between V m id C omega o.

See we know that ib is C dvb by dt ok. Now if I take omega ot between alpha and alpha plus 60 or 120. So, up to 120 alpha plus 120, what is ib? ib is.

Student: Id.

Id. So, this equation can be written as id C d v b by dt. So, vb goes from minus Vm to.

Student: Plus V m.

Plus vm. So, the change in vb is 2 V m divided by the time taken. So, it is linear in fact, it is linearly increasing. So, the slope is constant for this 120 degrees. So, what is the duration? What is the duration?

Student: (Refer Time: 28:42).

See what I am trying to do is I am just writing the right hand side C dvb by dt. So, dvb by dt, the rate of change of vb with respect to time.

Student: 120 degree equal to (Refer Time: 28:53).

It is 120 degree. So, I mean. So, 2 pi by 3 in radian by.

Student: Omega.

Omega o, is that? So, the time is angle divided by the angular frequency. So, this actually simplifies to Id is equal to omega o C Vm into 3 divided by pi ok

So, I can relate Id omega o C and Vm yeah based on. So, can I write the expression for vb for alpha to alpha plus 120. In terms of V m, it is easy to write in terms of Vm. So, that is why I introduced a notation Vm.

So, what is vb in terms of Vm see it is just a straight line segment say from alpha to alpha plus 120, vb is a straight line segment. What is the equation of the straight line segment? That is all I am asking.

Student: (Refer Time: 30:10).

Student: vb.

V?

Student: Vm.

Vm into.

Student: 2 omega naught (Refer Time: 30:35) minus omega minus.

Sorry.

Student: (Refer Time: 30:41).

See, I want it as a function of omega ot that is all Coo as a function of omega ot.

Student: Id by C o omega o t.

We need not I mean it is easy to write it in terms of Vm instead of writing it in terms of Id. So, let us write it in terms of Vm.

Student: Minus Vm.

Minus Vm.

Student: Plus.

Plus.

Student: Vm by pi by 3.

Vm by.

Student: Pi by 3.

Pi by 3.

Student: Into omega t minus alpha.

Omega t minus?

Student: Minus alpha.

Minus alpha, that is all. That is the equation of a straight line. So, we know the expression for vb. So, let me come back to the previous page. See why I want this expression for vb. So, I want the voltage across valve 1, voltage across the outgoing valve from alpha to alpha plus 60. So, that is in terms of va and vb. So, we got the expression for vb. what is the expression for va? What is the expression for va? We know that va and vb are identical except that va leads vb by 120 degrees it may be easier.

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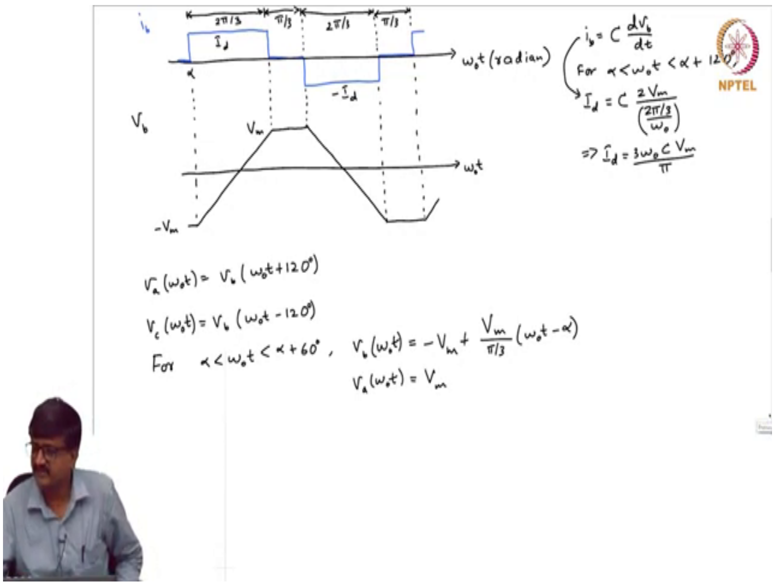


If I instead of taking it up to 120 alpha plus 120 if I make it alpha plus 60. It may be easier to write the expression for va. What is va?

Student: Minus

Student: (Refer Time: 32:25) depends the alpha..

Why should it see that is what I am saying from alpha to alpha plus 60, what is va?

Student: (Refer Time: 32:40) vb from alpha plus 2 alpha.

Hmm So, what it is.

Student: V m.

It is nothing but?

Student: Vm.

Vm. See from alpha to alpha plus 60 va is Vm see you have vb shifted to the left by. By how much?

Student: 120 degree.

120 to get va, you have to shift it we shift vb to the left by 120 degrees. So, for alpha to alpha plus 60 va is equal to.

Student: Vm.

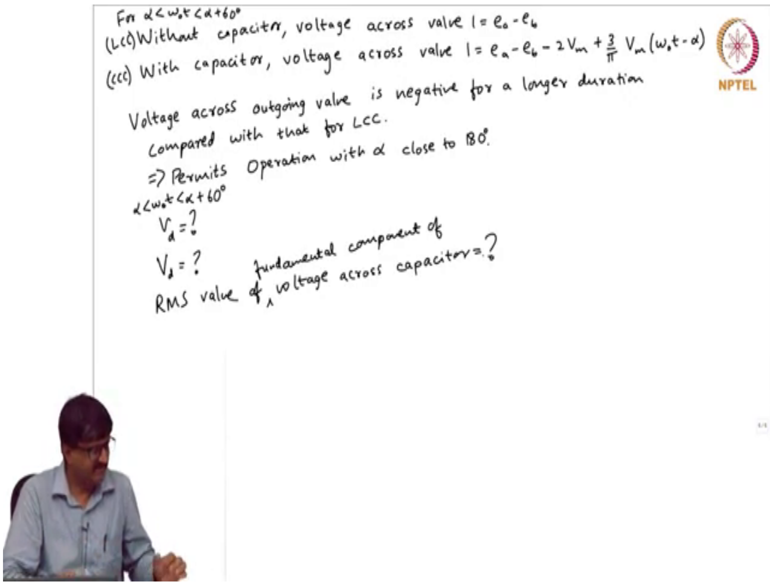
Vm. So, we have the expressions for va and v b for alpha to from alpha to alpha plus 60. So, substitute this in the expression for voltage across valve 1. So, I have minus va is nothing, but minus Vm and minus sorry, not minus vb plus vb. So, plus vb is minus Vm plus 3 Vm by pi omega ot minus alpha. So, this is the expression for voltage across valve 1. Now what is the voltage across valve 1 without a capacitor?

Student: e a minus e b.

It is ea minus eb. So, with the addition of a capacitor there are a few more terms. Now because of these few more terms will the voltage across valve one be negative for a longer duration.

Student: (Refer Time: 34:32).

(Refer Slide Time: 34:51)



Let me summarize here. See what I am trying to say is without capacitor ok. So, we are only talking about alpha to alpha plus 60 degrees. So, for one interval for which what is the I mean we want to see what happens to the voltage across valve 1. So, without capacitor, voltage across valve 1 is e a minus eb. With capacitor; that means, for a capacitor commutated converter see without capacitor means it is LCC Line Commutated Converter this is LCC.

So, capacitor commutated converter CCC is. In fact, an abbreviation for capacitor commutated converter. So, with capacitor voltage across valve 1 is in addition to this ea minus ev I have minus 2 e m plus 3 by pi V m 3 by pi V m into omega ot minus alpha yeah. Now, what we want for the voltage across valve one it should be as.

Student: Negative.

As negative as possible for a long I mean for as long a duration as possible. Now first of all do you see that this voltage across valve 1 with capacitor is more negative.

Student: Yes.

Minus 2 V m plus 3 by pi V m omega ot minus alpha do you see that it is negative.

Student: Yes.

So, it is always negative. For alpha to alpha plus 60, it is negative. So, due to that it takes longer for the voltage across valve one to become positive. So, it helps in commutation that is all. So, that is the idea. So, the purpose of capacitor is only that ok. So, for inverter operation we can go for alpha closer to 180. So, in the in the previous case of LCC, there was a limit on alpha. So, one cannot go to values up to close to 180. So, now, we can go even with I mean even for inverter operation.

So, voltage across outgoing valve. So, though I have taken just the example for a valve 1, any outgoing valve is negative for a longer duration ok. So, this is compared with the the situation of LCC, compared with that for LCC ok.

So, this means that it permits operation with alpha close to 180 close to 180. We have the expressions for vb and of course, from that I can get the expressions for v a and v c can I get the expression for DC side voltage vd and from that get the expression for the average vd. See what is the instantaneous vd. First of all one has to note that what will be the time period of minimum possible time period of vd.

Student: 60.

60 degrees, 60 degrees. So, if I can get for any interval say alpha to alpha plus 60, what is vd? So, for alpha to alpha plus 60, what is vd? Then from that get the average Value of vd ok. So, I would suggest that you please try to get these things. Now, there are a few other things

which are very easy I would also suggest that try to get the expression for RMS value of voltage across capacitor I mean to be precise RMS value of fundamental component of voltage across capacitor ok.

So, please try to get these expressions. I think they are straightforward, I will not be trying to do the I mean do I mean I will not be trying to do this in the class, but I will give the answers ok.

So, we will stop here we will continue the discussion on this in the next class.