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

Lecture – 24
2 and 3 valve conduction mode of 6 pulse LCC: DC side voltage and voltage across a valve

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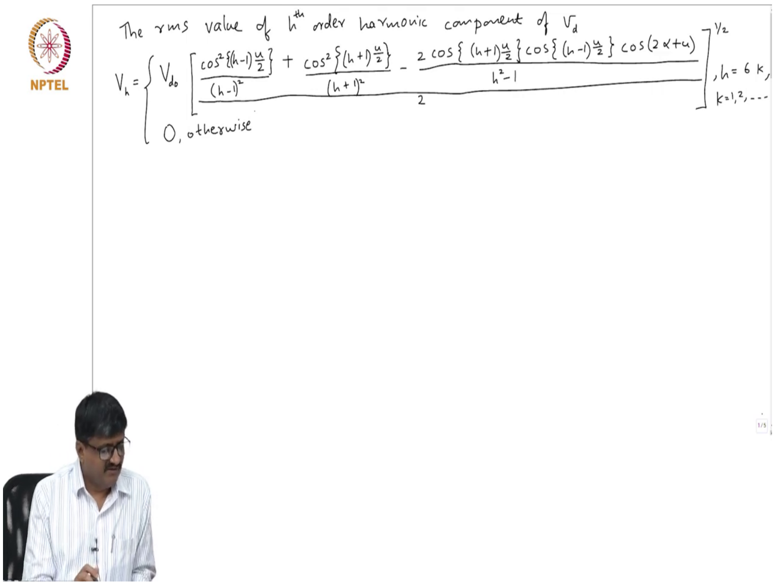

Now what we will do is we will look at other quantities see what we have seeing is only the DC side voltage so far. So, we are considering what is known as 2 and 3 valve conduction mode. So, the we will continue with the discussion on 2 and 3 valve conduction mode and look at other quantities for 2 and 3 valve conduction mode. Here we have two sub intervals in each interval so; that means, in 1 cycle we have 12 sub intervals. So, if there are 6 intervals and 2 sub intervals in each interval in the cycle, we have 12 sub intervals.

So, we will form a table as in the case of 0 overlap angle. So, see the purpose of forming a table is to show that what is the expression for the DC side voltage instantaneous DC side voltage in each sub interval. And what is the voltage across the valve ok. So, we will list all the sub intervals.

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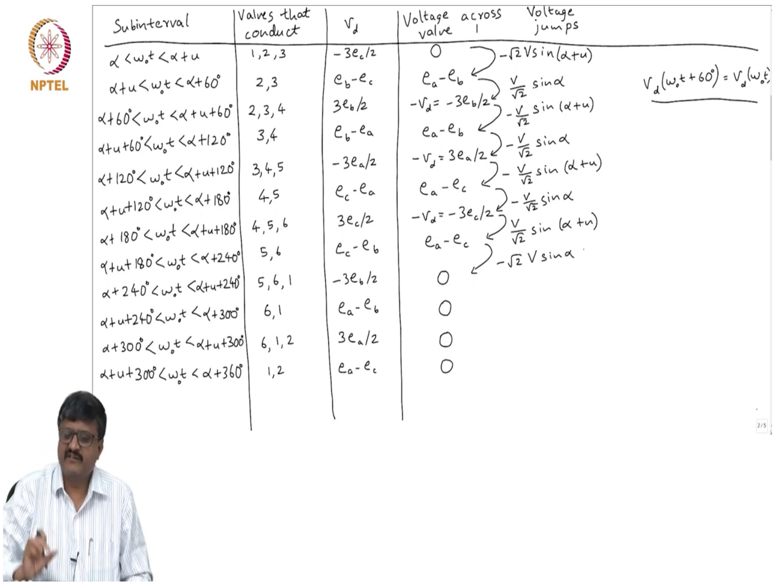

So, I will take the first column of the table where I show the sub interval. And the second column, I show what are the valves that conduct. Then the expression for the instantaneous DC side voltage v d and I show finally, the voltage across valve 1. So what is a first sub interval? So, we always take the starting point as the instant of turning on valve 3. So, valve 3 is turned on at alpha. So, the first sub interval is from alpha to alpha plus t u. So, well let me first write down all the sub intervals the second sub interval is alpha plus u to alpha plus.

Student: 60.

60 degrees. So, then it is straightforward, alpha plus 60 degrees to alpha plus u plus 60 degrees. Then alpha plus u plus 60 degrees to alpha plus 120 degrees; alpha plus 120 degrees to alpha plus u plus 120 degrees. Alpha plus u plus 120 degrees to alpha plus 180 degrees, alpha plus 180 degrees to alpha plus u plus 180 degrees, alpha plus u plus 180 degrees to alpha plus 240 degrees. Alpha plus 240 degrees to alpha plus u plus 240 alpha plus u plus 240 degrees to alpha plus 300 degrees. Alpha plus 300 degrees to alpha plus u plus 300 degrees, then alpha plus u plus 300 degrees to alpha plus 360 degrees.

So, that completes 1 full cycle consisting of 12 sub intervals. So, let us look at the second column, valves that conduct in the first sub interval what are the valves that conduct? 1 2 are already conducting. So, 3 is turned on. So, as soon as 3 is turned on 1 will not stop conducting it continue to it will continue to conduct. So, it is 1, 2, 3.

So, at alpha plus u valve 1 stops conducting. So, the valves that are conducting in the subinterval 2 is are 2 and 3. Then at alpha plus 60 valve 4 is turned on 2 and 3 are already conducting; at alpha plus u plus 60 2 stops conducting so, it is 3, 4. So, similarly we can just write down what are the valves that conduct. 3, 4, 5; 4, 5. 4, 5, 6; 5, 6. 5, 6, 1; 6, 1; 6, 1, 2; 1, 2 then again the cycle repeats.

Then the next column is v d we got the expression for v d in the first sub interval what are the expressions we derived it in the last class. So, you can write it in terms of e a e b e c. So, it is 3 by 2 minus 3 by 2 e c minus 3 e c by 2. The expression for v d in the second sub interval is e b minus e c. Now, it is easy to get the expression in the second sub interval because there is no drop across the inductance so.

Student: (Refer Time: 07:13).

From the circuit we can straight away say what is the expression for the DC side voltage in the second sub interval, that is in all the sub intervals where only 2 valves are conducting its a straightforward ok. So, let us try to fill this column first of all I will try to right to fill the column I mean the rows which are easy to do ok.

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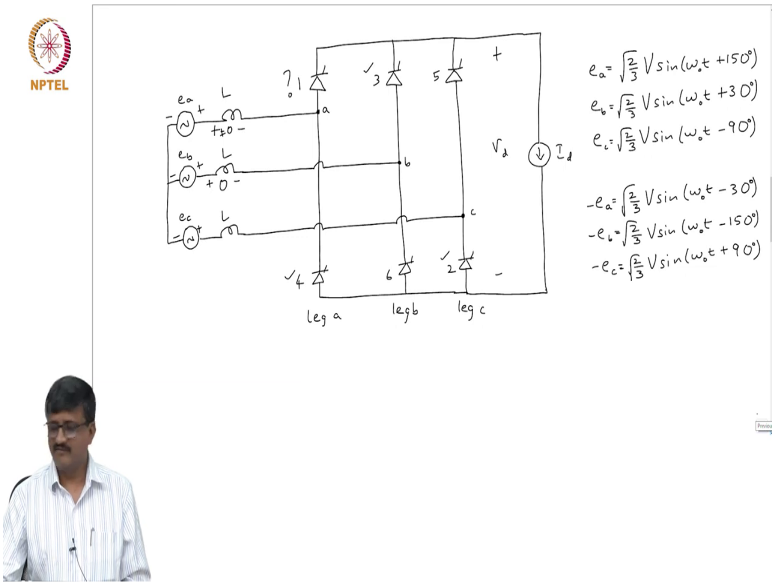

So, for the sake of let me just take the circuit or of the converter. So, using the circuit I will be able to fill the entries in the table. So this is our circuit. So, let us go back to the table. So, as I said its easy to fill the third row; I mean sorry the third column wherever there are only 2 valves that contract. So, if I take the fourth subinterval 2 valves are conducting 3 and 4. So, when 3 and 4 are conducting. So, 3 and 4 are conducting. So, when 3 and 4 are conducting, the current id is passing through inductance which is connected in series with e b.

And its also passing through the inductance which is connected a in series with e a. Say when 3 and 4 conduct the voltage sources the single phase voltage sources through which there is a non 0 current is e a and e b. So, the inductances which carry the same current id will not have a voltage drop across it because current is constant. So due to which I can easily write the expression for v d. So, when 3 and 4 conduct the anode and cathode of 3 are at the same potential and they are same as the potential of the positive terminal of what?

Student: e b.

e b So, that is nothing, but the positive terminal of v d. Then negative terminal of the DC side is actually connected to the positive terminal of e a; because L acts as a short circuit of course, our thyristor valve is a short circuit. So, we can easily say that the expression for v d is.

Student: e b minus e a.

e b minus e a. So, I will come to the third row shortly, I will just fill the easier ones first. Then if I come to the fifth sub interval again there are 2 valves conducting 4 and 5. So, when 4 and 5 conduct. So, can I say what are the what is the expression for v d 4 and 5 conducts? e c minus e a. So, e c minus e a then 5 and 6 conducts e c minus e a 6 and 1 conducts.

Student: e a minus e b.

e a minus e b then 1 and 2 conduct e a minus e c. Now, let us fill the other rows, there is a third sub interval with in which 3 valves are conducting 2, 3, 4. Now should I do a derivation similar to the one that was done for first sub interval?

So, can I get an expression for the instantaneous DC side voltage v d in the third sub interval when 2 3 and 4 conduct without doing any derivation? I mean how do we get? I mean let us get there I mean see the expression later but can I try to get an expression without going through the derivation? Say we got the derivation for the first sub interval minus 3 by 2 e c.

Student: (Refer Time: 12:37).

How did you get that?

Student: (Refer Time: 12:41).

Say if you look at there are DC side voltage, the DC side voltage repeats after every after what every.

Student: (Refer Time: 12:51).

Every.

Student: 60 degrees.

60 degrees. So, the point is if I take v d at instant omega o t plus 60 degrees it is equal to v d of omega o t. Now, if I want to satisfy this equation; that means, v d being periodic with period 60; of course, its periodic with period multiples of 60 also. We are using that fact to say that all our waveforms have a period which is 360 degrees, but its also having a period of 60 degrees ok.

So, using that can I say that I can get an expression for v d in the sub interval in terms of e a e b e c. So, I how to take instead of minus e c, some other waveform which is lagging or leading e c by 60 degrees. So, which voltage is lagging or a leading e c by 60 degrees? Should I take lagging or leading? See, the first sub interval has minus 3 by 2 e c ok. So, what is the expression for e c? Let us look at the expression for e c. e a is 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, e c is root 2 by 3 v sin omega o t minus 90 degrees ok.

So, these are the expressions of the three voltages. Now the negative of these three voltages and these three voltages themselves; form 6 voltages which are this I mean equal in magnitude and I mean displaced by 6 degrees. So, if I take minus e a minus e a is root 2 by 3 V sin omega o t what is the phase angle of minus e a?

Student: (Refer Time: 15:21).

Of course, if I restrict myself to minus 180 and 180. So, I will restrict the phase angles to be within minus 180 plus 180. So, its minus 30 and minus 80 is root 2 by 3 V sin omega o t minus 150 degrees; minus e c is root 2 by 3 V sin omega o t plus 90 degrees. So, you see that this e a, e b, e c minus e a minus e b minus e c are all having the same r m s value and they are 60 degrees apart ok.

So, what I can do is, use this information and also the fact that the DC side voltage is periodic with 60 degrees I can get an expression for v d. So, what I have to do is, I have to take some voltage among e a, e b, e c; minus ea, minus e b, minus e c which is actually lagging minus e c by 60 degrees. So, look at minus e c; minus e c is having a phase angle of plus 90 degrees. So, which waveform is lagging minus e c by 60 degrees?

Student: e b.

e b. So, e b so; that means, this expression will be 3 e b by 2 is that ok? Then in the fifth interval I have to take a waveform which lags e b by 60 degrees. Again if you look at e b is one actually 30 degrees. So, something which lags e b by 60 degrees is.

Student: Minus e a.

Minus e a; is it? I mean, what is the wave form? Minus.

Student: Minus e a.

Minus e a. So, it is minus 3 a by 2 ok.

Then, for the sub interval in which valves 4, 5 and 6 conduct. So, minus e a is having a phase angle of minus 30; I have to get a wave form which lags this by 60 degrees. So, it should have a phase angle of minus 90 which is nothing but e c. So, this is 3 e c by 2; then the sub interval in which 5, 6, 1 conducts is 3 by 2 into some wave form which lags e c by.

Student: 60.

60 degrees. So, e c is having a phase angle of minus 90. So, which wave form lags e c by 60 degrees.

Student: e c.

So, e c is having a phase angle ok, e c is having a phase angle of minus 90; minus e b minus 3 e b by 2 then, you have to next take the wave from which lacks minus e b by 60 degrees which is?

Student: e a.

e a. 3 e a by 2. Now let us look at voltage across valve 1; some of the entries are very easy, whenever a valve is conducting voltage across the valve is 0. So, the first sub interval voltage across valve 1 is 0 let us light the write the easier ones first, the last two four sub intervals if you see the last four, in all these four sub intervals 1 is conducting. So, it is 0 there also. Now, let us come to the second sub interval alpha plus u to alpha plus 60 degrees valves 2 and 3 are conducting what is the expression for v d? So, voltage across valve 1 is?

Student: e a minus e b.

e a minus e b. So, there is no current through the inductance connected in series with e a. So, the positive terminal of e a is at the same potential as an anode of valve 1. And the cathode of value 1 is at the same potential as the positive terminal of see 2 and 3 are conducting. So, the cathode of valve 1 is same as the positive terminal of e b. So, the voltage across valve 1 is e a minus e b.

So, let us again do the easier ones first, let us take the sub interval in which 2 valves 3 and 4 are conducting. So, when the valves 3 and 4 are conducting, what is the voltage across valve 1?

Student: e a minus e b.

e a minus.

Student: e b.

e b, then valves 4 and 5 are conducting.

Student: e a minus e c.

e a minus e c when valves 5 and 6 are conducting.

Student: e a minus e c.

e a minus e c. Now, let us come to the sub intervals in which 3 valves are connecting. If I take the third sub interval, valves 2, 3 and 4 are conducting let us come to this circuit. So, valves 2, 3 and 4 are conducting what is the voltage across valve 1?

Student: e a minus e b.

e a minus.

Student: e b (Refer Time: 21:17).

Now, you have to note that when 3 valves are conducting, though the drop across inductance is not 0; only when 2 valves are conducting the voltage across the inductance is 0 because its constant.

Student: (Refer Time: 21:35).

I did not get can you please.

Student: In this case that (Refer Time: 21:43).

So, what you are saying is here the voltage is 0. So, will that answers the question?

Student: e a minus (Refer Time: 21:59) minus v required minus v d is equal to (Refer Time: 22:05).

No, the point is what he is saying is when valves 2, 3 and 4 are conducting; the voltage across this inductance in series with e b is 0.

Student: Yeah.

From that can I get an expression for a voltage across valve 1?

Student: (Refer Time: 22:25).

e a minus.

Student: (Refer Time: 22:29) 4 to valve (Refer Time: 22:31).

But the point is this is not 0.

Student: (Refer Time: 22:35).

The voltage across the inductance in series with e a is not 0; this may be 0. See, the valve 4 is also conducting. So, where should the current through valve 4 flow? It should flow through one of the sources on the AC. So, it will flow through e a. So, this current is actually not constant. So, this is not equal to 0.

Student: e a minus e b e a minus e b minus e c by 2 omega.

Student: 2 minus (Refer Time: 23:11).

See what I want is an expression in terms of e a, e b and e c; see I am trying to get expressions in terms of e a e b and e c. Can I write it in terms of v d? What is the voltage across valve 1 in terms of v d, in this case valves 2 3 and 4 are conducting can I write it in terms of v d? No, why in terms of v d is we already know what is v d.

Student: (Refer Time: 23:41).

So, if I know in terms of v d it becomes easy, see v d you have already written in terms of e a e b and e c. So, the hint is there is an easy relationship to v d. See in a leg, see let me just explain. Suppose I have these 3 points a b c these are the AC side terminals; a, b, c this is called leg a, leg b, leg c. Now, if I take leg a, when 4 is conducting, when 4 is conducting voltage across valve 1 is what is voltage across valve 1?

Student: (Refer Time: 24:19).

No, it when I say voltage across valve 1, I have defined voltage across a valve, it is voltage of anode with respect.

Student: (Refer Time: 24:25).

To cathode so, it is minus v d. So, voltage across valve 1 when 4 is conducting is minus v d, is that fine? So, I need not do any derivation, I can just say it is minus v d which happens to be minus; I mean 3 e b by 2. So, if I want in terms of e a e b e c it is minus 3 e b by 2 is that ok? So, I need not do any further derivation. So, the result I am using is, I am trying to express the voltage across valve 1 in terms of v d that is all. So, when 4 is conducting, the voltage across valve 1 is minus v d.

Student: (Refer Time: 25:07).

Now, let us go again go back to the table. So, if I go to the sub interval in which valves 3 4 and 5 are conducting.

Student: (Refer Time: 25:29).

So, even here 3, 4 as long as 4 is conducting, voltage across valve 1 is minus v d ok. So, it is minus v d. So, minus v d, but it cannot it is not the same expression in terms of v abc look at the expression for v d, now it is minus 3 a by 2; so, this will be 3 a by 2. Then what about now the next sub interval in which 3 valves are conducting 4, 5, 6 again 4 is conducting. So, when 4 is conducting its again minus v d. So, it is minus 3 e c by 2; is that clear? Now, using this table, we will look at the voltage jumps across a valve voltage jumps.

So, how many voltage jumps are there? See the voltage jump means, the discontinuities in the voltage across a valve. So, this discontinuities are ideal because we have neglected the switching times the time taken to go from on state to off state or off state to on state ok. So, since we are neglecting that there is a discontinuity but, in practice its a large rate of change of voltage which has to be taken care of. So, the valve has to be designed to withstand these rate of change of voltages. So, how many jumps are there?

Student: 8.

8. There is a jump at the end of first sub interval there is a jump at the end of second, third, fourth, fifth, no there is a jump in the end of first sub interval itself then seventh, eighth ok. So, let us try to get an expression. So, what I will do is, I will not try to derive this expression for voltage jump.

So, what you have to do is, take the expression for e a minus e b and substitute for omega o t what value? First jump the first jump is at the end of the first sub interval so, alpha plus u. So, you have to just substitute alpha plus u for omega o t the expression for e a minus e b. So, I will leave it to you to show that this is minus root 2 V sin alpha plus u so, minus root 2 V sin alpha plus u.

So, it is the say the jump is actually at alpha plus u and the jump actually is e a minus e b minus 0 that is all its e a minus e b minus 0. Similarly, the next jump is minus 3 e b by 2 minus e a minus e b evaluated at alpha plus 60 degrees. So, this jump you can verify. So, I will just give the result I will it to you to verify v by root 2 sin alpha your second jump. Then the third jump at alpha plus u plus 60 degrees is minus v by root 2 sin alpha plus u. Now, please note the jumps we cannot say whether the jumps are positive or negative looking at this expression it depends on alpha and u ok. So, only restriction on u is it is less than the only restriction we have put on u is it is less than?

Student: 60 degrees.

60 degrees that is all ok. So, we have not put any restriction on alpha and of course, v is the rms value so, it has to be positive. Then, the third jump is minus v by root 2 sin alpha plus u; the fourth is jump is minus v by root 2 sin alpha then it is minus v by root 2 sin alpha plus u minus v by root 2 sin alpha v by root 2 sin alpha plus u. The last jump is 0 minus e a minus e c evaluated at alpha plus 240 it is minus root 2 V sin alpha ok.

So, we have got the expressions for voltage terms. So, the idea is the rate of change is actually not infinity, the rate of change is nothing but the entries in the last column the voltage terms. So, divided by the switching time, the time taken to go from on state to off state or off state to on state I mean that is dependent on the device ok. So, based on that value of the time that goes in the denominator this comes in the numerator ok. So, do not go by the ideal characteristic of the device that we are using, that will give infinite. So, in practice its not infinite the rate of change of voltage is not infinite.