DC Power Transmission Systems
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Lecture - 25
2 and 3 valve conduction mode of 6 pulse LCC: Fundamental and harmonic components of AC side current

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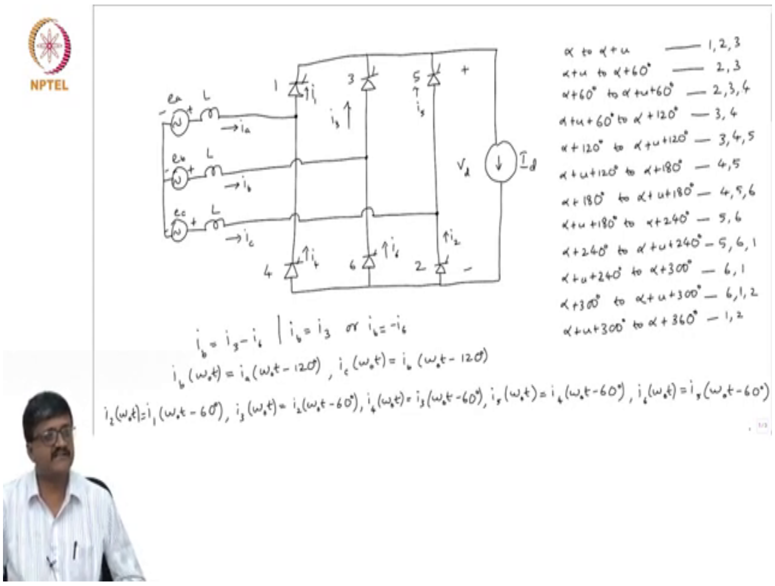

If you look at the circuit ok, let me draw the circuit. So, I will come to the expression of i b, so I have three legs. So, I have the current i a shown as leaving the positive terminal of e a, then i b, i c. So, this is 1, 3, 5, 4, 6, 2, V d is here. So, i b is a current that flows I mean or it has a nonzero value if and only if valve 3 is conducting or valve 6 is conducting say it is either equal to i 3 or

Student: Minus i 6.

Minus i 6; one can say that its i 3 minus i 6 say by Kirchhoff's current law, it is i 3 minus see the current through the valve 3 is i 3, current through the valve 6 is i 6. So, i b I am not worried about i a or i c right now. So, if i just look i b, it is i 3 minus i 6 ok. Now, we also saw that there are 6 intervals and 12 subintervals.

So, if you look at the table, the first subinterval is from alpha to alpha plus u, alpha plus u to alpha plus 60 degrees, say these are the values of omega o t. Alpha plus 60 degrees to alpha plus u plus 60 alpha plus u plus 60 to alpha plus 120, alpha plus 120 to alpha plus u plus 120, alpha plus u plus 120 to alpha plus 180, alpha plus 180 to alpha plus u plus 180, alpha plus u plus 180 to alpha plus 240, alpha plus 240 to alpha plus u plus 240, alpha plus u plus 240 to alpha plus 300, alpha plus 300 to alpha plus u plus 300, alpha plus u plus 300 to alpha plus 360. So, these are the 6 intervals and in which there are 12 subintervals.

So, we know what are the valves that conduct. So, if you take the first subinterval, the valves that conduct are 1, 2, 3, the second subinterval it is 2, 3, then 2, 3, 4; then 3, 4, 5, 3, 4, 5, 4, 5, 4, 5, 6, we already form this table I mean I am just trying to again use this information. Say the table had some more information that actually we know we do not need for analyzing the AC side current, then 5, 6; 5, 6, 1, 6 1, 6, 1, 2, 1, 2 ok.

Now, there is one type of symmetry on the AC side I mean on the AC side, if you look at the currents the currents are identical except for a phase shift of 120 degrees. So, if you take i b of omega o t, then it is nothing but i a which is delayed by.

Student: 120.

120. So, it is omega o t minus 120, i a of omega o t minus 120 will give me i b. Similarly, if you take i c of omega o t, it is i b delayed by 120. So, i c of omega o t is i b of omega o t minus 120. Now, if you look at the currents through the valve say if you take any current say I

can have a current through valve 1, which is i 1 current through valve 2 which is i 2 current through valve 3 is i 3 current through valve 4 is i 4 current through valve 5 is i 5.

Now, I will try to use one fact which I think we are all familiar with, I mean what do we expect for these 6 currents i 1, i 2, i 3 up to i 6, I mean are they same similar identical with phase shift I mean I mean can we say anything about that or we cannot say anything, are they are different, do they satisfy some condition, i 1, i 2, i 3, i 4, i 5, i 6?

See please note we derived this from a very general circuit say. This circuit is not obvious, this is the great circuit say 6 legs sorry 3 legs 6 devices and 3 AC side terminals 2 DC side terminals is something which is not an obvious circuit ok, it was derived in fact from something which was more obvious. So, this is known as the great circuit.

So, here there are 6 devices and I all I take the all the currents which are flowing from anode to cathode, all the 6 currents are flowing from shown as flowing from anode to cathode. So, what do you say? If you go back to the derivation, do you see that there is some pattern in these currents, are they identical except for phase shift, do you see that? Because if you go back to the derivation, these devices are connected in series with voltage sources, so there are 6 voltage source connected in series with these 6 devices, and these 6 voltage sources are actually identical with the phrase shift of 60 degrees.

So, if you take the 6 voltages, they are all identical voltages, and phase shift between them is 60 degrees. So, these currents are also actually identical with a phase shift of 60 degrees. Now, you see that the sequence of turning on is 1, 2, 3, 4, 5, 6, see the numbering is in such a way that they are in the order of turning on ok. So, that means, i 1, i 2 up to i 6 are identical except that there is a phase shift between the any two currents. If I take i 2 it is identical to i 1 except that there is a delay of 60 degrees; similarly i 3 is identical to i 2 except for a delay of 60 degrees. So, if I take i 1, it is related to i 2. So, if I take i 2 for example, i 2 of omega o t, can i say that its equal to i 1 of omega o t minus 60 degrees?

And if I take i 3, it is nothing but i 2 minus 60 degrees, i 2 of omega t omega o t minus 60 degrees. Then i 4 of omega o t is i 3 of omega o t minus 60 degrees. Then i 5 of omega o t is i

4 of omega o t minus 60 degrees, then i 6 of omega o t is i 5 of omega o t minus 60 degrees. And of course, i 1 of omega o t will be i 6 of omega o t minus 60 degrees ok.

So, what we have is identical currents in the valves except for a phase shift of 60 degrees. And of course, I can also relate in each leg the valve currents and the current on the AC side just as I related i 3, i 6, and i b; I can relate i 1, i 4 and i a; I can also relate i 5, i 2 and i c ok. So, but I am not going to do that I mean that is just application of Kirchhoff's current law. What I will do is, I will just restrict myself to this i b, one of the phase currents.

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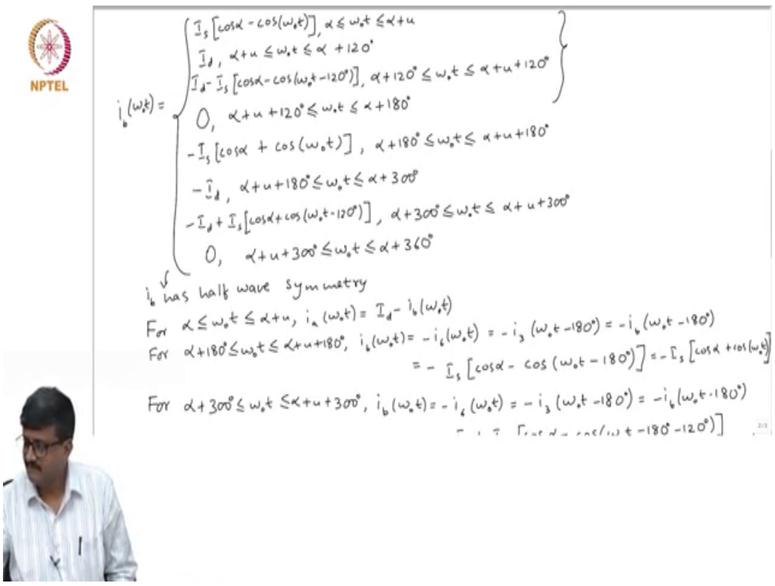

So, I am interested in the expression of i b; so i b as a function of omega o t ok. Let us try to get the expression in all the 12 subintervals. So, we are interested in all the 12 subintervals ok. So, the first subinterval is alpha to alpha plus u. So, what is i b from alpha to alpha plus u? See from alpha to alpha plus u 1, 2 and 3 are conducting, valves 1, 2 and 3 are conducting.

So, i b is dependent only on the current through either 3 or 6. So, whether one or two conduct does not matter, so i b is equal to i 3; i 6 is 0, because i 6 is not conducting. So, i b is i 3 in the first subinterval. And we got the expression for i 3 ok. So, we derived the expressions for i 3, it is I d cos alpha minus cos omega o t. So, this is the expression for i b in the first subinterval alpha to alpha plus u ok.

Student: I s.

Oh, sorry, I am sorry, I am sorry, please correct this, it is I s, sorry it is I s into cos alpha minus cos omega t. I s is the short circuit current.

Then if I take the second subinterval alpha plus u to alpha plus 60 degrees, the current i b is equal to the current i 3. Now, please note that in the next subinterval alpha plus 60 to alpha plus u plus 60 also, I have only valve 3 conducting in the upper commutation group. See upper commutation group is 1, 3, 5. Say when only 3 is conducting among 1, 3, 5, i b is equal to i 3 ok.

So, please note in any of if you look at this 12 subintervals, is there any subinterval where both 3 and 6 conducts, there is no subinterval where both 3 and 6 conduct. So, it is i b is either equal to i 3 or equal to minus i 6 ok. So, based on this information, I can say that i b is either equal to i 3 or i b is equal to minus i 6. I can say easily.

Of course, this also covers the case of i 3 being equal to 0 as well as i 6 being equal to 0, say there are some subintervals where neither is there a subintervals, see there is an subinterval where only 4 and 5 conduct. So, when 4 and 5 conduct neither 3 is conducting nor 6 is conducting, that means, both i 3 is 0, i 6 is also 0. So, I can still use this relation that i b is either equal to i 3 or equal to minus i 6 ok.

So, if you look at the subintervals 2, 3 and 4; subintervals, 2, 3 and 4, there is only one valve that conducts in the upper commutation group that is? Valve 3.

Student: valve (Refer Time: 14:43)

Valve 3; valve 3 is the only one which is conducting among 1, 3, 5; from alpha plus u to alpha plus 120 ok, so that means, for alpha plus u to alpha plus 120 i b is equal to?

Student: i d.

I d. So, it is equal to I d for alpha plus u to alpha plus 120. Now, one can easily observe one fact that unlike the previous case were L was 0, here L is nonzero, L is nonzero, i b cannot have discontinuities. So, when i b cannot have discontinuities, then I can easily say what happens at omega t equal to alpha what happens at omega t equal to alpha plus u?

So, I can replace the strict inequality by less than or equal to. Now, this was not possible in the previous case where L was 0, see there were discontinuities in the current. Now, the I mean i b will never be discontinuous because of the presence of L – nonzero L ok, so that is the expression for i b up to alpha plus 120.

Then in order to get the next expression say the next is subinterval is alpha plus 120 to alpha plus u plus 120. So, in this case, what is the expression for i b how to get the expression? So, we saw that, so I mean just in the previous page i b of omega o t is actually i a of omega o t minus 120. So, if I know what happen to i a 120 degrees ago, I can find i b now that is what it means ok.

So, I know what happens for alpha to alpha plus u, see I am interested in let me tell, I am interested in the expression for i b from alpha plus 120 to alpha plus u plus 120. Now, this subinterval is nothing but the first subinterval shifted to the right by 120 degrees ok; shifted by 120 degrees, that means, you get the take the expression for i a in the subinterval alpha to alpha plus u, shift, I mean if you shift that by 120 degrees you get the expression for i b. I think I need to use one more equation.

So, what is I mean what is i a? Say I do not have the expression for i a here in the interval alpha in the subinterval alpha to alpha plus u. What I have is the expression for i b from alpha to alpha plus u. So, if I know i a from alpha to alpha plus u shift it by 120, I get the expression for i b. So, what is the expression for i a from alpha to alpha plus u?

Student: (Refer Time: 17:53).

Yeah. So, for alpha less than or equal to omega o t, less than or equal to alpha plus u, i a of omega o t is nothing but I d minus i b of omega o t. So, I know the expression for i a. Now, I use this equation i b of omega o t is equal to i a of omega o t minus 120. So, if I do that I get the expression for i b as I d minus I s into cos alpha minus cos omega o t minus 120 degrees ok. So, is that ok. So, we got the expression for i b up to alpha plus u plus 120.

Then what happens after that? So, go come back here alpha plus u plus 120 after alpha plus u plus 120 the next subinterval is the one where only 4 and 5 conducts. When 4 and 5 conducts i b is 0. So, when 4 and 5 conducts i b is 0. So, the that 0 value of i b holds up to alpha plus alpha plus what?

Student: (Refer Time: 19:21).

180. So, it is equal to 0 for alpha plus u plus 120 less than or equal to omega o t less than or equal to alpha plus 180, then after that what happens? So, the next interval is alpha plus next subinterval is alpha plus 180 to alpha plus u plus 180, alpha plus 180 less than or equal to omega o t less than or equal to alpha plus u plus 180. So, what should be the expression for i b?

Student: Minus of that which was 140 (Refer Time: 20:15).

Yeah, what is that equation that we use to arrive at that? How do you say it is minus of ok. So, if you take this subinterval alpha plus 180 to alpha plus u plus 180.

Student: In the circuit.

So, which valve is conducting?

Student: 4 and 5.

4, 5?

Student: 4, 5, 6.

4, 5, 6. So, i b is equal to minus i 6 ok, let me first write that. So, for alpha plus 180 less than or equal to omega o t less than or equal to alpha plus u plus 180 degrees, i b of omega o t is equal to just now we saw, so in this subinterval, 4, 5 and 6 conduct. So, when 4, 5 and 6 conduct, i b is equal to? See in general it is i 3 minus i 6, but i 3 is 0, 3 is not conduct. So, it is minus i 6. So, it is minus i 6 of omega o t. Now, what is the use of having minus i 6, I mean, what does I mean is there any purpose served in having minus i 6?

Student: (Refer Time: 21:38).

Yeah, i 6 is related to i 3. So, i 6 is identical to i 3 except for a phase shift of?

Student: (Refer Time: 21:43).

Yeah, go back to the, say in the last line I have the phase relationship between i 1 i 2, i 3 i 2, i 4 i 3, i 5 i 4, i 6 i 5. So, from that I can I get the relationship between i 6 and i 3. So, i 6 is identical to i 3 except for a phrase shift of?

Student: 180.

180 degree, 60 into 3, so 180 degrees. So, what does that mean? It is minus i 3. So, or in another words ok, I can write it as minus i 3 of omega o t minus 120 1 minus 180 degrees.

Student: Yes.

i 3 and i 6 are identical except for a phase shift of 180 degrees ok. Now, do I have the expression for the now I need the expression for i 3 for which subinterval, see I am current subinterval of interest is alpha plus 180 to alpha plus u plus 180. So, I want to know what happen to i 3 180 degrees ago.

Student: Yes.

That means which subinterval?

Student: Alpha to alpha plus.

Yeah, you just subtract 180 degrees from the upper and lower limits of omega o t. So, from alpha to alpha plus u, what happened to i 3, we should know do you have the expression for i 3 from alpha to alpha plus u it is nothing but.

Student: i b.

i b, it is nothing but i b. So, what I have to do is just take the expression for i b from alpha to alpha plus u. Yeah, it is not difficult, I mean, it just takes some it requires some concentration nothing more than that ok. So, let me write that also. So, can I say it is minus i b of omega o t minus 180 degrees; i b is equal to i 3 is that or not?

Student: (Refer Time: 23:45).

Ok. So, now, we have this expression. So, this is equal to minus I s into cos alpha minus cos omega o t is there I should replace that by cos omega o t minus 180 degrees. So, this is nothing but minus I s cos alpha plus cos omega o t. So, I will write just write this expression here minus I s cos alpha plus cos omega o t. So, this expression is applicable from alpha plus 180 to alpha plus u plus 180, then is this clear, then we will go to the next subinterval alpha plus u plus 180. So, at alpha plus u plus 180 degree, valve 4 stops conducting, so 5 and 6 conduct. So, when just 5 and 6 conduct, then i b is equal to.

Student: Minus (Refer Time: 25:19).

Minus i d, i b is minus i d. Now, you see that even in the next subinterval, though there are three valves 5, 6, 1 conducting, in the lower commutation group only 6 is conducting. From alpha plus 240 to alpha plus u u plus 240, 5, 6, 1 conduct. So, only 6 is conducting in the lower commutation group. The same thing happens even in the next subinterval alpha plus u plus 240 to alpha plus 300, 6 and 1 are conducting. So, as long as only 6 is conducting among 2, 4, 6, i b is equal to?

Student: Minus i.

Minus i ok. So, that happens from alpha plus u plus 180 degrees to alpha plus 300 ok. So, the expression is minus I d for alpha plus u plus 180 degrees to alpha plus 300 degrees, is that ok, because from alpha plus u plus 180 to alpha plus 300 only valve 6 conducts among the valves 2, 4, 6. So, anyhow valve 3 are not conducting. So, i b is minus i c which is minus I d right.

Now, let us take the next subinterval. The next subinterval is alpha plus 300 less than or equal to omega o t; less than or equal to omega ah sorry less than or equal to alpha plus u plus 300. So, in this subinterval, so if you look at the subinterval alpha plus 300 to alpha plus u plus 300, valves 6, 1 and 2 are conducting. So, when valves 6, 1 and 2 are conducting, then what is i b?

Student: (Refer Time: 27:40).

Of course, it is minus i 6 i; b is minus i 6, but how do I get that I mean what is the use of that? Ok, let me write here for alpha plus 300 to alpha plus u plus 300 i b of omega o t is equal to minus i 6 of omega o t. Now, again we use the same result that i 6 of omega o t is equal to i 3 of omega o t minus 180 degrees. So, it is minus i 3 of omega o t minus 180 degrees. Now, this can be written in terms of i b. So, can I say that this is minus i b of omega o t minus 180 degrees?

So, we know the expression for i b in the, so which sub which sub interval we have to look at for i b, see the current subinterval of interest is alpha plus 300 to alpha plus u plus 300. So, for this subinterval, we are getting an expression for i b. So, this is in terms of i b which was obtained for a subinterval which was 180 degrees ago. So, which one, it is alpha plus.

Student: 120.

120 to alpha plus u plus 120. So, we have the expression for i b from alpha plus 120 to alpha plus u plus 120. So, this is equal to minus I d plus I s cos alpha minus cos in place of omega o t, I have omega o t minus 180 degrees. So, this can be simplified. So, this can be written as minus I d plus I s into cos alpha. So, minus cos omega o t minus 180 minus 120 is plus cos omega o t minus 120, is that ok. So, this is the expression up to alpha plus u plus 300. Then if I go to the next subinterval, it is alpha plus u plus 300 less than or equal to omega o t less than or equal to alpha plus 360 degrees.

So, in this subinterval, alpha plus u plus 300 to alpha plus 360 degrees, valves 1 and 2 are conducting. So, neither three is conducting nor 6 is conducting. So, i b is 0. So, this is 0. So, we have the expression for i b for one full cycle from alpha to alpha plus 360 degrees. Of course, though there are 12 subintervals, some expressions are applicable for multiple subintervals that is why we have only 8 expressions; of course, some of them are say it is zero for two of these subintervals also. Now, if I want to find the fundamental component RMS value or harmonic component RMS value, I have to do Fourier series, but any simplification is possible. Do you see any symmetry in i b?

Student: Half wave.

It has.

Student: Half wave.

Half wave symmetry. So, i b of omega o t plus 180 degrees is equal to minus i b. So, you see that this has half wave symmetry. So, i b has half wave symmetry. So, what is that mean I need not use the entire expression from alpha to alpha plus 360, I can just use the expressions applicable to one half of the cycle, say alpha to alpha plus 180 that is sufficient. So, I can just use say for example, these four expressions do Fourier analysis, and get the RMS value of the fundamental as well as harmonics. So, I will leave that to you. So, I will give the answer.

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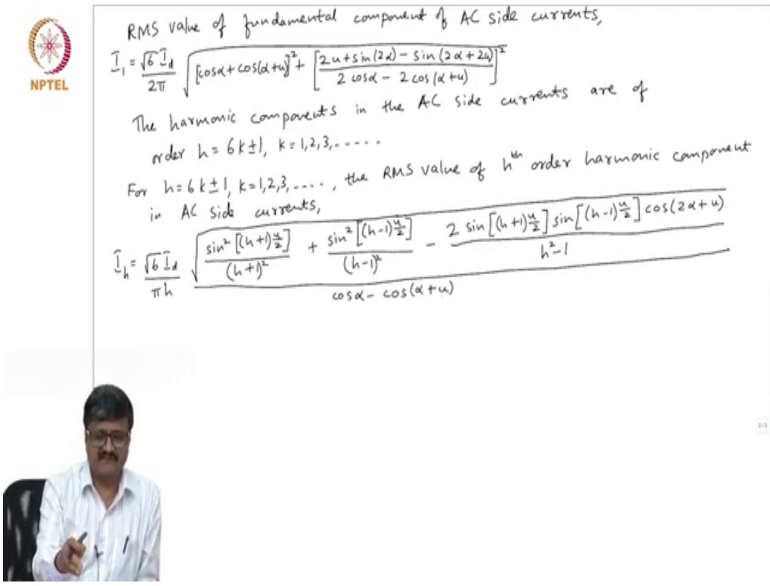

RMS value of fundamental component yeah this is a very good example to know that how laborious it can be to apply Fourier analysis ok, this actually this particular example, of course, I took some long time to get this RMS value of fundamentals component of AC side current.

So, I use the notation I with the subscript 1. So, the expression is root 6 I d by 2 pi into square root of cos alpha plus cos alpha plus u whole square plus 2 u plus sin 2 alpha minus sin 2 alpha plus 2 u divided by 2 cos alpha minus 2 cos alpha plus u.

Say the main point here is if you apply Fourier series for such a waveforms you get an expression which is 2 page or 3 page longer, I mean the I mean only the main work involved is simplification, and do some trigonometric manipulation and simplify that is all. Say once you integrate after integration your expression will be very long I mean may be 1 or 2 pages long. So, after simplification you get this ok, so that is the idea.

So, if this is the fundamental component now what are the harmonic components, I mean what is the order of the harmonic components that are present? See there is half wave symmetry. So, due to half wave symmetry, you will not have even harmonics, you will not have even harmonics due to half wave symmetry, second harmonic, fourth harmonic, sixth harmonic are not there, any other harmonic is not there?

Student: Third harmonic.

Third harmonic?

Student: Triplen.

Triplen harmonics, why?

Student: Therefore, balanced.

Because i a plus i b plus i c is 0. So, triplen harmonics are also not there. So, the harmonic components are of order 5, 7, 11, 13, 17, 19. So, the harmonic components in the AC side currents are of order h equal to 6 k plus minus 1, where k takes all positive integer values ok. So, if you put k equal to 1, you get 5 and 7, k equal to get 2, you get 11 and 13 so on. So, these are the order of that.

So, what is the expression? I mean you have to apply Fourier analysis to get the expression for the RMS value of the harmonic component. So, for h equal to 6 k plus minus 1, k equal to 1, 2, 3 so on, the RMS value of hth order harmonic component in AC side currents; of course, for other values of h, it is 0. So, I will use the notation I h. So, it is root 6 I d by pi h into sin square h plus 1 u by 2 divided by h plus 1 whole square plus sin square h minus 1 u by 2 divided by h minus 1 whole square minus 2 sin h plus 1 u by 2, sin h minus 1 u by 2 cos 2 alpha plus u divided by h square minus 1, its entire thing is taken under root, this is divided by cos alpha minus cos alpha plus u. So, that is the expression.

Of course, there can be one obvious question why I am writing separate expression for I 1 and for I h where h is not equal to 1. See, Fourier series does not distinguish between h equal to 1, and other values of h. Now, the purpose of writing two expressions is to say that I cannot use the general expression for I h for I 1. Why I cannot do that? I mean that is for you to answer. So, you can try say instead of trying to get first I 1 and then I h, why do not you see the I mean in the expression for I h you actually it is obvious there is h minus 1, so that is why I cannot use that.

So, there is some problem in using this expression for I h when h is equal to 1 ok. So, this expression is applicable only when h is not equal to 1. So, for I 1 you have to do a separate derivation.