DC Power Transmission Systems
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Lecture - 60
Effect of firing angle errors

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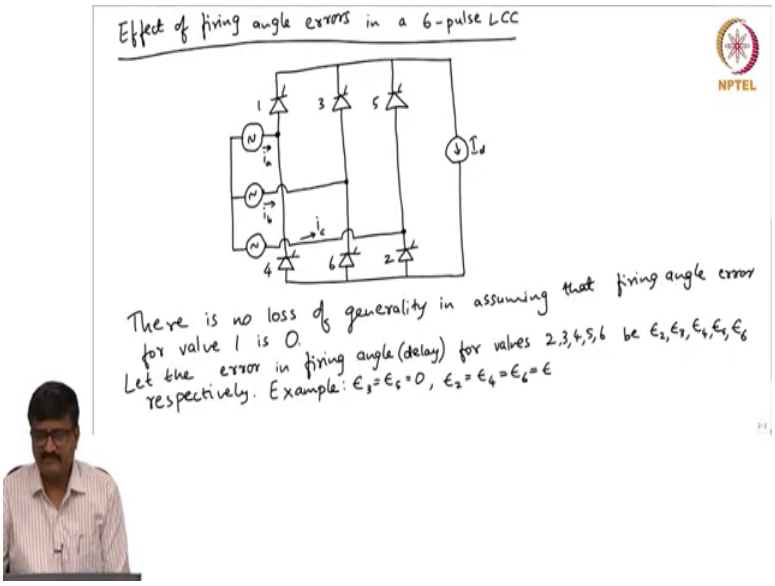

Effect of firing angle error. So, for the sake of explanation I will take a simpler case a 6 pulse LCC Line Commutated Converter. So, the circuit I am considering is this. So these are 6 pulse LCC. I will consider the DC side to be represented by a current source I d, it is constant. And the AC side for the sake of simplicity represented by a 3 phase balanced voltage source.

Now, when I say firing angle errors there are 6 thyristor valves, valves 1, 3, 5, 4, 6, 2. So, there can be firing angle errors for all the thyristor valves. Now suppose there is an error in all the thyristor valves firing angle; that means, I am supposed to give a firing angle or a gate pulse at some instant, it gets delayed. Now, if it gets delayed by the same amount for all the 6 valves will it lead to non characteristic harmonics.

Student: Hm.

It is only firing angle error, but it will not lead to non characteristic harmonics ok. See the point is if I delay the firing angle by the same amount for all the 6 thyristor valves it is a actually saying I am.

Student: Changing (Refer Time: 03:08).

Changing alpha that is all. So, it is the error, but it will not lead to non characteristic. Now, so, what can I do is; I can assume that one of the firing angle errors is 0. That means, for 1 thyristor valve so, there is no loss of generality. In assuming that, the firing angle error for one of the valves is 0. So, firing angle error so, one of the valves means I take say valve 1, firing angle error for valve 1 is 0.

So, that means, there are firing angle errors for the other thyristor valves say, let the error in firing angle. So, I will consider an example where there is only delay; that means, there is no advance. So, the firing angle error means a here the gate pulse is delayed. See I can also consider error in the form of an advance of the gate pulse, the gate pulse is coming before it is actually required ok. So, the error in the firing angle which is a delay for valves 2, 3, 4, 5 and 6 be. So, I call, I denote this firing angle error by epsilon 2, epsilon 3, epsilon 4, epsilon 5, epsilon 6 respectively ok.

So, let me take one example. So, there are many possible ways of getting this firing angle errors, let me take an example. So, in this example, epsilon 3 and epsilon 5 are say 0 and epsilon 2, epsilon 4 and epsilon 6 are equal and since they are equal I will use a common notation epsilon, this is just 1 example ok.

Now, let us see what is the effect of this firing angle error on the harmonic components of the AC side current, see there is an AC side current here. So, in phase a I have ia, in phase b I have i b, in phase c I have i c. So, we know ideally what are the harmonic I mean harmonic orders in these currents ia, ib, ic. They are of order 5, 7, 11, 13, 17, 19 so on ok. So, we will see whether this will result in any harmonics other than these characteristic orders. So, for that, what I will do is, I will try to plot the currents.

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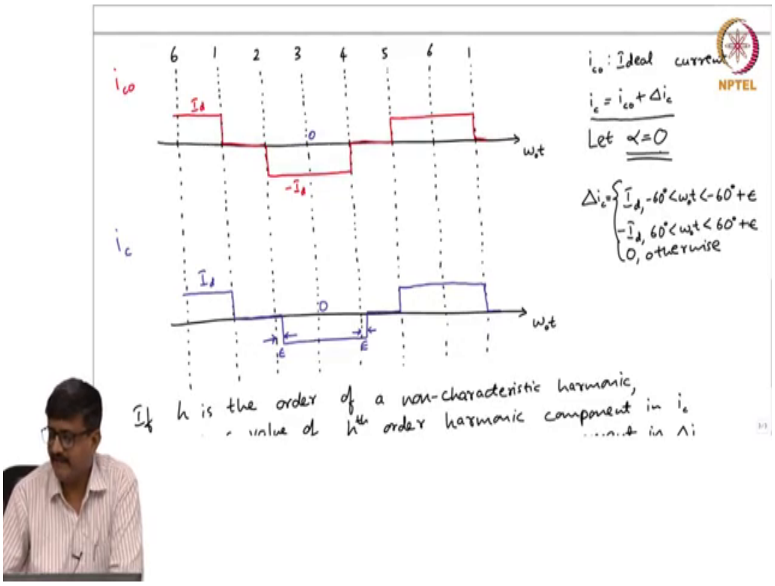

I will plot one of the current say, one can verify that the currents ia, ib, ic for this case can be identical, I will plot one of the current say ic. Now what I will do is, I will use a notation i co for ideal i c. So, i this is the ideal current in phase c. And due to firing angle error the current in phase c is ic which is nothing but, i co plus some error, I will call that error as delta ic or the deviation in ic. So, I will plot first the ideal current ico, then I will plot ic due to firing angle error.

Now, if you look ok, let me come back to the circuit. For this circuit are they harmonic component magnitudes dependent on alpha. If I take the AC side current harmonics are they dependent on alpha.

Student: (Refer Time: 08:06).

Are they dependent on alpha?

Student: (Refer Time: 08:12).

It is independent of alpha, for this circuit it is AC side harmonics current harmonics are independent of alpha ok. So, without loss of generality I can fix some value of alpha, it is independent of alpha in fact, ok. So, let alpha be 0, let alpha be 0. So, let me take the plot of ico which is the ideal current. So, I am marking every 60 degrees.

So suppose, the first step I have shown here is the instant at which say valve 6 is turned on, then valve 1 is turned on at this instant, then 2, 3, 4, 5 and again 6, again 1. So, I will not marked any numbers on the omega o t axis, but instead I have shown the instance at which the valves are turned on ok. Now between these 2 instants that is the instant at which valve 6 is turned on and the instant at which valve 1 is turned on, what is the value of ic, ico, the ideal current? I am not marking, I mean I think it should not be difficult to answer. See when 6 is turned on which 2 valves conduct?

Student: (Refer Time: 11:48).

5 and 6. When 5 and 6 are conducting what is it is ico?

Student: Minus (Refer Time: 11:55).

Minus?

Student: (Refer Time: 11:57).

Minus I d.

Student: Plus I d.

Plus I d, it is plus I d.

Student: Yes.

It is plus I d ok. So, between so I will use a different color for icos, let me take ico of course, for ic I use so, plus I d. Now as soon as valve 1 is turned on, what happens to ic?

Student: (Refer Time: 12:37).

Hm.

Student: (Refer Time: 12:39).

0, so, it goes to 0 and it remains at 0 till valve 2 is turned on. Now, what happens when valve 2 is turned on? What happens to ico?

Student: (Refer Time: 12:52).

Hm?

Student: Minus Id.

Minus I d. So, it goes to minus I d and remains at minus I d for how many degrees?

Student: (Refer Time: 13:00).

120 degrees. So, till valve 4 is turned on. Then again it goes to 0, then when valve 5 is turned on, it goes to plus I d and it remains at plus I d for 120 degrees.

So this is the ideal wave form. So, it is either equal to I d or minus I d or 0 fine. Now let us come to the actual ic which is the wave form when there is firing angle error. So, what is the firing angle error? The firing angle error is only in valve 2 and valve 4 and valve 6. So, all these valves 2, 4 and 6 which from the lower commutation group there is a delay of epsilon in the firing angle ok.

So, due to that ok, I made a sorry, I made a mistake this is ico, let me use a different this is ico. So, there is no error in valve 1 of course, valve 1 we have said without loss of generality error is 0. And there is no error in valve 3 firing and valve 5 firing. So, there is only error in 2, 4, 6. So, does the error in the firing angle of valve 6 affect ic. It will not affect.

So, if I plot ic it will not affect I can still have the same wave form from the instant of uh turning on valve 6 and to the instant of turning on valve 1. Now there is no firing angle for valve 1 so, it remains as it is. What about the firing angle error in valve 2? Due to which the 5 valve 2 is turned on at a later instant. So, there is a delay so, there is a delay. When there is an error in the firing angle of 4.

So, due to which it does not go to 0 as in the case of the ideal condition, it goes to 0 at a later instance then it remains at 0 for less than 60 degrees then there is no error in the firing angle of valve 5. Then the firing angle error in valve 6 has no effect on ic, again valve 1; there is no error ok.

So, there are two deviations in one cycle say if I take turning on of valve 1 and the next turning on of valve 1, it completes one cycle ok. So, there is an epsilon width which is an error here similarly this width is also epsilon. Now I said alpha is 0 which is without loss of generality. That means, the instant of the see, alpha is the instant of turning on of valve 3. So, our ea, eb, ec, the 3 voltages on the AC side are defined in such a way that the instant of turning on of valve 3 is alpha. So, that means, this is the instant; omega ot equal to 0. The instant at which valve 3 is turned on which I have chosen to be 0, so this is 0.

Now if I look at ic, ic is given by the ideal ico plus a deviation delta ic. Now let us look at delta ic. So, if I just want to know what is delta ic in one cycle. So, the deviation from the ideal case is only at two places due to the firing angle error in valve 2 due to firing angle error in valve 4. So, it is, what is the deviation? Due to firing angle error in valve 2 delta ic is nonzero and what is the value?

Student: Id.

Id, from for what values of omega ot?

Student: (Refer Time: 18:08).

Minus.

Student: (Refer Time: 18:10) minus pi by 3 (Refer Time: 18:11).

Minus pi by 3 or 60 degrees to.

Student: Minus (Refer Time: 18:14).

So, omega ot greater than minus 60 degrees and less than minus 60 degrees plus epsilon and there is one more error due to firing angle delay in valve 4. So, that will result in delta ic equal to

Student: (Refer Time: 18:35).

Minus I d, minus I d and this is from 60 degrees to 60 degree plus epsilon. Now why I am interested in delta ic is, I am interested only in the non characteristic harmonic. I am not interested in the characteristic harmonics. So, if there is some non characteristic harmonics, it will be there in delta ic ok, that is the idea.

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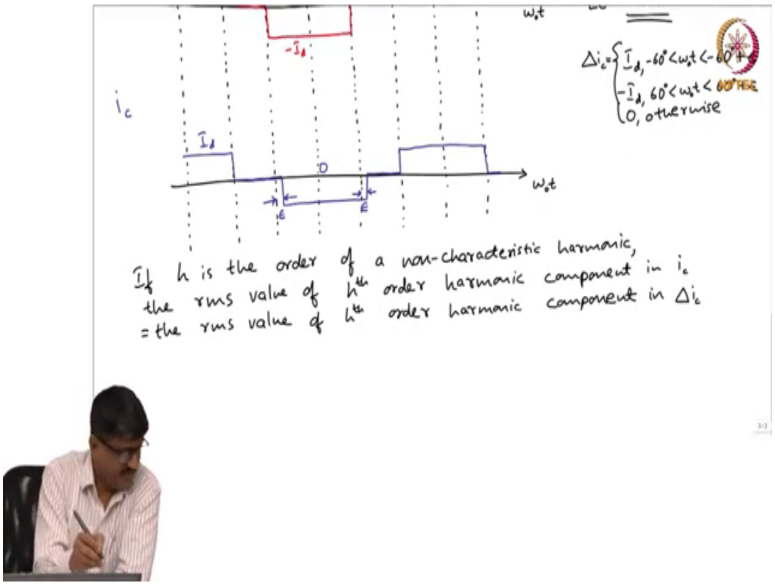

So, what I am trying to say is if h is the order of a non characteristic harmonic. Then the rms value of h th order harmonic component in ic is equal to the rms value of h th order component in what?

Student: At delta ic.

Delta ic. So, if i find a harmonic component in delta ic, it is nothing but a non characteristic harmonic component in ic, that is what I want. So, instead of trying to find harmonic component in the current ic I find the harmonic component in.

Student: (Refer Time: 20:38).

Delta ic. Because, I only interested in the non characteristic harmonic now. Is that ok? Is that ok? Yes or no.

Student: yes (Refer Time: 20:47).

Yeah.

Student: 1 (Refer Time: 20:50) to 0 frame.

Where?

Student: Here instant (Refer Time: 20:52).

Let me make a few points more clear. So, what I have shown here; delta ic, the expression first of all I have said wherever it is non zero. So, it means it takes the value 0 otherwise that is 1 thing. So, this gives a the expression for delta ic in one cycle. Your question is why I have taken 0 at the instant of turning on valve 3. So, I said without loss of generality, alpha is 0. Alpha corresponds to instant of turning on of valve 3 yes.

Student: (Refer Time: 21:32) characteristic harmonic components are not same in ico and ic.

Harmonic.

Student: Characteristic harmonic components.

They are not same. So, if I take any characteristic harmonic, ic and delta ic will not have the same values of characteristic harmonics. Now my intention right now is to show that there is some non characteristic harmonic. So, if there is a harmonic in delta ic it means it is a non characteristic harmonic.

Student: Delta ic will be equal to.

So.

Student: Might also have.

It might also have.

Student: the characteristic order or a harmonic.

It may it may also have.

Student: Characteristic order harmonic.

What I am trying to show is it will have non characteristic. So, instead of showing it in ic can I show it in delta ic

Student: Yes it will have non characteristics, but not only non characteristics.

My intention is to show that there is some non characteristic harmonic.

Student: Ok.

So if I show it in delta ic is it sufficient is a question.

Student: Yes.

It is sufficient to show it in delta ic.

Student: Yes.

Instead of taking the actual current I am taking the deviation that is all ok. So, let us try to see what happens to the harmonic component in delta ic. So, go to the next page. So, I know the expression for delta ic I have given here it is either equal to I d or minus I d or 0 and it is equal to I d for a small duration epsilon and it minus I d for a small duration epsilon.

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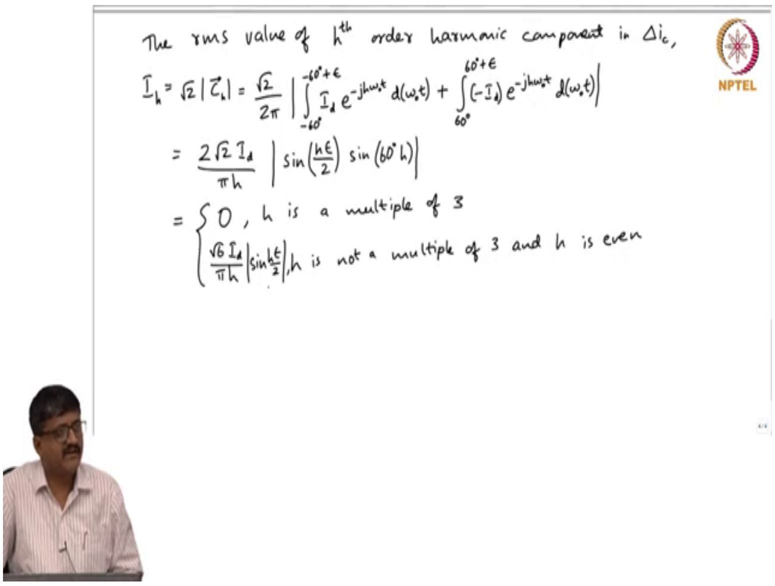

So, the rms value of h th order harmonic component in delta ic suppose, I use this notation i h ok. Suppose I use Fourier's series we can write this as if I use the exponential form of Fourier's series it is C h where C h is complex.

So, root 2 times absolute value of C h. So, if see I could I can as well write it in terms of the trigonometric form coefficients ah and bh also. So, it is root 2 by 2 pi into. So, if you look at the definition of C h it is 1 by 2 pi into integral over 1 cycle ok. So, here from minus 60 to minus 60 plus epsilon, I have a non 0 value that is I d exponential of minus jh omega ot d omega ot. And there is 1 more duration for which it is equal to minus I d.

So, plus integral 60 to 60 plus epsilon. So, here it is minus I d, exponential minus jh omega ot d omega ot. So, one can actually try to simplify this I will not do the simplification, but I will try to give the final expression which we obtain after all manipulation.

I will leave to you to show that this is equal to 2 root 2 I d by pi h into absolute value of sin h epsilon by 2 into sign 60 degree into h. So, this is the expression that we get after integrating and doing all trigonometric manipulations conversion from exponential of the complex number to sin and cos and such things. So, this I will leave it to you to show. So, please derive this yes.

Student: (Refer Time: 25:53).

No, it is degree. So, since I have written 60 degree h is a just an integer, h is just an integer ok. So, it is 60.

Student: (Refer Time: 26:08).

Sorry.

Student: 60 5 to epsilon (Refer Time: 26:13) tan h (Refer Time: 26:17).

Sin so, whether h epsilon is in degree or radian depends on whether epsilon is in degree or radian that is all. So, I have not said anything about that you take in degree or here other factor I have said 60 degree means 60 degree into h is also in degree of course.

Student: Sir h is by (Refer Time: 26:36).

So, I am only looking for a non characteristic. So, my goal here is to show that I get some non characteristics, that is my only goal see if we get again characteristic that we already know. We know some characteristic harmonics are there non characteristic harmonics are present I mean; the presence of non characteristic harmonics have to be proved here that is what I am trying to do, that is all by that way of taking an example. So, can h take any non characteristic value is the question is there any value of h for which this is 0 first of all.

Student: 3 (Refer Time: 27:15).

3.

Student: 6.

6, 9, all multiples of 3 it is 0 ok. So, one possibility is 0 if h is a multiple of 3 right. Now suppose h is not a multiple of 3, h is not a multiple of 3 and if I want only non characteristic harmonics h should be. See please note, I am not say this will not give characteristic harmonics in ic. If I want characteristic harmonics in ic I have to take ic only I cannot take delta ic please note that point if I want characteristic harmonics what is the effect on characteristic harmonics I cannot take delta ic, I should take ic ok. Now to show the presence of non characteristic harmonics, what I am doing is? I am taking delta ic. So, non characteristic means h is not a multiple of 3 and h is

Student: Even (Refer Time: 28:35).

Even, h is.

Student: Even.

Even is that ok. See if h is odd and not a multiple of 3, then it is not non characteristic it is characteristic. Then all this analysis becomes meaningless. See, please go back to the sentence if h is the order of a non characteristic harmonic only then doing harmonic analysis of delta ic makes sense, otherwise i have to do harmonic analysis of ic only ok.

So, if h is not a multiple of 3 and h is even, what is the expression? What is sin 60 degree into h? You take any h which is a multiple of which is not a multiple of 3 and which is also even.

Student: Plus minus root 3.

So, absolute value means root 3 by 2.

Student: Root 3 by 2.

So sin 60 degree into h is root 3 by 2. So, I get the root 3 by 2 means; root 6 I d by pi h into absolute value of sin h epsilon by 2. So, this is the expression if h is not a multiple of 3 and h is even. Now this one will be non zero as long as sin h epsilon by 2 is non zero. So, there is a possibility of h taking value such as 2 can h take a value of 2 and the sin h epsilon by 2 is still non zero. Suppose, h is 2, then this absolute value is sin epsilon absolute value of sin epsilon. So, it can still be non zero for some value of epsilon.

So, there is a possibility of a non characteristic harmonic. So, 2 is a non characteristic harmonic. Similarly 4 ok so, this example just shows that 1 can have non characteristic harmonics by firing angle errors. So, that is the I d. So, if I want to i mean eliminate a non characteristic harmonics only way is by ensuring that there are no firing angle errors I and I have symmetry in the 2 transformers I mean the parameters are almost identical that is comes by design only and the operation also there should be no imbalance in the operation of the 2 bridges.

So, that way one can avoid the non characteristic harmonics. So, characteristic harmonics are always there and we have seen how to eliminate by using only 12 pulse, but that will not be sufficient. We still have in the 12 pulse converter a eleventh order harmonic, thirteenth order which can be I mean a significant harmonic component. Ideally, we want sinusoidal current we drawn from the AC system. So, how can we achieve that objective of going towards or tending towards sinusoidal wave form using a twelve pulse of course.

What we do is? We use a filter. So, one can use a filter to reduce the harmonic component drastically. So, that the current drawn from the AC system is almost sinusoidal. So, we look at the filters in the next class, but why do we knew in filters why not I mean; if harmonics are there, what is the problem? What is the problem? If there is leave the harmonics, let it be there do not use filter. Let it be there 12 pulse LCC is there the harmonics are 11, 13, 23, 25 and so on. So, these harmonics are there let it be there, what is the problem?

Student: Power factor (Refer Time: 32:23).

Power factor, how is harmonic relate to power. You are talking about.

Student: (Refer Time: 32:30).

That is one thing, anything else?

Student: And then.

No, say think of some tangible effect, see power factor is again abstract say one then ask the question ok, let it be let the power factor be low. See I can only understand things like I have to pay for it.

Student: If power factor is low (Refer Time: 32:53).

That means, where do you pay I mean.

Student: Electric.

Student: Losses.

Losses there will be more losses.

Student: Losses.

So, see losses is not only causing additional power to be lost whenever there is loss, loss is in the form of.

Student: Heat.

Heat. And heat means you have to make additional expenditure to cool.

Student: (Refer Time: 33:19) material yes cool.

Cool, I mean cooling arrangements have to made. Wherever there is loss a I mean in excess of what is actually expected, you have to make cooling arrangements. It is not just power is lost you have to make additional cooling arrangement for that. And there are a few other problems I mean; we will look at all these problems with harmonics due to which we have to use filters ok.

So, we will discuss about that in the next class.