High Voltage DC Transmission
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Module No. # 05
Lecture No. # 01
HVDC Components Design

Welcome to this new module that is module number 5 and in this module I will discuss about the various component design in the components. I am not going to discuss about the converter design because, already we have seen complete converter analysis, required features then, we saw the various output voltages, etcetera, mal-operation of converter, etcetera, that is done. Now, in the component design I will discuss mainly the filter part, the filter design, DC line design and also, I will not discuss about the transformer design because, the transformer is more or less similar to the AC conversional transformer specially, some special features already I have discussed in the previous lectures.

This module is mainly dedicated to this your filter design as well as the DC line design. To design the filter we must know what are the various type of harmonics in the system because, the purpose of the filter is to filter out the harmonic components means, other than fundamental components. To know this we have to go for the harmonic analysis.

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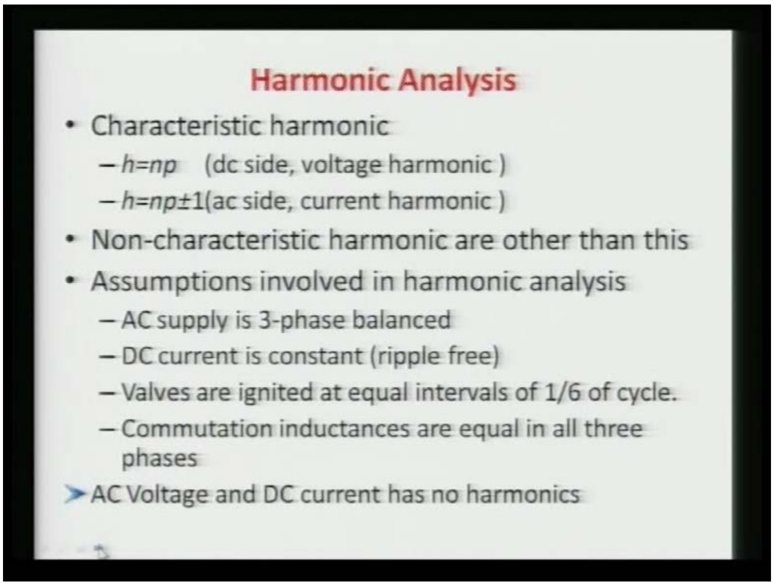

What are the various elements those are generating harmonics in HVDC system are three major components. First one is no doubt, is the converter which is the huge source of harmonics generation; another is your transformers and those are this OLTC transformers that is called the converter transformers and third is your AC system itself.

Normally, it is believed the harmonics generated by AC system or generators are very less but, it is also generating some sort of harmonics. It is very higher order due to this non uniform of the flux in this or you can say non uniformity of the field winding in the stator. So, it generates some of the harmonics but, it is very low order and very low magnitude. That is why we assume our supply system is balanced and it is free from harmonics.

Second one is your transformer; the transformer here is the special transformer where we have to go for the more flux density. Normally, it is designed to give more leakage reactance so that, it is can protect your the fault it can limit your fault current as well. So, you know these transformers once it is saturated because all those transformers normally they are operating at the new point, so, if the flux density is uniformly here your flux if it is your flux I can say phi it is perfect sinusoidal.

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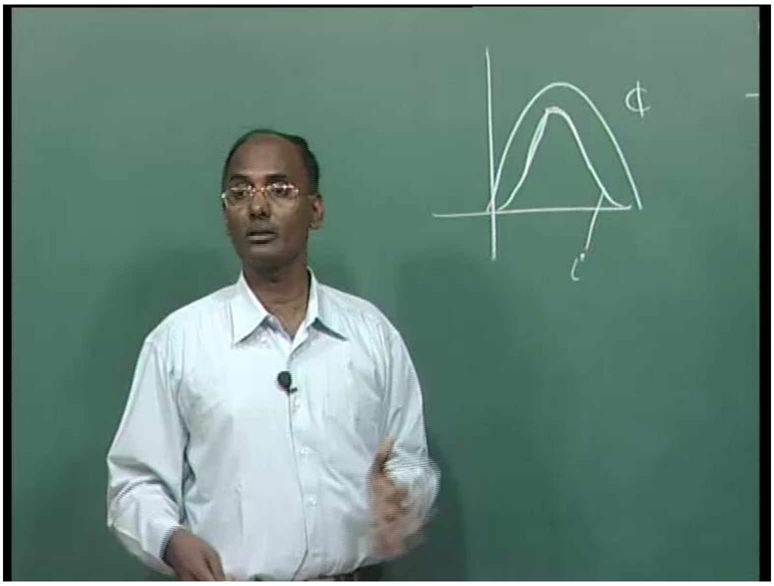

So, your excitation current will be here will be like this and you know this is not here. This is a current; that is the excitation current here it is not a sinusoidal and there by itself this will generate some harmonics. So, this is also a source of harmonics but, again if you will see the component here some of the components here are the magnitudes are very less but, some of the components like the second and your even though third order is a quite bit here in this harmonics component.

So these are there but, again the magnitudes are very less so we can just not discuss here. My concern here that is harmonics generated by your converter circuit because, these transformers are also in your complete AC system but, only the problem here. This harmonic generated by the normal conventional transformer is less compared to the converter transformer because this converter transformer works for the high flux density; so more flux more distortion more harmonics.

To analyze the converter circuit which is generating harmonics here there is a two type of harmonics are there. One is called the characteristic harmonics the components of harmonics means, other than fundamental and another is called your non-characteristic harmonics that is, other than this. Your characteristic harmonics here you can see the DC side we are having the harmonics component n into p where n is any integer n p is your pulse number and this harmonics is not a current harmonics; it is your voltage harmonics means there is a distortion in the voltage.

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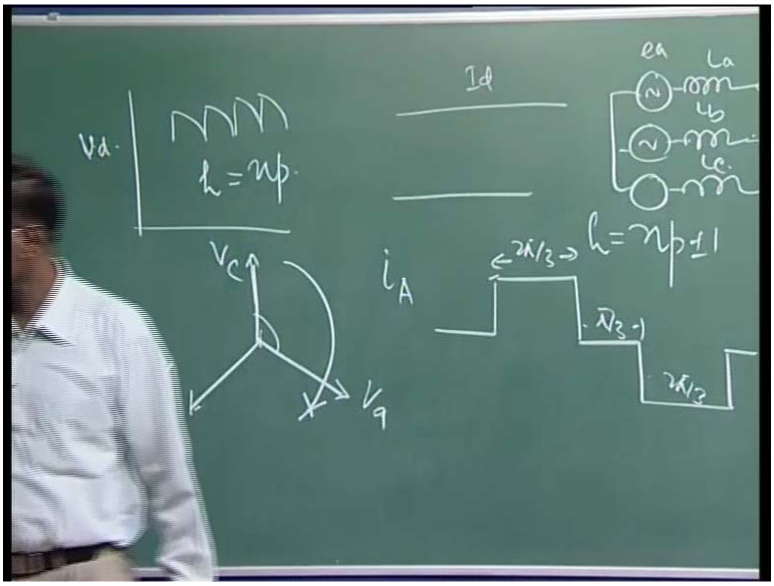

We require the DC smooth DC voltage but, it is not there it is as you know here the voltage whatever it is appearing here it is just like here in if it is 6 pulse show in one cycle there is a pulses so it is voltage magnitude because we have assume our current here is the smooth this is your I d here it is your here it is your V d.

So, in the DC side we are having the voltage harmonics and we are assuming the current is ripple free because we are using this smooth rector and that is why there is no harmonics in AC side here we are assuming that we are giving the balance supply means your AC voltage here is your balance this is your V a here it is your V b here it is your V c this is a balance and you know the qualification of the balance already I've discussed in when I was describing the converter circuit analysis.

Here it should be the magnitude of each phases should be equal and it is displaced by 120 degree and it will be the face sequence here the positive it will be in your clockwise so the positive sequence voltage is given and here there is no harmonics. This is the balance sinusoidal but, due to this we are having the current here. We are having some sort of pulses if you have seen here again the different type of configuration of your transformers here it is basically thus 2 pi by 3 here is your pi by 3 here it is your again 2 pi by 3 this is basically any phase current I can say a so it is having now current harmonics.

So, this here that is why I have written this is ac side and ac side we are having the current harmonics dc side we are having the voltage harmonics and they are categorized by this especially if you are assuming there is no overlap if the instantaneous here is there so we can analyze and we can see we are getting the harmonics here this is your n p that is your h component means for h 1 h 2 we can keep on going and here we are getting n p plus minus 1 the h component here we are going to we will just see it and we are going to get it.

Now to analyze this we have to make certain assumptions and those assumptions are here as already I stated that AC supply is three phase balanced means again the e a e b c here we are giving the balance supply already I defined the definition of this and the DC current is a constant that is a ripple free we have assumed this and also it is assumed that is all the valves are igniting at the equal intervals at 1 by 6 of your per cycle. Here, we are going to analyze for 6 pulse convertor right now and if we are having the 2 6 pulse convertor connected by star star and star delta transformers two bridges are there in series then we can have the 12 valves we will see.

The commutation inductances are equal in all three phases here we want to say that this is your the e a this inductance here L a it is equal to your this inductance here L b and so on. So, it is your L c so these are equal in the magnitude.

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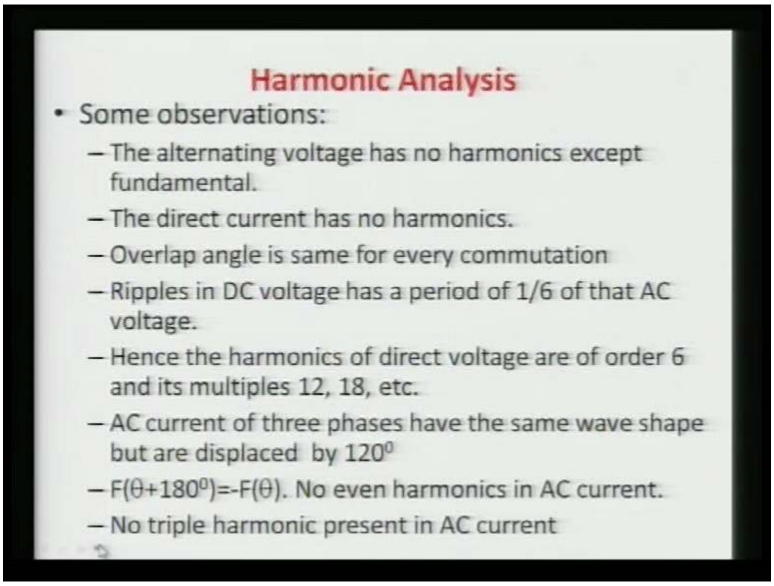

From one this two assumptions we can say our AC voltage and the DC current has no harmonics and some other observation we can make from this assumptions as well as the kinematic tripology. The first two already we saw that is here there is no harmonics no harmonics here it is also assumed that overlap angle is same for everyone because here these values are same and the DC current is constant.

In the beginning we will take there is no overlap and then we will analyze the harmonics component for the current and then we will see it the ripple in the DC voltage has a period of here of again 1 by 6 hence the harmonics of direct current are order of 6 and its multiple so here the 6 pulses; so it is here. We are going to get the 6 12 18 etcetera. AC current of three phases have the same wave shape but, the displaced by 120 degree because e a is this one. So, we are getting same wave shape but, your i b here this i A current here it will be displaced by 120 degree.

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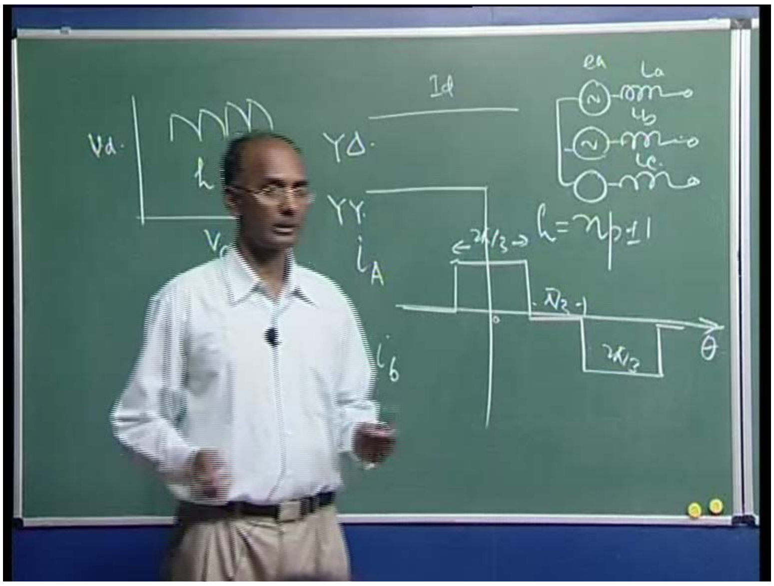

We also find from this wave shape that it follows that is this is theta; that is omega t here we will find that the F theta plus 180 degree is equal to minus of F t you can take at any point you will find. Let us see here or if it is 0 you add 180 degree and we will find the magnitude will be the negative of this one. So, this is the property here what we are getting although this wave shape is for your star configuration if you are seeing for your star delta no doubt here shape is changed but, still that valid holds and this shows that if this property is there so with the fewer analysis we can say there will be no third harmonics component at all.

We will also see in analysis but, even though you find this property holds means you do not have the third couple triplen harmonics third components, no, this shows that there is no even harmonics in the AC current means there will be no even harmonics means you do not have the 2 4 6 etcetera harmonics you are having one but, the triplen harmonics will also absent we will see based on this property we can say the triplen harmonics will be also absent and we will prove also for the various cases.

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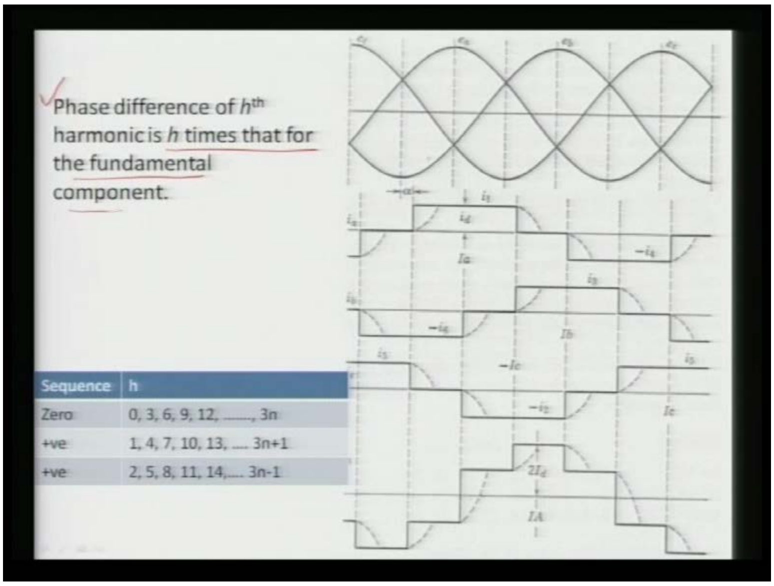

Now, here it is written the phase difference the phase difference of any h th harmonics is h times for that of the fundamental component what does it mean if your phase difference means there is a phase here is shifting by your 120 degree; so it is multiplied by that component.

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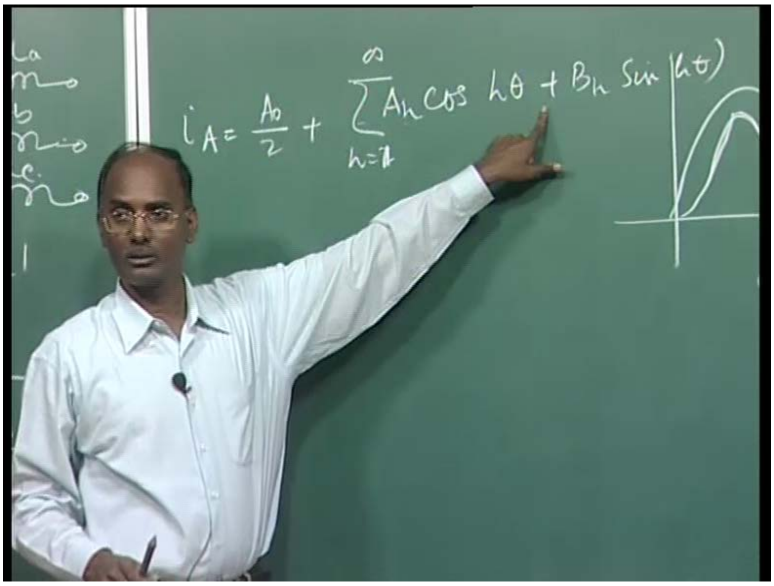

So, your components it suppose if I am going to write i A here it is means some there will be some component here that divide 2 plus here we are going to get this sine and cosine components and that here we will get we will get here cos h theta here your h is equal to 1 to your infinite similarly, we are here component we also getting A h and we are going to get here B h sin h theta.

Basically, this you can see h time it is going to multiplied to whatever the fair shaped is there it is a fundamental component it is h times of that one we will also see the various components here that is arising means you can see the triplen harmonics 0 sequence; always it called the triplen harmonics here. So, there sequence component here it is starting 0 since it is a three phase so we will have the three components 0 positive and negative so you can see the here this is 0 components there is no DC at all here because upper and lower is same so average is 0 so there is no DC current at all so 0 is this then we are having the positive sequence the one is the fundamental component and two is your negative sequence component is a general definition no doubt with this wave shape we will having some components 0 like we will not have the second harmonics because there is no even harmonics because it is the following the property but we can analyze here this 0 1 2 it is negative then again third is a triplen harmonics. Then, 4 5 here 6 7 8 and so on; so far what will happen your positive sequence component that is going to be added the positive here 3 n plus 1 triplen harmonics will be 3 and your 3 n minus 1 will be your sorry it will be your negative components so this is your I can say it is a negative sequence here is negative sequence component.

Now, from this figure here it is a simple phase voltages and now here you can see this is at this point your valve 5 and 6 were conducting because you can see the current 6 here the lower 1 is 6 and here is a now at this point alpha can be fired because this is a commutation voltage of valve 1 that is your e a c because the 5 is conducting to c is coming just you can imagine here this is your 6 this is your 1 3 5 4 6 2 a b and c.

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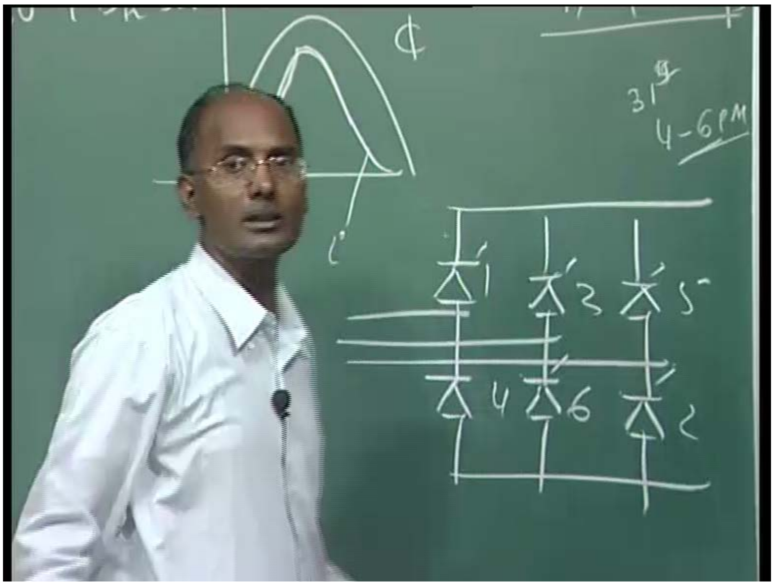

So 5 and 6 are conducting then it is coming here c so e a c is the commutation voltage of valve 1 and at this point it can be fired but, we are delaying let us suppose your alpha degree and this alpha that is why it is mere measured from here. Once it is taking then current if it is a there is no overlap angle is 0 then instantaneously it will take the current I one and it will reach here and then it will go up to 120 degree and then it will be off when your three will be fired so at this point your three is coming to the picture but, due to the overlap what will happen this current will there will be some commutation process between 5 and one so the dotted line basically is the due to the overlap period and this current again I 1 3 is going to be fired then this current is going to decrease and three is going to picked up.

So to analyze first do not consider the dotted line we are just whatever here I showed you can see here we are getting this 120 degree here the positive pulse and then here the 60 degree 0 current and the negative here 120 degree. This is the case when we are having star connection of the transformer if you are having star delta then the line current here that side we are going to have this shows already we just site already we have drawn also on this completely wave shape and we are going to get in this wave shape.

Now, from here we can just analyze the harmonics component and we can use let us suppose this is your phase a current. Similarly, we can have the phase b current here because 6 is in the b and then we can have the phase c currents here and you can see it is only nothing but, it is a shifted by 120 degree here this is 60 this is 60 you can see from here it is shifted here the 240 degree; so it is as I said it is a shifted only 120 degree here.

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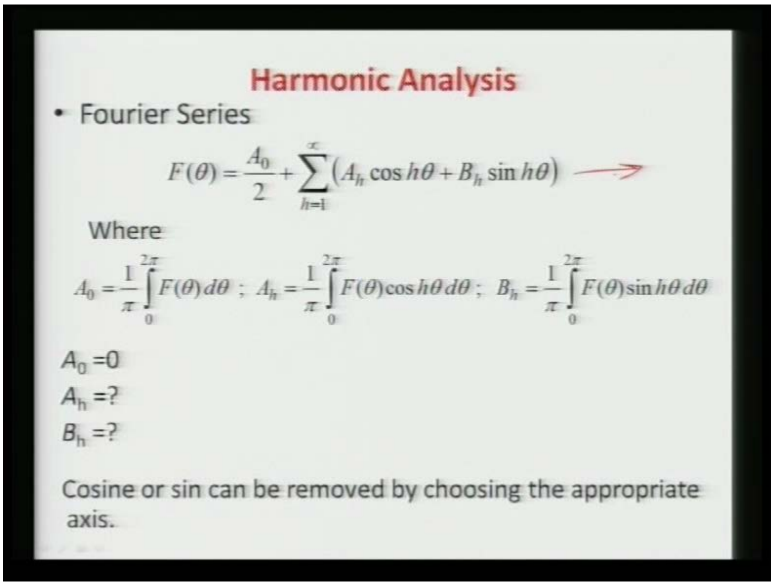

Let us take the ideal condition for this and analyze the Fourier the components that is a here this Fourier series and you can say the general Fourier series can be given by this equation.

Now, this series is having a DC component that is a not we are having a cosine component here that is a magnitude here is A h h is number of harmonics 1 2 3 one is the fundamental and other than one is the harmonic component and then we are having a sine component as well with the coefficient B h and this coefficients are defined as this formula is the Fourier series analysis.

Now, here to with that diagram we have to determine the a not A h and B h components but, this A h and a A 0 can be easily understood by looking at the figure because this average you are adding for into one cycle it is 0. So, whatever this upper part the lower part is same area so add it so average is 0. So, for this case here it is 0; now we have to go for A h and B h now the A h and B h basically depends upon where you are choosing your axis there is a possibility that if you are choosing your axis here.

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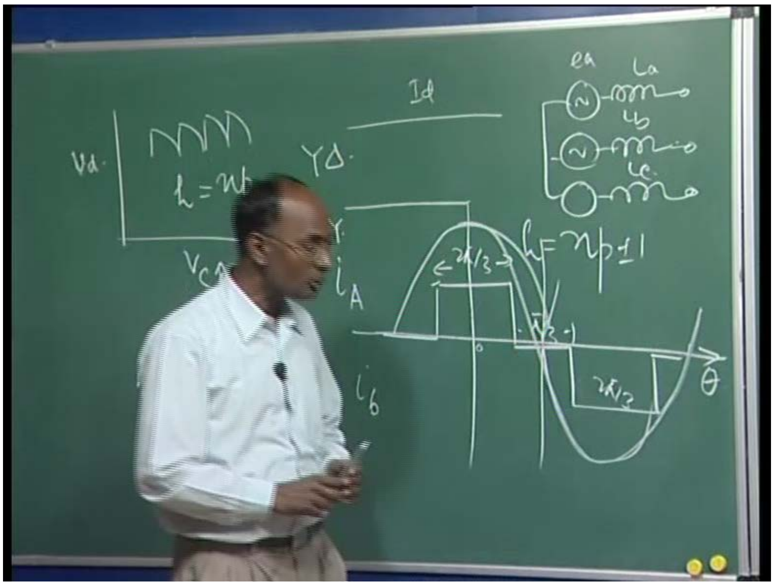

For example, you can see here if you are choosing axis here your component will be like this the fundamental component will be like this or if you are choosing your axis here. This, is just like a sine component so you can say cosine and sine component depends upon where you are choosing your axis if your axis you are choosing in the between of this. Then, there will be no sine components it will be only the cosine component if you are choosing here you are having the sine component there is a no cosine component means there are the two properties.

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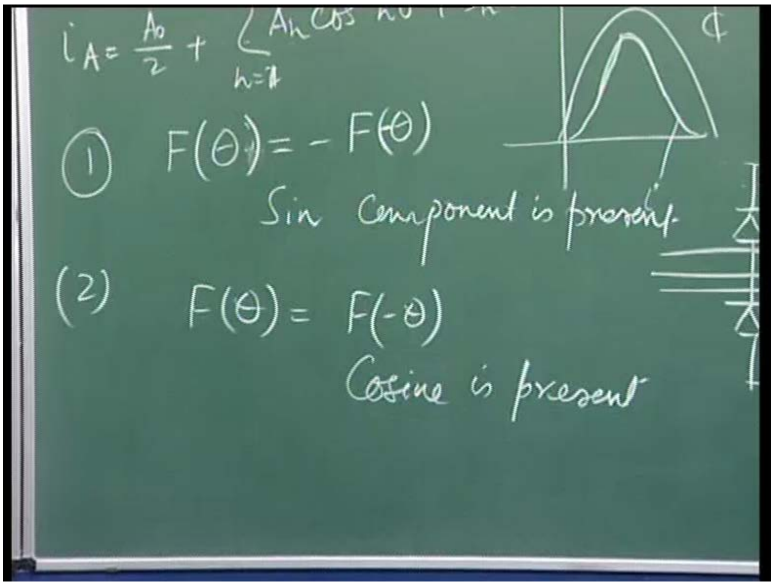

The property number 1 it says that if you are having here F theta plus here if I can write this property here F theta if it is equal to your minus F theta good then there will be only the cosine component sine component sine component and it is only sine here and cosine will be absent minus here that is correct minus of this and if you are having F theta is equal to your F minus theta. Then you are having only cosine component. Again, it depends if you are choosing here axis at this point. Then, you are having the cosine you can see this follows here because this side theta here this is a magnitude is equal and you can just move here so here if you are taking at this so your sine component has gone vanishes and if you are taking this means you are having here you can say it is positive it says negative here is a positive here negative here.

We are having that component this is this component is present here the cosine is present and if you are taking any arbitrary here in between then you are having both sine and cosine components. Let us take for analysis purpose we can just consider this axis here I can take axis here as this point to meet up this.

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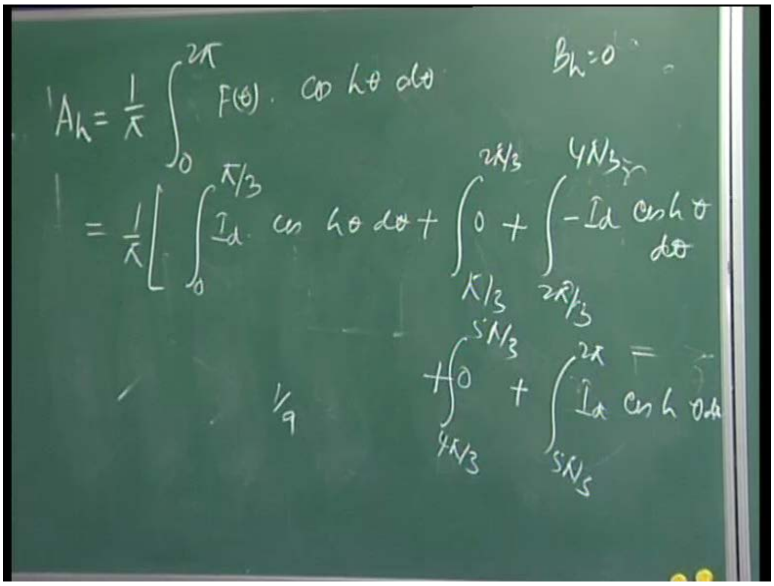

From here we can as per this analysis we have to now find the A h value and your A h it is your 1 over pi integration 0 to 2 pi here your F theta into your cos h theta d theta means this component here we can get from this axis here we are taking axis here as a 0 and then we are analyzing and here is a 2 pi or pi it will be 2 pi because, you are talking through cycle.

Now, from this we can analyze now it is 1 over pi the integratal we can say from 0 to here we are starting 0 so this value is pi by 3 3 because this pi by 3. So, it is pi by 3 so I can say I d into your cos h theta mind it this h is not hyperbolic is a number so that is why I am separating here from here there is a gap then we can here it is your 0 this value is 0 so we can write 0 here so it is 0 plus and this is your pi by 3 to 2 pi by 3 here 2 pi by 3 to 4 pi by 3 minus I d cos h theta d theta because this is a negative current this magnitude is I d so we are just doing this then plus. So, here we are just coming this is a pi by 3 pi by 3 pi by 3 here this and then it is a positive so 1 is 0 here that is your 4 pi by 3 to 5 by 3 plus here 5 pi by 3 to 6 pi by 3 that is your 2 pi and here it is your I d cos h theta into this.

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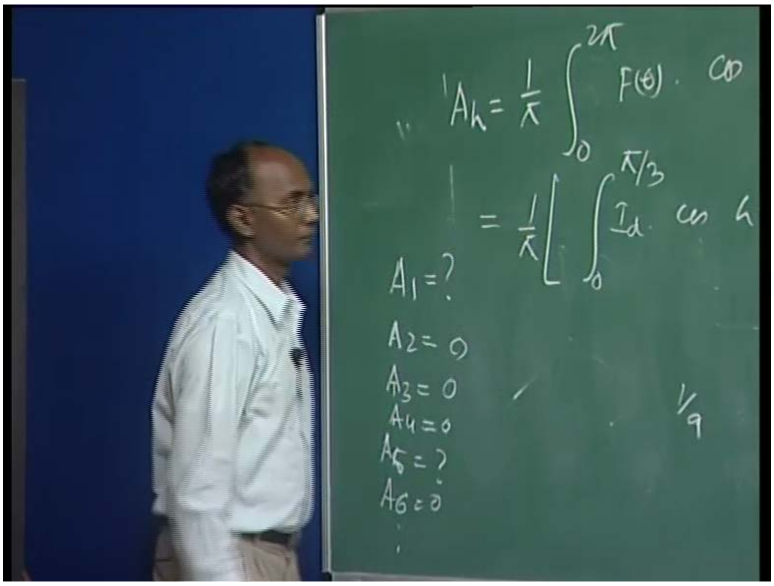

Now, with this no doubt b component just we are assuming we are taking axis in a such a way that we are having this B h is 0 and A naught was already 0. I want to write a general expression in terms of h so that, for putting the value of h means we can get solving this I want to get what will be the value of A 1 A 2 to all you can say A h value we can determine it so one is your fundamental component this component as I said it will vanish it will be 0. But, we can also see from the analysis because it satisfied the Fourier analysis property so A 1 will be 0 so A 3 it will be also 0 A 4 it will be also even it will be 0 your A 5 it will have some componential DC and your A 6 will be also 0 and so on so far.

Here, we have to determine this two components we can also show what will be the value here. Now, A 7 will come of course, A 7 will come and we will see those values now from here I d is common.

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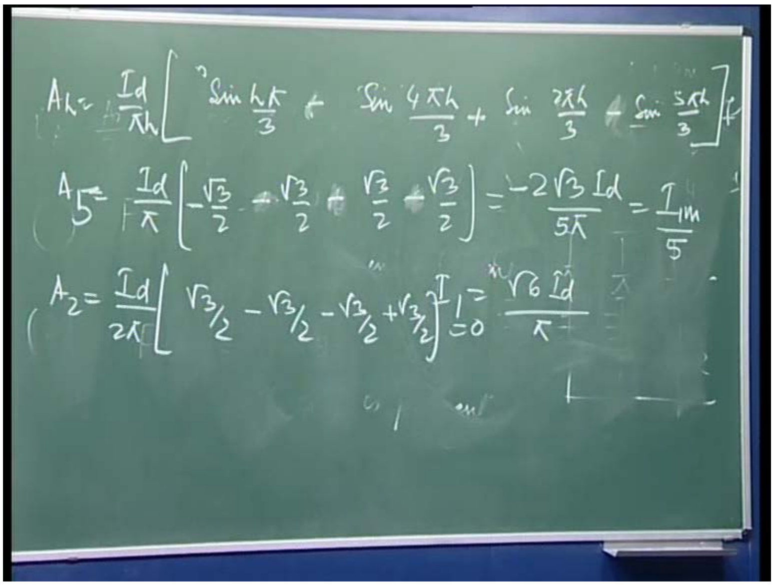

So I can say A h your I d by pi this here everywhere there is A h so it will be if you are integrating it will become down here so it will be I can write this h now here it will be sine h cosine will be sine so this will be sine 0 0 so this will be your pi by 3 for this integration this is 0 and for here I want to write here sine now this value here is a minus so I can write here it is a minus your 4 pi h by 3 plus your sine 2 pi h upon 3 because this is a 2 pi by 3 here and this is going with so it will be positive.

Now, here it will be plus sine 5 pi by 3 h and now 2 pi sine 2 pi is 0 every time what will be h k value so it will be 0 and we are going to get this four components it was minus here yes sir because it is this is a lower one so it is minus because this minus this now let us see for the simplicity this is A 1 so I can say it is your I d upon pi h is 1 here we are going to have pi by 3 and pi by 3 means under root 3 by 2 now this value sine 4 4 pi upon 3. What will be this value under root 3 this will be plus under root 3 by 2 this will be also under root 3 by 2 this will be also under 3 by 2. So, we are going to get 2 under root 3 I d by pi means and this component is the peak value mind it because whatever the component which is coming to your the Fourier series analysis the value is the peak value.

So here it is nothing but, it is your I 1 m I can say the peak value it is not rms value to get rms value I 1 here it will be your under root 6 I d by pi to see it here I want to show that A 2 will be 0 as even though property also shows it will be 0 just put the value of two here your I d divided by the twice pi here you will find 2 pi by 3 means it is your under root 3 by 2 here 2 it is 8 pi by 3 how much this value plus or minus 3 by 2 here it is A 4 4 it was it will be minus 3 by 2 here it will be plus under root 3 by 2 and finally, it is 0 it is correct.

We can see also A 3 will be 0 A 4 will be 0 A 5 will be not 0 and once you are going for the A 5 here I can say it is you're A 5 this is your 5 pi by 3 this value will be your minus 3 by 2 this value here the 5 is 20 pi by 3 it will be your minus here this value here you are opposing tan pi by 3 it is also minus and this will be also minus so we are getting this 5 and finally, I can say it is by 5.

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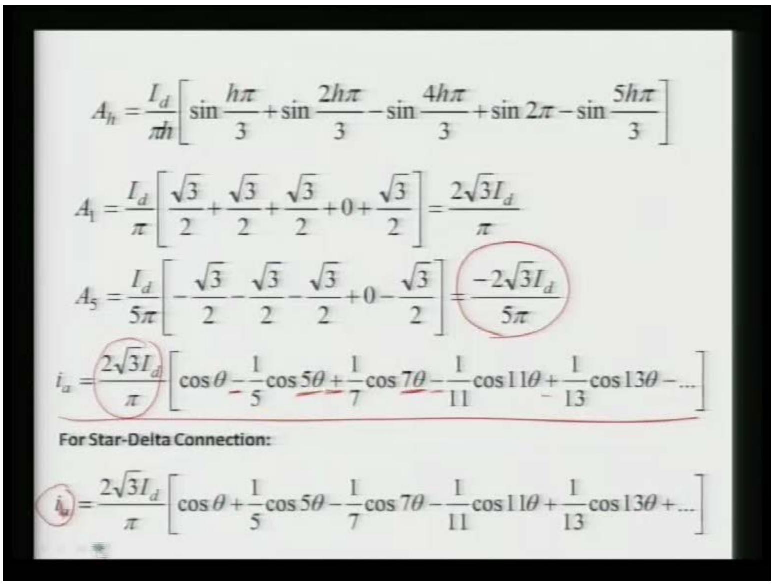

So, your fifth harmonics you can see it is your under root here this value we are getting it can be also seen the fifth component which is appearing it is nothing but, it is your negative sequence component and that is why it is negative term is coming seventh was in a positive if remember here I wrote here 0 1 2 3 4 5 6 7 your 8 here this 5th was your negative component and then magnitude here is coming negative here the 7th is the positive and value will come in the positive.

So your you can also verify and put the value A 5 you will be getting the same value so I can say your i a that current will be, this is your fundamental component that is complete outside and we are giving the various the 5th harmonics we are giving 7th harmonics but, here the 5th (( )) component is negative here it is you can say is a positive here again negative and positive and so on.

So we can see the major observation here that the component which are of higher order is divided by that order component so this magnitude is keep on dividing and it is going to be reducing so the magnitude significant for our consideration is 5th 7th 11th and 13th after that we are going to get what it is your 17th and 19th harmonics will come and then we are going to a 23 and 25th and so on so far.

So, those are very small magnitude and that for that we never design the filters but, for these four components we have to design the filters and because they are the significant even though 1 upon 13 means 10 percent is this here it is 8 percent here it is on a 15 percent or so approximately 15 here it is approximately 20 percent of the fundamental components are there so this is the case when we have our star star connection and we are talking mind it if your transformer is there here so we are talking at this primary side of the transformer.

No doubt in this star star connection this side is the same then this side because, the same unity ratio if you are assuming the unity ratio whatever is here that will be coming here but, if you are going for your star delta here so we are going to go for the phase current here and that phase current is coming to line current here because this phase will be this phase this will be your this. Whatever the phase here this component is different the similar to here whatever we are getting but, inside the phases is the different because it is this minus this current is the this one line current and that just we I showed you here in this figure here you can see this is your now I can say it is your i a current.

This is the case when we are having your star delta configuration and in this case you can see if you are taking your axis here then your this is your cosine component here it will be your cosine component will be coming if you are taking your axis here then it is your sine component will be coming so the analysis similar analysis can be done and you will find here the current here i a. Now, I can write here I capital because it is the star delta and the component here is just changed with the different one because there is a shift of

30 degree so here this component now becomes positive this components become negative this was the as negative here which was the negative here and this becomes positive.

So you can see the components are same average value is same everything there only here the components which was the earlier the positive it is going to be negative here it was a positive negative but, this is the same and now you can see to minimize the harmonics if you will add this two together then these components will be cancelled only we are going to get this one and this is the main feature of the 12 pulse converter that you can use this star star and star delta transformer this components will be get cancelled and we are having only means pulse number now it is 12 and thereby we are getting again the our formula while it that is your n p plus minus 1 and it is we are going to have 11 and 13 and then we are going to have 23 and 25 so 23 and 25 are gone because we never design the filter for that because the component is very less so but, we design 11th and 13th. If you are operating your 6 pulse convertor then you have to go for at least this 4th even though required then you can go for the 17 and 19th as well.

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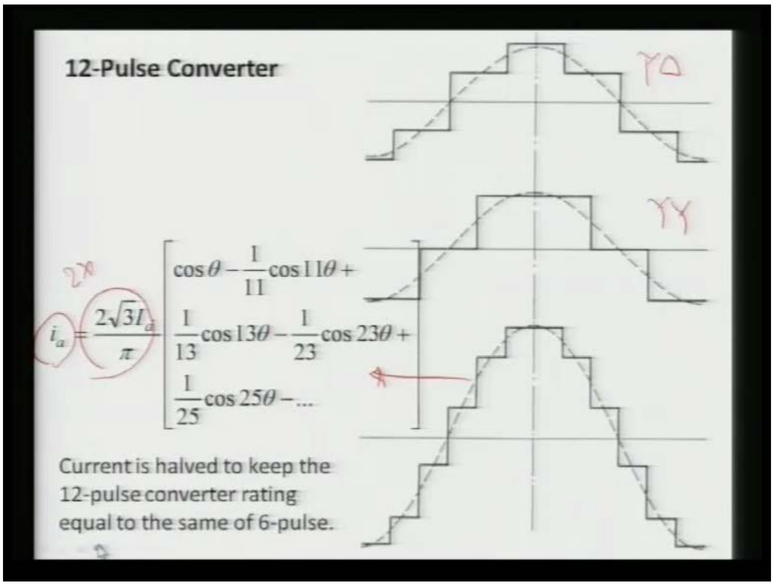

So, in the 12 pulse here you can see this is your this is the condition for your star star here is your star delta and if you are adding you can get here the 12 pulses and you are just getting this component here so your i a is here. Now, the question if you are adding these two currents the value should be the double of this.

For example, this one sorry if you are adding this current and this current now for the fundamental what is happening here is a 2 cos theta this is cancelled this is cancelled here again the twice of this here the twice of this. We are getting the twice of this but, this twice of this is not we are trying to equalize that the per unit power given by 6 pulse is equal to if 12 pulse then the magnitude here can be written in this form again the fundamental component. So, the current is halved here means whatever the power it is coming out it is the same for power so current should be reduced here half of this and the other side is halved so this value is there but, if it is not so then you can add together the two here the two will be there multiplied by this.

This is your component and you can see 11th 13th and 15th are appearing so we analyze this current harmonics here in the AC circuit and with this assumption that there is no overlap angle.

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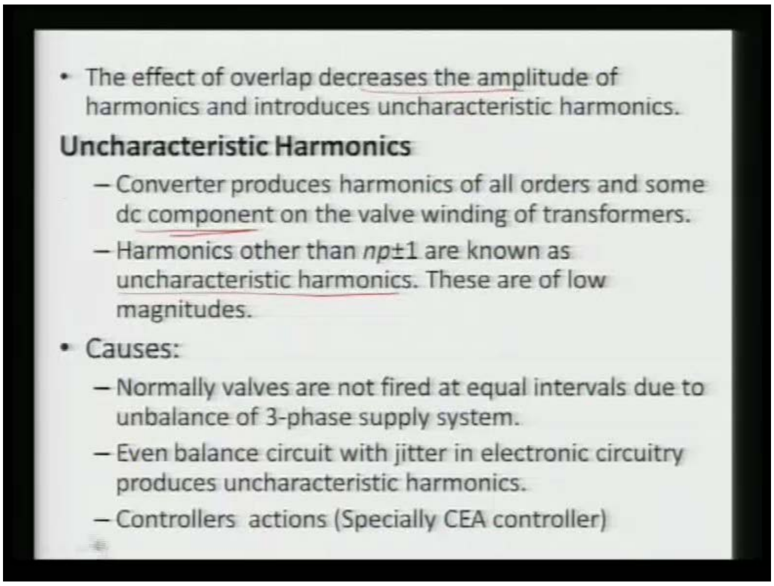

Now what will be the impact in actual case this overlying angle will be there may be the value is very small but, it cannot be 0 because we are having lot of inductances in the circuit there is a commutation inductances so what we will having the effect of overlapped. Basically, that decreases the harmonics but, it introduces some uncharacteristic harmonics.

An uncharacteristic harmonics those are other than characteristic harmonics which we are we analyze we analyze whatever here the components those were the characteristic harmonics where is n p plus minus 1 other than that will be arise due to the overlap and also the magnitude of the harmonics will be reduced so what is the this uncharacteristic harmonic basically here it is stated that is converter produces harmonic of all orders it is not is the one fifth, seventh, etcetera it is all the orders and some DC component also arises here on the valve winding of the transformer.

Why this you can see this is the DC component this may not be equal you can see this is here you can see this area may not be equal to this area and sub component may be arise there will be some DC component but, very small this area because, this is here decreasing this is increasing there may be possibility that you cannot have the complete and some small amount of the DC component will be there and also here this will decrease your it will decrease the values as it is said and there may be some DC component as well but, the uncharacteristic harmonics components are very less low magnitude. But, sometimes these harmonics also create some problem into your system but, it is very difficult to know what will be the magnitude of these uncharacteristic harmonic all these varies depending on your u angle depending your alpha angle depending on your beta angle and otherwise your inverter angle.

All the DC angles if it is changing these components are changing the previous case we analyze for any value of alpha there is no overlap angle it was the we are getting same 5th 7th and 11th 13th harmonics but, if you are your u value is changing the uncharacteristic component will arise and you have to magnitude will be changed accordingly.

So people have analyzed for the different value of u and they have plotted the shape etcetera and they found that these components are very very small. But, still sometimes they are significant but, they say it is a low magnitude. So, we never design the filters for this uncharacteristic harmonics sometimes they provide some filters sub and pass filters that is if it is a higher order it may be passed out but, the tune filters we provide for the significant amount of the components like 5th, 7th, 11th, and 13th, etcetera.

So, what will be the causes of uncharacteristic harmonics it is normally the valves are not fired at the equal intervals due to the unbalance of 3 phase supply system if your supply system is unbalanced then the firing because the 0 crossing if it is unbalanced the 0 will not fall at 120 degree displace of all the 3 phases. So, what will happen? Because, we are having the current controller it is sensing the 0 crossing and based on it is giving the firing pulse.

Thereby, if it is not equally spaced means it is not 60 degree then again you are having the different components as well. So, one is your overlap another is your this unequal firing of the gate pulses; so this will also introduce some uncharacteristic harmonic even though balance circuit is there you are using the electronic circuit to control it to measure it and due to this electronic circuit the 0 crossing may be shifting here and there and that may also introduce the uncharacteristic harmonics balance is very clear because 0 crossing is shifted it is not 120 degree displaced. So, it may create problem but, even though it is balance supply you are using the power electronic device which is measuring there is a some signal professing another things are doing it may be 1 or 2 degree if there is a displacement and that displacement may again introduce some uncharacteristic harmonics.

Here the control actions you know the I discussed about the HVDC controllers the controllers basically see the current magnitudes if it is shifting here and there then your the firing angle of the coming valve it is changed so angle here is a changed and due to this change again we are introducing the harmonics specially the CEA control is very very prominent because we are calculating this your angle well in advance the beta and we are maintaining the gamma and if there is some problem because the AC inverter side is very weak system and it create lot of problem so the CEA control introduce more harmonics due to the control action rather than CC but, both introduces uncharacteristic harmonic the current controller that is rectifier side CEA control use in the inverter side but, this is more prominent because more fluctual it is changing.

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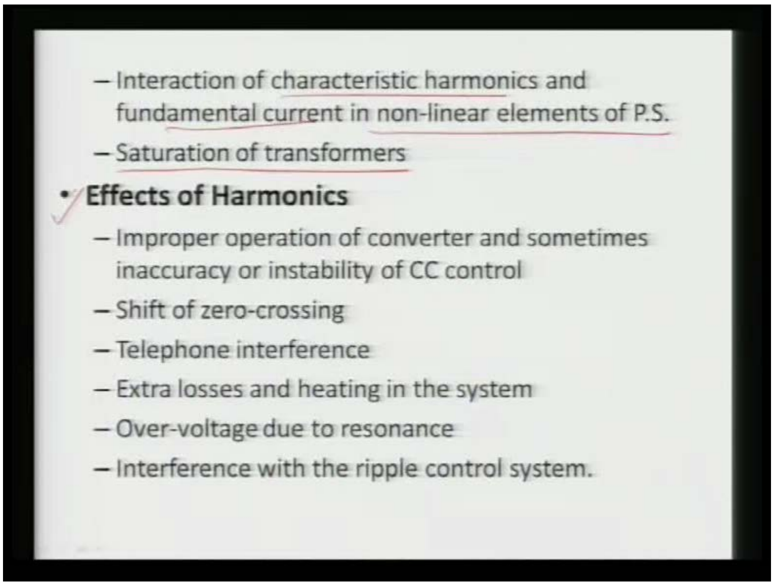

Another here the cause of this is the interaction of your the characteristic harmonics already we are getting the characteristic harmonics your 7th, 5th 7th 11th and 13^{th}. If that is interacting with your fundamental component and there is some non-linear elements we are having the non-linear elements in the power system that is the non-linear elements or inductors are installed in non-linear because you are they are coming here then what happens they are going to interact and that is creating problem.

We are using so many other power electronic devices like your even though filters are may be having some power electronic devices means, if you are having any non-linear element in the system then enters interaction of these may also introduce some uncharacteristic harmonics. Another already I discussed that is the saturation of the transformer you know this we are having huge current which is flowing in the primary side it is sudden jumps and sometimes sudden current is increasing and there is a saturation of the transformer and due to this saturation what happens? We are injecting harmonics in the system and that it is not of this 5th 7th it is uncharacteristic harmonics.

The harmonics generated by transformer is not a characteristic harmonics. Now, the effect of harmonic in general it is not uncharacteristic or characteristic whenever harmonics are there in the system means you are just your operation of your converter circuit is in trouble because we require the smooth sinusoidal rate because we are measuring the 0 crossing we are measuring so many other things based on our whole control circuitries design so this is a operation may be disturbed and sometimes the accuracy of CC control is also not ( ) and may be if sometimes it is unstable because your controller is hitting here and there due to the change in this harmonics component shift of 0 crossing because your controller CEA and CC control is measuring 0 crossing this may be shifted and that may cause another problem.

So, it is a you can say, accumulative process even though your 0 crossing is shifted your firing is different again you are introducing more and more harmonics. So, this is another one here interference with the harmonics telephone system because, if you are having higher order components that may interfere your communication system and that is another issue.

Here if you are having more losses then your elements like machines in terms of it are not only rotating may be static machine. Your transformer will cause more loss so the losses will be more if there are some machines nearby. There will be more heating in the system as well the over voltage due to the some resonance because, some of the components because we are having complete RLC circuit in the your even the inverter side this is your AC side I can say and both converter inverter side and if that component is entering in that system then there is a R c resonance R l resonance and that resonance may sometimes huge voltage across either capacitor or across the inductor and that may damage your elements so the over voltage may cost and that may create problem to the your system.

Another is your interference with the ripple control systems ripple control system I mean to say that sometimes some utilities provide the power to the consumers at the off peak hours I mean to say that there is a possibility that is we can use the same communication your wire business that is a power line for using the communication because if you are a user and power is to be given to you at the off time so sitting in the sub-station. A person can switch it and the signal can go to your contractor and may be on and off depending upon that so if this component that harmonics component may be 1 kilo hertz it start at 260 hertz to 1 kilo hertz and you can see your frequency component are falling in that one if it is going there unnecessarily then it may your contractor may be open or close and that may create problem to that one.

Here, the ripple control system basically I want to say that your sometimes consumers are being operated at the different time intervals and that signal is generated from sub-station and same wire that the power line is used for the communication giving signal of harmonics and that harmonics may interfere with this and you can get unnecessary opening or closing of the contract contractors and thereby it will be operation.

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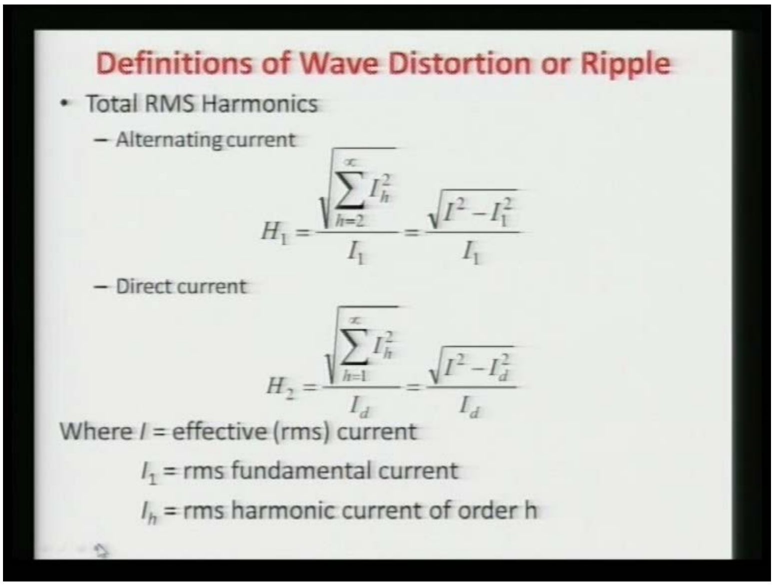

Now, how to judge that whether your system is perfect or not because we are having so many components some components may be higher order magnitudes some are less so there is some performance indices or you can say the definition of the wave shape distortion or ripple are defined and basic primary is your RMS harmonics. How much harmonics you are having the system? It is a defined if you are talking about the AC current side AC current here it is your harmonics component means all this rms currents added square of the rms current except your 1 here is a starting with the 2 added with all infinity all the components. They are square of this added then if you are taking under root divided by the fundamental component.

So, this is a H 1 index is basically your alternating current this can be also defined this total I that is effective value here I is effective rms current minus your fundamental component square and you are taking under root divided by this; you can get this H 1 component. So, this is one indicating how much H 1 component you are having in per unit because you know current divided by current it is in per unit.

Similarly, the DC side here we are talking about the current similarly, we can talk about the voltage what will be the here the now we are the v h here the v 1. So, it is for the current is same so we can just replace with the voltage also in the DC side it is your here we want the DC value even we do not want the fundamental component so it is all the components of the current in the DC side if it is there then it is H 1 to infinite here it is only the difference here it is a H 2 here is h one and it is divided by the average current that is a DC current.

We do not want the because we want the DC current in the DC we do not want even the fundamental component so that is also treated as a harmonics with respect to the 0 frequency here and that is here. Again, we can say total effective the rms current minus the average current square under root divided by this so this is your the total harmonics RMS harmonic component it is a average here.

Now, normally we want the DC is a ripple free but, it is not so, there will be some changes in the current no doubt but, again the how much here this value is two is there it is the deciding factor for the analysis we said that it is a DC is constant if DC is here. This fixed value ripple free this value will be 0 means if your H 2 is 0 means we analyze here the component with the assumption that H 2 is 0 because, this value is not there we assume this a ripple free but, it is not ripple free it will be having some component and based on that then we can analyze even we can find what is the value of H 2.

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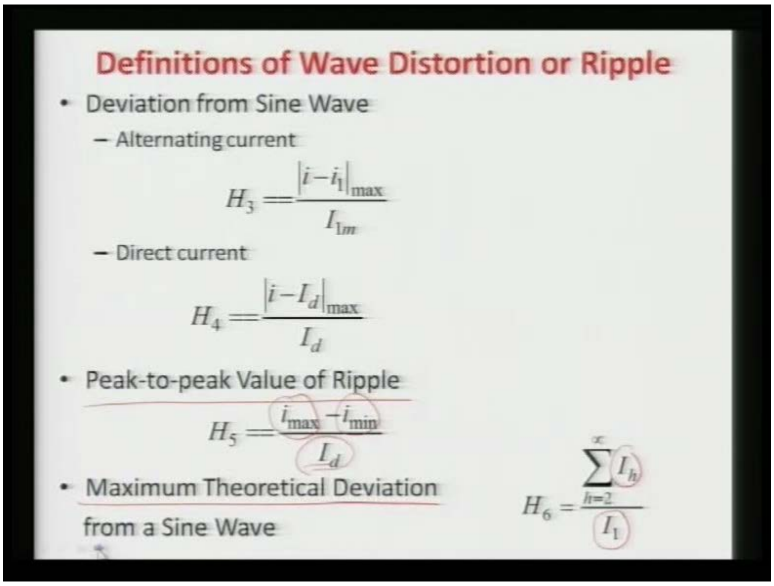

Another indice that is indices are used that is the deviation from the sine wave here this is the very easy that is your instantaneous current I that is total I minus your fundamental component instantaneous value you are just subtracting and then you are taking the peak value of that because your value is there some distorted wave shape that is I instantaneous value minus to your perfect sinusoidal component or fundamental component here. We are talking the instantaneous value and then we are taking where is the difference the maximum difference because where is a happening maximum difference then divided by your the peak value of that one because here we are talking the peak value and this your H 3 component is defined this is another criteria to see whether your system is well or not.

Similarly in the DC if your current here is not perfect DC it is having some instantaneous value some current which changing with the time then divided by your subtracted by your average current and then we are going to take the absolute where the maximum is up here because it will be changing may be some where it is 0 also may be negative so we are talking here the maximum difference divided by your average value for this is a direct.

Another criteria is to define it is to the peak to peak and the peak to peak is very clear. Here, we are talking here this ripple this i max minus i min divided by this average value and this is basically we are talking from the DC side because this average here, we are talking here. So, the difference where is the peak and there is negative and that is also it is called peak to peak value of the ripple.

Another component normally it is defined that is called maximum theoretical deviation from the sine wave here. Why we are going for this value? You can see here it is not a square. It is just similar to the previous case. The first case here you can see this instead of squaring and adding here and squaring and then adding and then under root taking under root here we are taking simply the RMS value of all the fundamental component other than fundamental divided by your the fundamental value.

This basically what happens sometimes it is very difficult to get the phase angle of the components because all square you are using so you know the phase angles of those components here some uncharacteristic harmonics are there so it is very difficult to know so it is better to divide by this instead of squaring and adding here simply you add it these components and then divide by this you are getting this 6 index this is a similar if you are taking RMS value to RMS value or you are taking here crust value to crust value. Crust means peak value so you are taking peak value of harmonics component added together then fundamental peak or you are taking this one here it is taken as RMS value.

But, same index is some people take for the crust value and then they define in this value. This is basically the analysis part of harmonics now the concern arise that how to minimize the harmonics how to eliminate how to mitigate this issue one is to minimize the harmonics we have to go for large number of pulses. Already we saw if we are using 12 pulse you are just minimizing 5th and 7th harmonics. If you are going for 24 then again harmonics your 13th and 11th are also gone your 23 and 25th will be only be there.

So, we can go for the large number of pulses to minimize it but, again if you are going for large number of pulses the complexity and the cost will increase because, you are adding the converters in a such a way or you are designing such a way. So, the complexity is increasing and therefore, always we go for the 12 pulse operation where we are having your 11th and 13th harmonics then we are having 23 and 25th harmonics and we can design the filter for 11 and 13.

Another is if you cannot minimize you can fix number of pulse operation then you have to use the filters now again we will see the various types of filters are there. It is either tuned filters or it is band power filters, whether it is a series filter, whether it is a sun filter. Again, the various type of filters it may be double frequency filters or single frequency filters. All these filters are basically now used to remove the harmonics that should not enter to your power system. If it is entering to the power system already we saw the various problems that it may introduce losses more losses it will introduce interference. It is also may be the resonance over voltage may arise and other activities will happen.

So, in this next lecture we will discuss about the filter design and we will see the various types of filters and then we will see some problems as well on this issue; so thank you.