Department of Electrical Engineering

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Indian Institute of Technology Kanpur

Module No. # 05

Lecture No. # 02

HVDC Components Design

Let us, start the lecture number 2 of this module that is module number 5.

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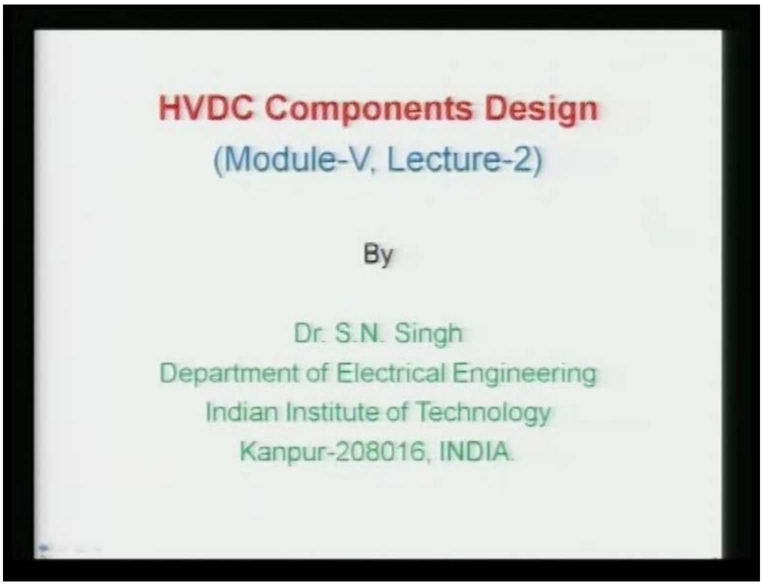

In the previous lecture, we analyzed the various harmonic component both, your A C and D C side. And that was for the ideal case, we assumed the overlap angle is 0, but in a practice, overlap cannot be 0 it is normally some significant value sometimes is just 5 to 20 degree.

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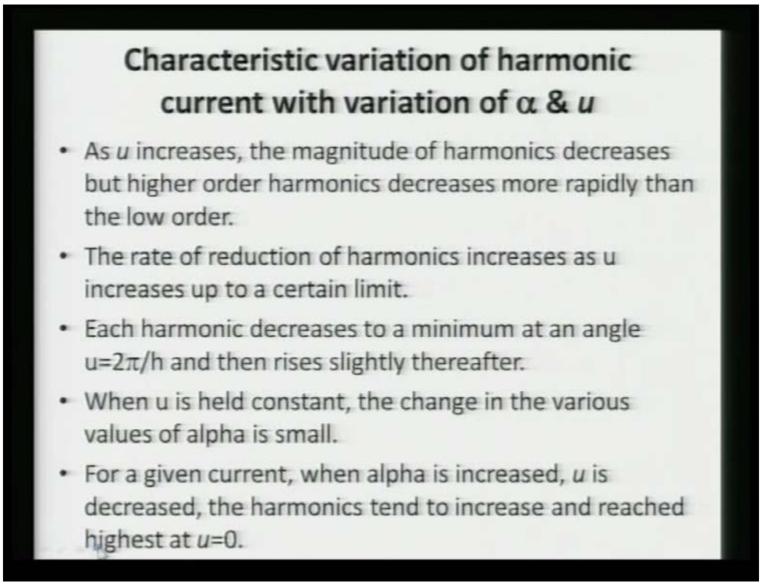

So, the impact of this u is also very significant in the harmonics. As u increases, because u we took u is equal to 0 and if u is increasing from 0, the magnitude of harmonics decreases, but the higher order harmonics magnitude decreases more rapidly than the low order harmonics. Basically, all these analyses are based on the various studies various reports and here then measurements people have summarized this, so here I am also summarizing here. So, we are not going to analyze the individual, but this is the summary gist of the various studies.

So, once u is increasing it says the magnitude of harmonics decreases, but the higher order harmonics decrease is more rapidly than your low order harmonics. The rate of reduction of harmonics increases as u increases up to a certain limit. So, it is basically increasing if u is having certain limit, then this increase reduction of rate of reduction increases very high value. It also say that, each harmonics decreases to a minimum at an angle u is equal to 2 pi upon h; h is your components means h is your 5th, 7th, 13 th and 11th.

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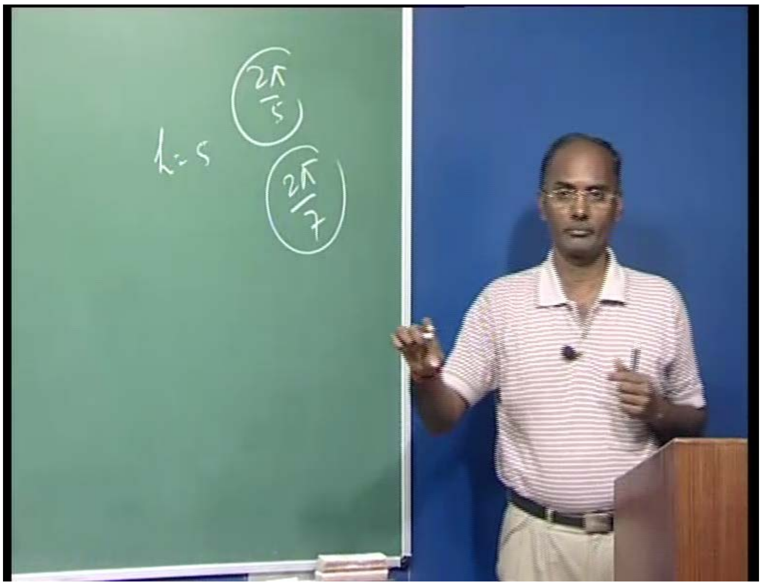

This once you are reaching this u at this value for let suppose, once your u is here, h is your 5 then 2 pi upon 5, then this component is basically decreases to its minimum value. So, if it is for 7, then it is a 2 if u is this, then the 7th harmonics is the minimum value. When u is held constant, because there is possibility that we are varying alpha is a intentional vary, because we want to change the voltage and we are just delaying this angle alpha as well as the beta you can change the inverter circuit; but this u depends upon your circuit, another network conditions. So, if this is a constant and you are delaying this you are changing basically this, then the impact of harmonics magnitude as well as its contents is very very negligible.

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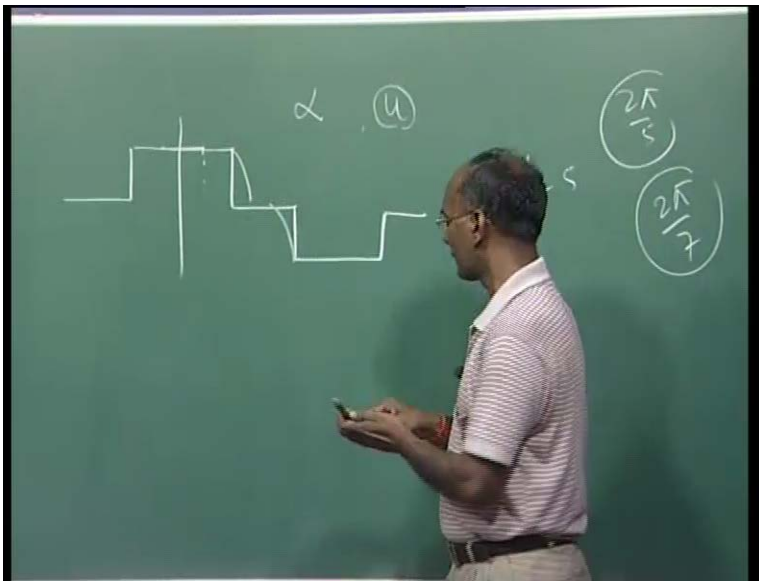

Why it is so? You can see here, if you will see this is your current this is 120 this 60 here, if you are delaying here in the ideal case, so only this is shifting. So, the magnitude will be the same, only this here your axis here there is some phase shift will be there nothing else. But, you are taking this u here that is going, then the impact will be there, but it is very very small, if your u is shifting.

It is also said for a given current, current means I am talking about the D C current. For a d given D C current, when alpha is increased means for a larger alpha, and u is less decreased, then harmonic tends to increase and the reached is highest value as u equal to 0. So, these are the basically five summaries when alpha and u are changing. This is a true for your rectifier circuit it is true for your inverter circuit as well.

But, the major components that is a coming your 5 th, 7 th etcetera those will be there, and they will share the highest or most of the current; this characteristic harmonics will be the highest in that 5th, 7th etcetera, that is the characterized by your n p plus minus 1.

So, the component here of this order of harmonics will be larger, and it will be there only the slight change in the magnitude once your u and alpha is changing. And some more components will arise, if your u is here significant, because when we are going to have other than these harmonics in your A C system; and that is called your uncharacteristic harmonics.

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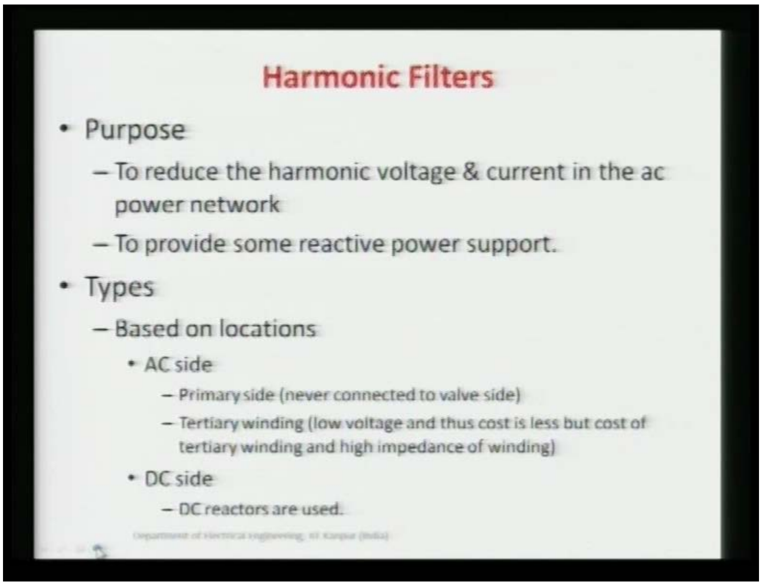

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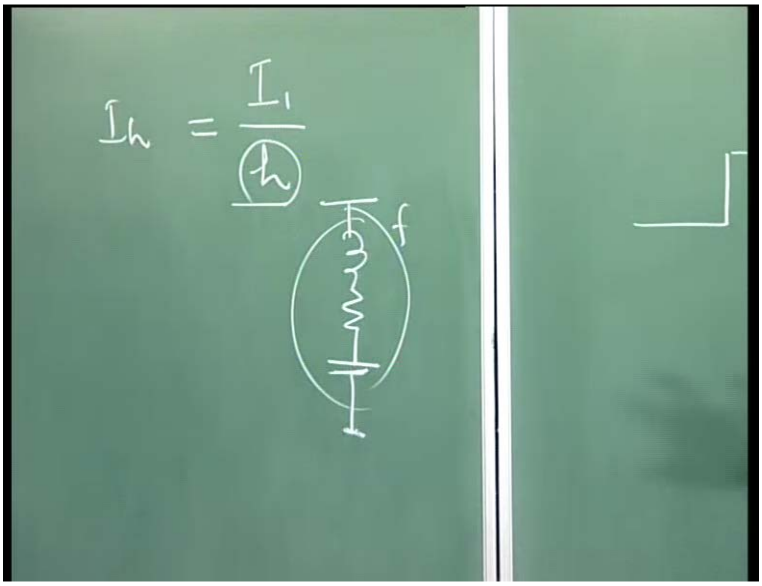

Now, to to filter out because, we saw your harmonics component here, it is basically if it is a fundamental component, then it is your h is harmonics; so, your highest current in A C side, it will be the fundamental component divided by that harmonics component. And now, you can see if it is this h is low this value is larger; and if it is h is higher this component value is very less. So, we should not worry about that, it can be allowed to enter into A C system.

So here, we want to filter out some of the harmonics that should not because it is magnitude is a significant. So, it should not enter to your c system. So, what we do? We use the filters and those are called harmonics filter. So, the purpose of harmonic filters is to reduce the harmonics voltage and current in A C power network. And also it provides some reactive power support at that A C bus.

We will see, if you are designing a filter for any harmonics and for that harmonics it will provide the minimum impedance, but for the fundamental component it will provide the reactive power support. I mean to say, if you are using your this shunt filter here it is your r l c circuit, this is a shunt filter, here at at particular harmonics what will happen? This l and c impedances will be minus and we will have only impedance here. So, for that it will give the minimum impedance.

But, for the same circuit if the frequency is your f that is a fundamental frequency, this circuit will behave like a capacitive circuit I mean it will provide the reactive power support; and we need it in converter stations, we require huge reactive power supports. So, some of the reactive power support is provided by filter section and the rating sometimes is denoted by the filter rating, is how much reactive power it will provide at the fundamental frequency? No doubt, its rating is for which frequency it is providing the minimum powers left over 5th tune filter or 7th fit tune filter. And also at the same time how much m v a are it is giving at the fundamental component.

So, the main purpose here is to no doubt to reduce the harmonic current as well as the voltage that is entering to your A C system or if it is going the D C side, the D C system. But, in A C system, it provides some reactive power support at the fundamental component that is required.

Now, the various type of filters are proposed and in theory and in also in the application various type of some filters are there. And we can categorize those filters based on the certain criteria and the first criterion is based on the location.

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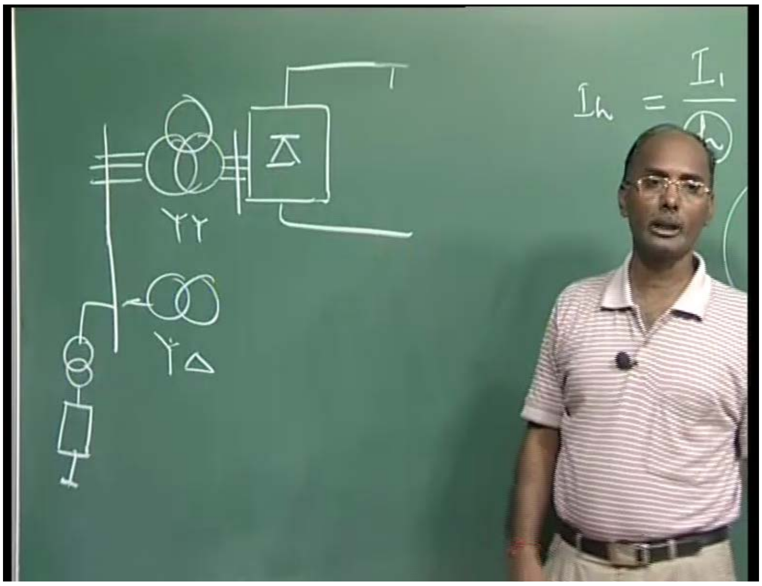

So, your H V D C system it will again this is your converter transformer, this is your A C system, we are having here rectifier, this is your link. So, if your filters are A C side, it is called A C filters; if you are using the filter the D C side, it is called the D C filters as usual. So, A C side basically we use the primary side of here. Now, the question is we can use, this is your three phase going, we can use the filter here, we can use the filter here.

(( ))

Yeah, it depends on what is if it is unity term ratio, so you can put here as well as here. But, normally what we do in the practice? We put the filter here rather than here, because here this O L T C is changing On-Line Tap Changes are changing here, and there by that may create some other problems to the system. So, we always try to put your filters that is A C side on the primary side of the transformer, not only for this region; let suppose this is your star star if you are using another system here, that is your star delta, then some of the component will be cancelled to each other.

Otherwise, what you are doing here, putting the filter for all 7 th, 5 th and 7 th and 11 th and 13 th; here you are also putting for that, but that is not required, because here it is not going they are cancelling each other. So, I put here that is why it is written it is a primary side never connected to the valve side, valve side means this side we put in the primary side of the transformer.

Sometimes, also we use the tertiary winding of this, because the voltage of this bus is very high normally, it is 400 k v A C system, this is a 400; and if it is coming this side may be it is depending upon if you are operating here the plus minus 500, the voltage will be calculated here what will be the voltage.

So, this 400 voltage is very very high. So, what we do? We cannot connect a filter at the 400 k v it is very expensive, because you require the insulation level of that voltage and your inductor capacitor and resister size will be very very un insulated properly. So, what we do, another option that we can use a tertiary winding of this transformer; even though here if you are putting the primary side, this will be through some transformers and then you can put the filter.

So, then you are incurring extra cost here, because from 400 you are going to may be 66 k v or 33 k v and then, you are connecting the shunt filters there. So, if it used here the filter in the tertiary winding, because the voltage is low, so you are minimizing the cost compared to this transformer, no doubt if you are adding another winding the cost will be more.

Another problem here, you are increasing the impedance, because here the l value is going to be higher. If you are using a tertiary winding that leakage flux is also coming here into the picture and effectively the reactants is going to high. So, that is why it is weaken the tertiary winding it is no doubt the low voltage we are getting through the tertiary winding and the cost will be less compared to this transformer no doubt, we are putting a extra winding extra cost will be there.

But, I am comparing the two winding transformer and this two winding transformer, then compared to a three winding transformer. So, this cost will be less, but here the impedance of the here the tertiary winding will increase and we are getting u will be more in that case.

So, another is your the D C side, because this side we are getting the A C current harmonics, here we are getting the D C voltage harmonics. So, we put the filters as usual and that filter is nothing but, your smoothing reactors you put the smoothing reactor this side and that is why the D C reactors are put. Sometimes, we also put here some reactors here in the shunt also for the voltage, because the current here we want the smoothing reactor to make the current constant ripple to be minimized. But, some of the harmonics it should not prevail, because the harmonics may cause extra loss.

So, we can put some here filters that harmonics can be damped out through the resisters and it should not flow in the transmission line. Because, if this is happening here that it is not a utilize power and the loading of the line will be more. So, we can filter it out without any problem. So, we use here again the reactors, if we use the reactors it will be going down. So, that is why the D C side we use the reactors.

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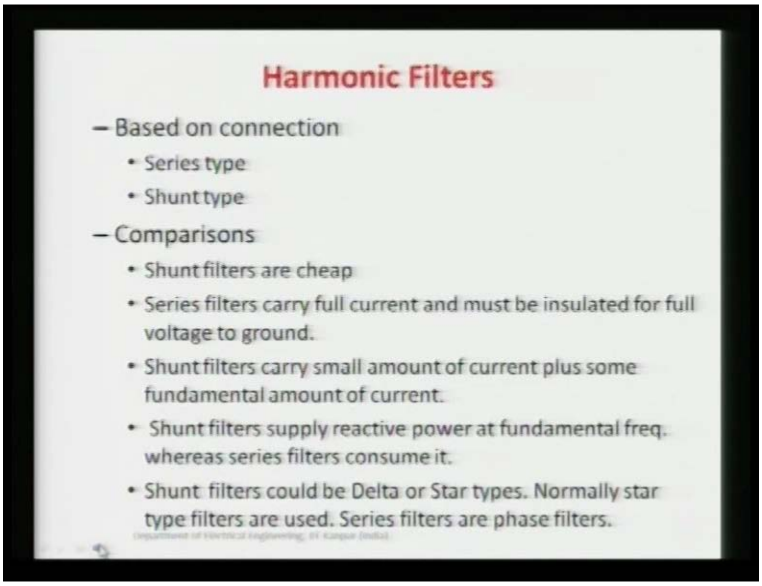

Now, another criterion is based on the type of connection. Here, every time I am showing this is just like a shunt. So, based on the connection we can say our filters can be categorized or you can you can say classified into the two types, one is your series type and another is your shunt type.

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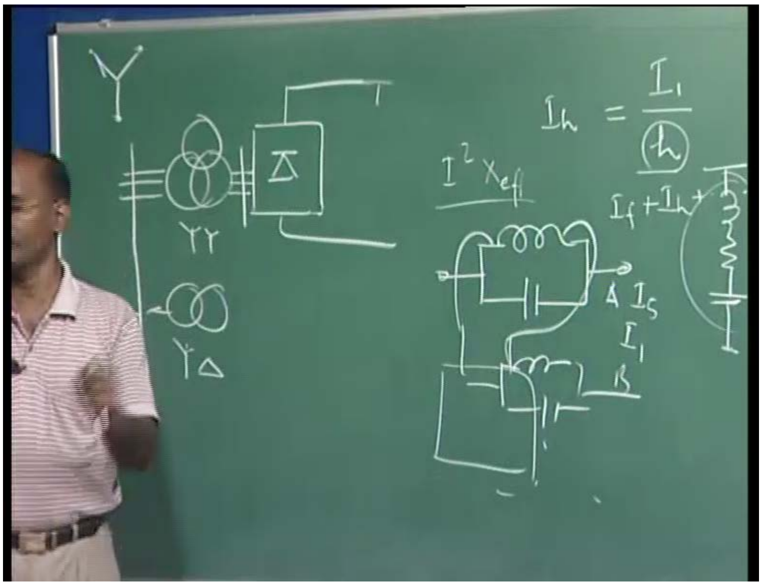

Series type as usual, here this is your inductor, this will be your capacitor and this is put in the line. So, if you are puttying here this is your series, this side also you can put here in the each lines, these filters what happens? They basically provide if any harmonic component entering here, the combination will provide the infinite path it will just behave like a open circuit. So, it will not enter to your A C system.

So, this is a series here just like open circuit. But, the fundamental component it will provide some reactance, but it will be not the open circuit, it will be minimum (( )). So, this is your series filter. And series filters basically normally in H V D C, they are not used they are used only the one filter here we use for the smoothing reactors that is in series. But, in A C side we prefer to use the series the shunt filter, because it has a several merits.

So, you compare with the here series and shunt, the shunt filters are cheap compared to your series filters. The reason here, because already here it is written yeah, the series filters carries full current and must be insulated for full voltage to the ground. Because, if you are putting here in the line, this inductance must be insulated properly through the ground, this inductor is not hanging in the air mind it. It will be the inductor will be on the ground, because wire cannot sustain this is a inductor means just like a transformer, air core transformer is a huge inductor.

So, it will be on the ground only just we are making connection here (Refer Slide Time: 13:56), means this is your inductor this two terminal will be basically coming here and here. The electrically I am just representing as a inductor here, but it is through not hanging in this air, it will be here, so this is a huge voltage inductor; so, it must be insulted from the ground. So, full voltage is appearing here, this is a 400 k v line 400 voltage must be insulated.

Another here, through this path we are flowing the full current. Now, you can imagine the current which is flowing in the kilo amperes, so here the kilo amperes is current flowing through this. So, huge the rating of this (( )) and the capacitors here, it will be very very high and that is why the cost is very high.

Now, as compared to your shunt filters, here this is a shunt filter, this is carrying the harmonics component current no doubt; some current will flow at the fundamental frequency as well, because this is some impedance is offered. But, for this fundamental component, the impedance here will be larger it will large enough; the impedance offered for the for which it is tuned it will be the minimum, because this it is cancel each other impedances, only we are having the resistance.

So and that current is flowing only the harmonics component, and that component here is basically this by h. So, this is sustaining the less current and thereby here, this is the cheap and it is containing the full current. So, that is why here I have written the series filter carry full current series filter carry full current and must be insulated from the full voltage to ground.

The shunt filter carries a small amount of current plus some fundamental amount of current; means no doubt it is that is a designed for I h means harmonics component current plus it will be flowing some I f plus also some other components. But, the I h here which will be the flowing here that is if you take the r m s value here I, the I which is flowing in the filter will be your I 1 square plus your here I can say summation of I h square. But, for which it is designed that component will be the significant, another component will be again less. So, basically it is carrying this amount I h in this.

And the better here I can say the best advantage here that is the shunt filters supply the reactive power at the fundamental frequency, whereas the series filter consume it. Now, means this effectively for the fundamental components, suppose it is a design that it will offer the open circuit for certain component; let suppose I am saying our 5 th harmonics current I 5 should not flow means the impedance here will be in such a way that the 5 th component it will be here, impedance will be infinite the effective impedance.

So, what happens here and if you will calculating this what will be your I 1 here means at value of total effective impedance at the fundamental component here it will be inductive; means it will consume that is consume here that is a whatever I square into this what will be your effective values. So, this reactive power it is consuming, here it will be generating and we need it it is a best option that we require this reactive power generation; we do not want it should consume, because then we require more a reactive power support at the convertor stations.

So, this is the best option that that is why we always use the shunt filters at the convertor station. Now, the shunt filters here since this is here the phase to ground, so we can have the combination of the star connections or we can have the delta connections; means this three phases are there here, so three phases can be connected here in your like this or we can have the three from here to ground, here to ground, here to ground then you are having the ground. So, what we do normally, we add the ground in part here and we can have this three way.

So, either it can be star or it can be delta, but it is again preferred the delta star is the preferred. How about the series filters? There is no option, you can have the delta and star, it is the phase wise, so it will be the phase connections. So, single this phase then we will have the similar another phase here for A, here for B and then, we have the further C as well. So, they are the in the phase.

This point number here is such this is the fourth point we will analyze this and we will see, really it is giving a reactive power means this whole becomes capacitive, when we are just operating at the fundamental frequency. If it is fundamental frequency, we will see the value of this.

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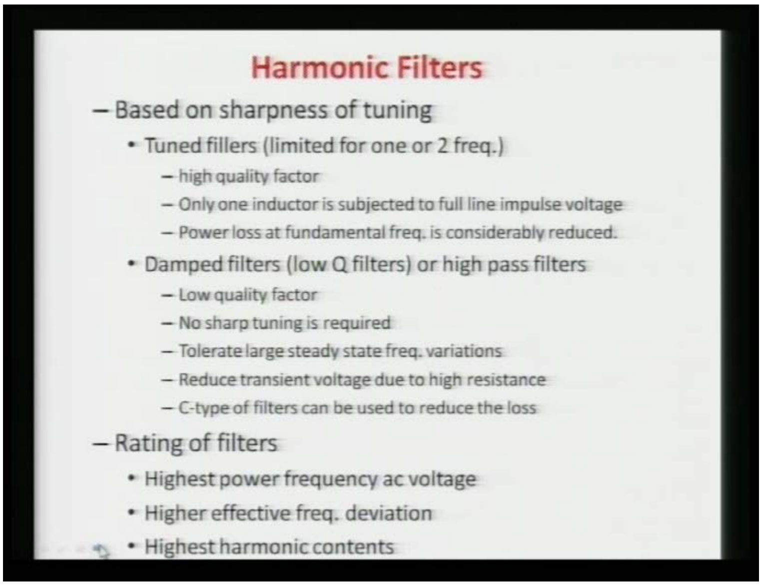

Another is based on your sharpness of tuning and you know there is a two type of filters are classified in this, one is called the tuned filters. Tuned filters, normally it is limited for 1 and 2 means you can go for single tune filters, we can go for the double tune filters. And another is your damped filter or sometimes called the high pass high pass filters.

The tuned filters are basically has a high quality, the quality factor; quality factor means it is defined where the inductor and capacitor values as a qualities normal quality just. And here only one inductor is subjected to the full line impulse voltage; I mean to say, if you are using here this is a tuned filter, in this tuned filter this is the one inductor here, which is sustaining the full voltage.

And but here, the power loss at the fundamental frequency is considerably reduced; means here the power loss is less, because this is the voltage here the current which is flowing here is very minimum at the fundamental component. So, this value is less. In the damped filter here, it is the high pass filters. It is the low quality with the quality of factor is less. It is a no sharp tuning is required; only problem here, you have to tune this filter.

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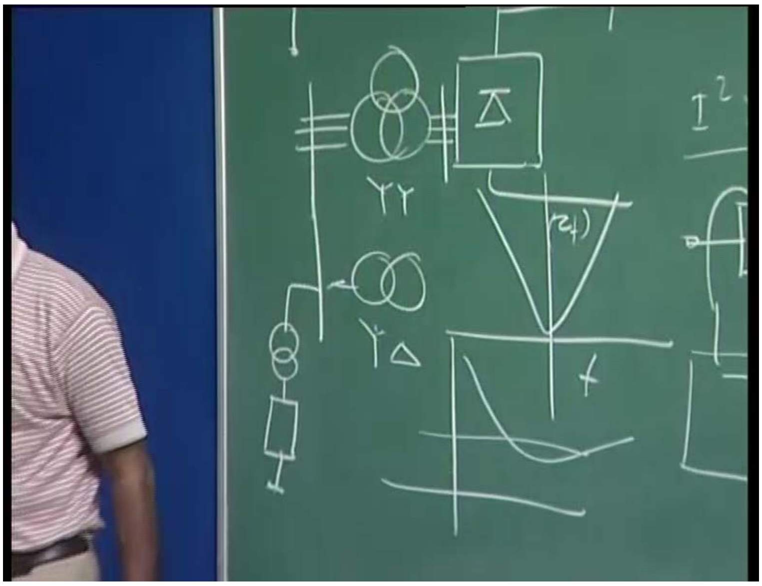

Let us, suppose this is we are tuning here for particular value, your impedance here this is your z f for a given frequency; if you are talking here, it should be tuned here. So, this is basically, but in the backward filter it is nothing but, it is characteristic here it is going like this (Refer Slide Time: 20:33). So, it the basically the remaining it is past and here it is providing some pass here and remaining it is just reduced.

So, it reduces also, it reduces the transient voltage due to the high resistance in this circuit. Another here, the C type of filters can be used to reduce the loss. This is the more (( )), but if the C type of filters are used then, it will be the loss will be reduced.

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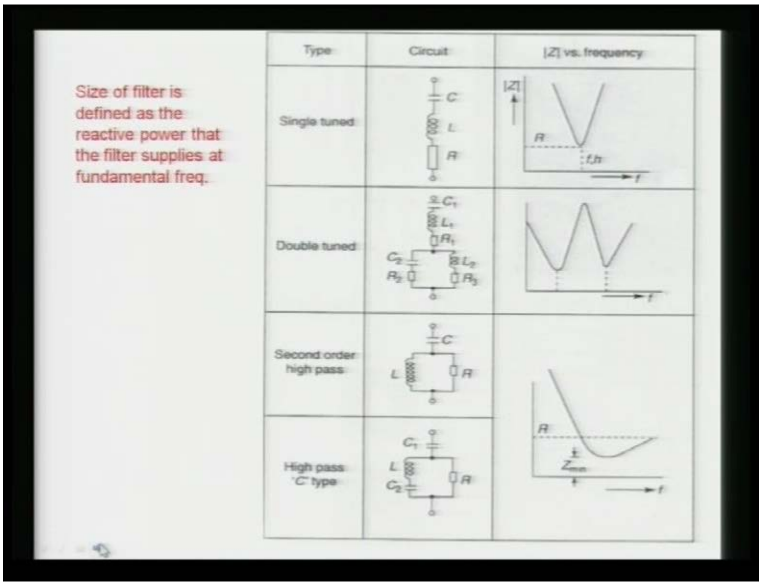

Let us see the, what is the C type and what is the configuration of this? You can see here, this is as I said, here it is your single tuned r l c filter here and you can say, it is tuned for particular frequency, one frequency where it is offering the minimum impedance that is the resistance r. And so this is a r l c series circuit.

Another, if you are going for the double tuned circuit, here we are having this is a second order this is here and you can say, this is a providing the minimum impedance for the two frequency that is f 1 and f 2. But, your high pass filter again it is a second order you can see we are using here the C capacitors here, inductors and is resistor here. So, this characteristic basically becoming like here (Refer Slide Time: 21:47).

Now, if you are using the C type of filter, what we do? Here, along with this inductor we put a capacitor, and that is why it is called the C type of a filter. And this what it does, it reduces the loss of the system, because here this is a just parallel to this and more current is flowing and more loss is there. So, this filter is more lossy compared to this. So, the C types of filters are used here.

So, that is why here I have written the C type of filters can be used to reduce the loss, because the normal here the damped filters the losses are more compared your tuned filters. Now, the rating of the filter how we will define the rating of the filter? The rating of filter basically decided based on the three here, one is the highest power frequency of the A C voltage, what is this insulation level? if I can say, this filter here is 66 k v means this is it is insulation level, where it can be connected. So, this is the power frequency voltage, if you are connecting here, so it is what about the voltage here. So, this is basically your phase voltage is not line to line, it is the phase voltage where we are talking.

Then another is higher the effective frequency deviation. Because, if you are talking here if you will see, a frequency is varying here we talk for a particular frequency; if your frequency is your 50 hertz, if you are designing this filter for 5th harmonic, then it will be 250 hertz here. So, in 250 hertz it is minimum impedance; but if it is changing, this will also change means if this frequency is 49 then what happens? Then you are not here, your 49 into 5 you are somewhere here, then impedance is increased compared to here.

So, once it is frequency is deviation we will see the d tuning impedance called d tuning and we will define another term here, this is a delta for this d tuning work, the change in the frequency deviation. And another is the highest harmonics content means for which it is designed means it is a 5th or 7th of it is then it is also defined.

Another criteria is also used that, how much reactive power it will provide to the system at the fundamental components. So, it is in m v r we say this m v r, this is a tune filter for 7 th harmonic. So, that is why here I have written the size of filter is defined as the reactive power that the filter supplies at the fundamental frequency.

So, sometimes its say it is 100 m v r filter 7th order. So, we can say 7th it is a tuned and it is reactive power support at the fundamental is 100 m v r or so.

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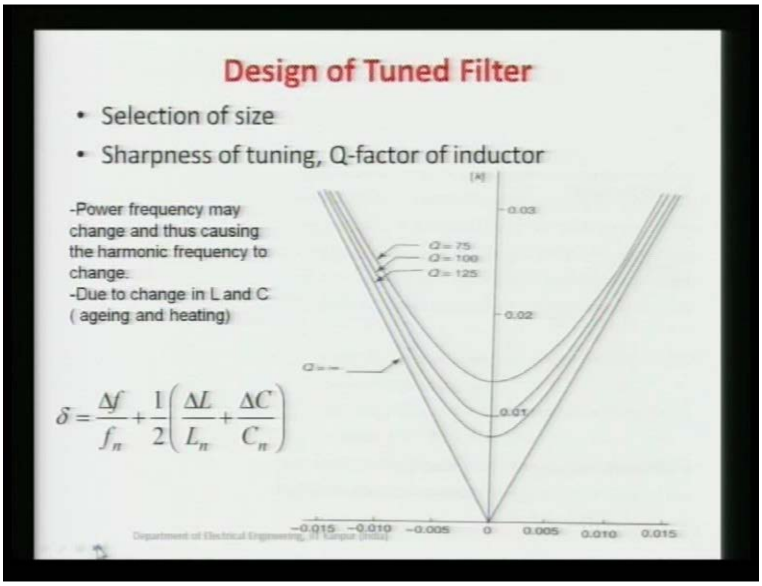

In this tuned filter design, what we do? We want the, what will be the size, and what will be the softness of the tuning, that is basically related with the quality factor of inductor. So, here I have written the few things here what is the changing the power frequency may change. And also, we can change L and C here due to the ageing and heating effect; to analyze this, let us consider the singer order tuned filter that is your r l c filter here.

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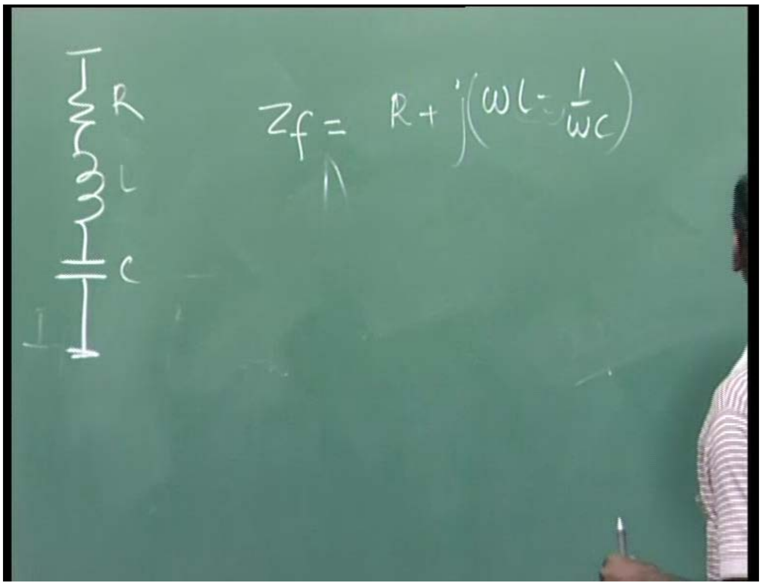

So, we are considering here this is your r and c here, this is a shunt filter, this is your resistance, here your l and c. So, total impendence at any frequency z f can be written here your R plus j omega L into 1 above omega C. We want to write this whole impendence it is characteristics in terms of where it is tuned for which frequency it is tuned; means the tuning means where this imaginary value is 0 means this is this minus this is equal to 0. So, that is called it is a harmonics components for which it is design your Young I can say the frequency.

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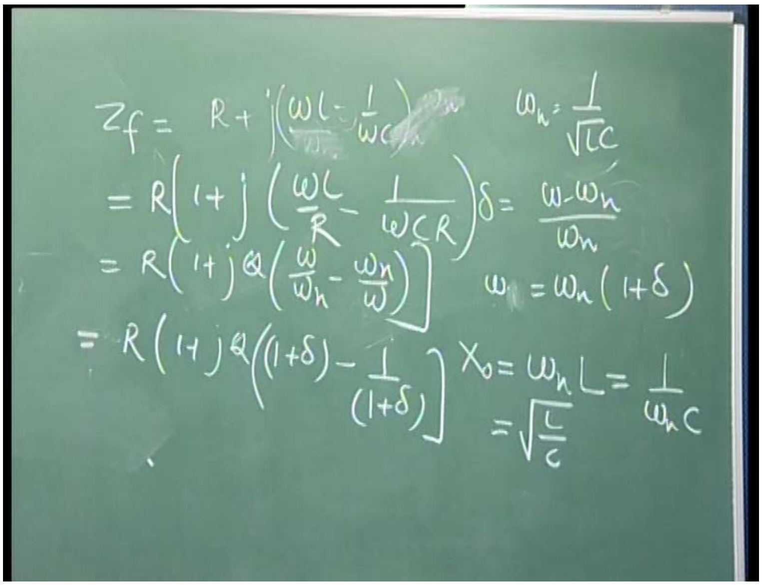

So, this value here will be equal to your under root L C as usual. Another term that is here, delta it is called the frequency derivation term, it is basically defined as omega minus omega n here divided by your omega n. This is also known as the d tuning factor or it is a deviation of frequency from the tuned frequency, this is your tune frequency.

So, how much it is deviating. So, it is defined this is a vector, where we normally draw it. So, using this here I can say this value going to be your omega n it is your how much? I can write here this is it is going to be here I can say omega is your omega n 1 plus delta.

So, for any normal frequency here omega, this is your tune frequency and plus here 1 plus delta will be defined from here. Now, I want to simplify this, I want to basically remove this L and C components, because L and C components may change and we want to remove this.

So, we can also see, your x naught means x naught is the reactance or it is a impendence, when it is a tuned one means here I can say, it is your omega n L; this will be equal to your 1 upon omega n into C, because at that time here this will be equal to this at the tuned frequency. What is this value of this x naught at that time?

Now, we can put this value here, this is R we can we can also here put this value is equal to your L by this under root L by C just put this value here, you are going to get this. Now, basically I want to replace this L and C. So, I can say here, it is your j I can say it is your just divide by here omega n, here by omega n and multiplied by omega n.

Basically, what I am going to do here is instead of this, I want to write or take it out here this is your j x naught means I want to use as I want to remove this L and C; what should be this, I want to remove this L and C, I want to write x naught and omega and omega n

(( ))

x naught by here.

(( ))

I think I have written here and this value will be, we can take first R outside or we can use in terms of quality factor also we can use in this term also. So, we can say here, it is R 1 plus j omega L by R minus 1 by omega C into R, it is better to use in terms of quality factor. The quality factor Q is defined as omega n L over R and also, it will be equal to 1 over omega n C into R.

So, here I can write this is R 1 plus j and here, I can take the Q outside, it is your omega by omega n minus omega n by omega, why I am doing this I finally, we will go for here in terms of this delta component. So, this we can write here R 1 plus j Q this will be, we can replace from here we are getting this value omega upon omega n. So, we are getting 1 plus delta and this is 1 over 1 plus delta.

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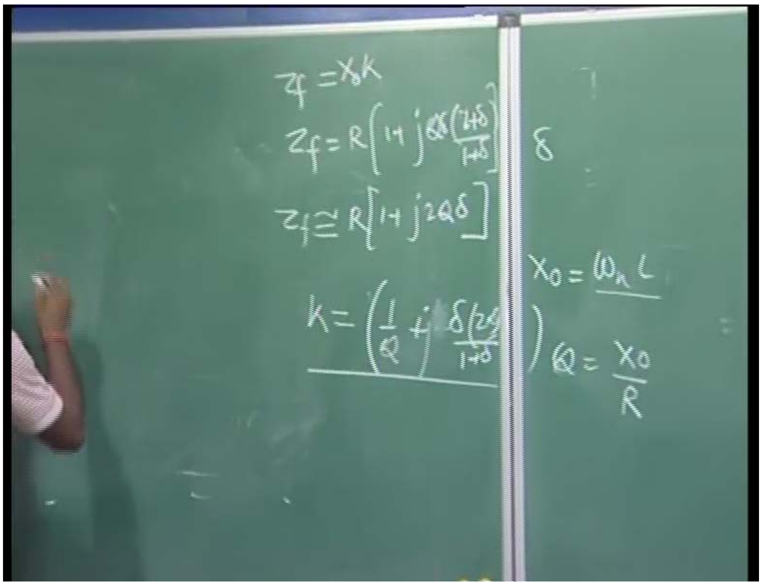

Now, since this delta value is very very small, then we can write our z f is equal to your R 1 plus j Q 2 plus delta divided by 1 plus delta, no into delta will be there (Refer Slide Time: 31:18). Or approximately, if the delta is very very small I can say delta is very very small this, then we can write this z f will be equal to your R 1 plus j 2 Q delta, Q is the quality factor.

Now, if I can write this value is equal to your x into k term, I want to write here this value here z f in this form. So, what will value of k? Because, the figure which is I am showing here it is in terms of k and here in terms of delta, this is x naught is nothing but the x naught we write here. So, we can write in the quality factor again, because this x naught here we can just write in terms of quality factor even for this example itself here.

So, tell me this is x naught into k, what will be the value of k? Can we write something here in terms of this, your x naught we can take this value in terms of again here it is we can write omega n L. But, mind it I do not want to use this L and C in this simplification I do not want this R can be there, no doubt what will be this value? Can we write something here in terms of x?

Q is x naught by R.

Q is x naught by R yeah. So, it is very simple here means here what we are going to k will be your 1 over Q plus 2 delta j term here; or we can write here this term, this is your 2 plus delta here 1 plus delta. So, here we got this k is equal to this.

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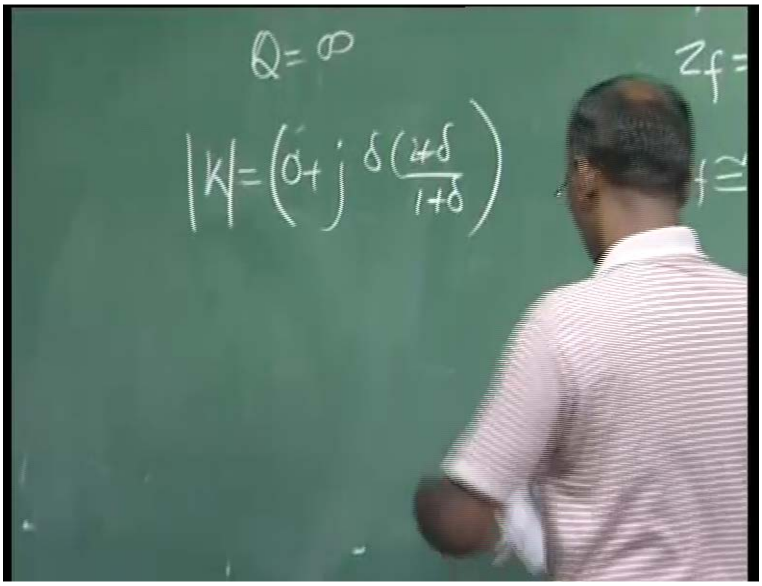

Now, you can see for the given value of your Q factors, if Q is your infinite, we are going to get this k value here it is your 0, this will be 0; and we are going to have j delta 2 plus here delta by 1 plus delta. And you can see from here, if the delta is 0 here, then k is equal to going to be 0 and this value is coming here; for other values here, if Q is not here infinite always we are adding some value here, basically this is the mod we can taking k mod here if I taking mod, so it will be going in the both sides.

So, now, you can say if Q quality factor is infinite which is not possible, then we are getting this y term; otherwise, it is shifting and some impendence some k value is appearing. So, and also you can see, this is the tuned filter the quality factor is still it is very high. So, that is why your tuned filter are shunt filters here, the quality factor is very high.

Another option here that is we can go for the double tuned filters. And double tuned filters are basically for the two frequencies. Here, I will come back here this derivation again in this double tuned filters are possibilities; let us suppose you are having one tuned filter and another tuned filter you can connect in the parallel. Then, it will be the two tuned.

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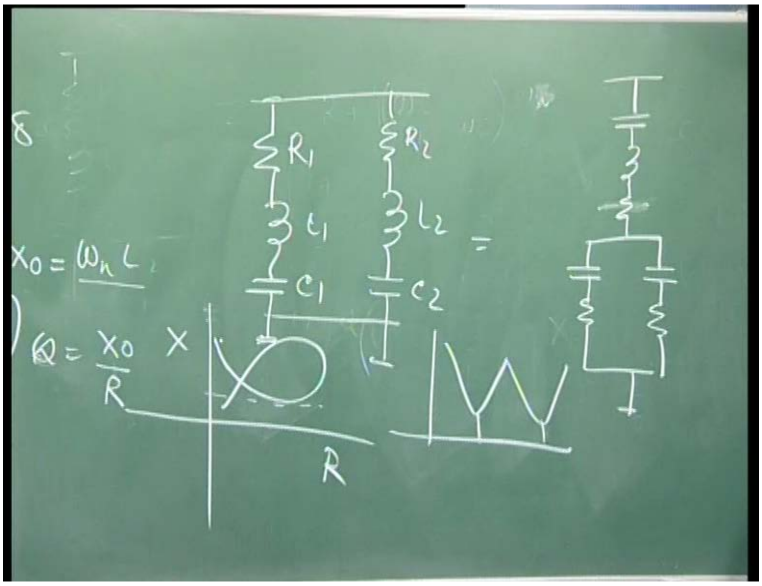

Like here, we are having your resistance, here your inductance and this is your capacitance, here ground I can say it is R 1, L 1 and C 1 this is tuned for one frequency; and if you are having another impedance here, resistance here, capacitance here I can say R 2, L 2, C if they are connected here the parallel here, then we can say it is a double tuned filter.

So, there is no special thing here, but only we are having the two big inductors together, and these inductors are very sustaining this total voltage of the supply. But, in actual double tuned filter, we can have here this is one is resistors, this is capacitor, here your inductor, here it is your resistor; and then we are having another capacitor, here resistance and here we are having another capacitance and inductance. So, this is second order here another double tuned filter.

In this case what is happening, you are using only one inductor (Refer Slide Time: 36:30), here you are using the two inductors. So, this is the single tuned true filters, here single double tuned filter are there. Basically, what happens this is more advantageous compared to here, because we are this only one inductor is sustaining the complete voltage and here also, so we are minimizing the cost; but no doubt, we are putting some capacitors and the resistors here in the circuit.

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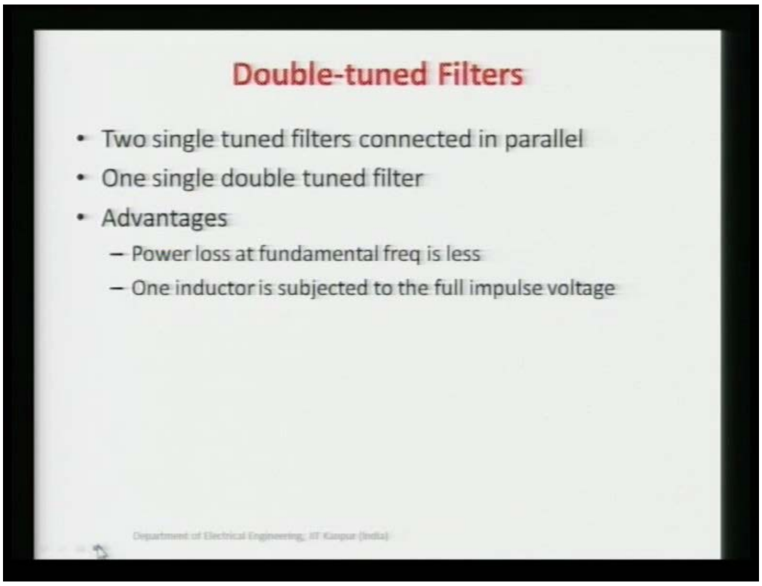

And we will see the various advantage here the two tuned filters as I said, they are connected in the parallel, so this is here. And we are having the single double tuned filters here. The major advantage here in this the loss is minimum. And also, here one inductor is subjected to your full voltage.

And the characteristics you know it is nothing but, it is you are the two tune filters here, the two frequencies it will provide the minimum path. And you see this, it is impedance diagram that is your resistance and x it is basically it is coming out together like this. You are involving here this this is your value of the minimum impedance is coming means you are getting the two impedances minimum for 2 R's are here for 1 x.

Now, this delta term why the delta we are using? The major function of this delta, because there is a possibility that there is a frequency change, and that frequency change is your operating frequency change; because this your A C system frequency may change, and there by your this this frequency tuning will also change, because you may land here or here that side, depending upon frequencies increasing or decreasing.

So, one factor here is the frequency change and another due to the change of the elements of that tuned filtered itself because, this inductance may change your capacitance may also change. Especially the inductance and capacitance changes due to the ageing or may be the due to the heating effect. This value changes no doubt the value change is very small, but is still so significant.

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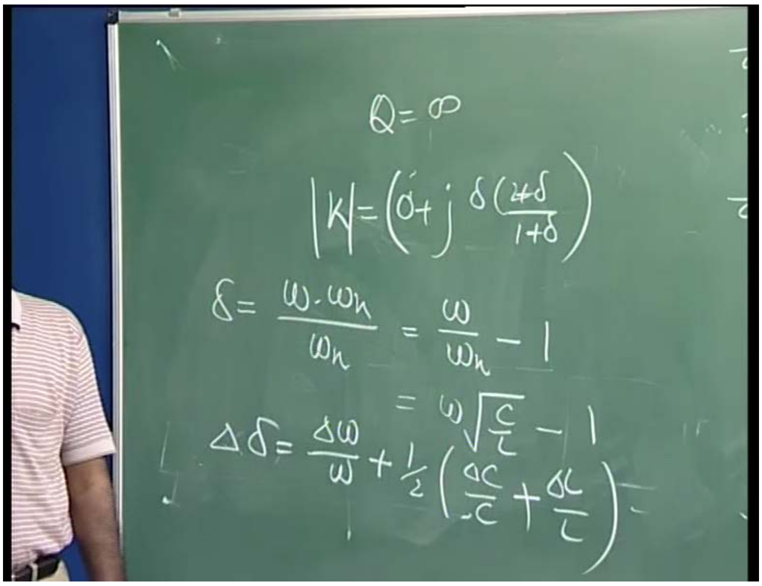

So, the changes delta is basically defined in terms of this. Now, why this is happening like 1 upon 2 and this is like here. What is your, this is the defined as your omega minus omega n divided by omega n; this is nothing but, your omega by omega n here minus 1, your this omega n here I can write this is your omega, this value is your C by L minus 1, because omega n we define here this is a root L upon C.

Now, you can use this change term, here this term is under root that is why it is coming 1 upon 2. So, you can see this is change here we can write the change in this frequency that is change in omega by omega plus this is under root 2. So, then it will be 1 by 2. If it is a square term that is a twice is coming, and then this is by 2. So, here del C upon C here term is coming negative, if you are differentiating here the partial differentiation, then it is your L upon C, but the always the error if we take as a positive rather than negative.

So, this here the derivation comes from here and you can say this is nothing but, your f upon f same. If your change in omega divided by omega is equal to change in frequency by frequency. So, this change basically delta C, here we are defining this delta and this term, so this is the change here. So, you can see, if there is some change here it is half of that change is coming into this delta, but the frequency change is directly reflecting here. That is why the frequency change is more prominent that the changing your C value or L value; and also impact is this change is so frequent that compared to this changes as well.

Now, another here we are going to just I am going to show you how it is your if this is the filter, which is giving tune for any particular harmonics component means it is providing the minimum impedance; whether it is circuit is behaving like capacitive circuit or reactive power it is providing at the fundamental frequency you know that right.

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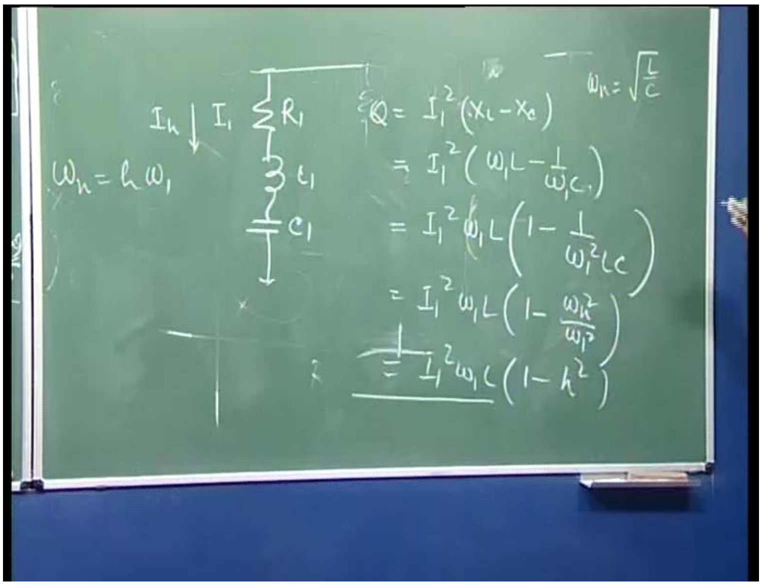

Let us, suppose the current which is flowing here it is your I this I 1 I am talking for the fundamental component and I h for which it is designed here which is flowing it is designed for that tuning. Because, it is having so many components, it is current is flowing, because it is offering the impedance for all these components I 1, I 2, I 3 whatever although it is 0, I 2, so I 5, I 7, I 11 or something all the component.

So, I want to show that this reactive power, Q is defined that your I 1 square into this your this reactance here your x L minus your x C total here x L, reactance some minus this because this because this effectively described this is your reactive power, which is total consumed are generated we have to see it.

Now, this value x L we can write here, this omega 1 is its I 1 square, here is omega L minus 1 over omega C; here I am writing 1 and 1 for the fundamental component; means that will be equal to I can say I 1 square here this I can take omega 1 outside and the even though L, this is the 1 minus here omega 1 square L into C right; and 1 upon L C here is omega n square. So, I can write here it is I 1 square omega 1 L 1 minus omega n omega 1 square. And this omega n is nothing but, it is h times omega 1.

So, I can write here it is your I 1 square omega 1 L 1 minus here this value is your, this is cancel, it is I can say h square simply. Because, this omega here n it is you are for which it is design h into omega 1. So, it is the 5 th (( )) it is a 5 times of fundamental frequency. And you can see, this value is always larger than unity, because we are designing for 5th, 7th etcetera. So, this value becomes negative, what does it mean? Means, this is the behaving as the capacity and you can see this is huge amount.

Now, you can imagine this is the 5th component, so 25 minus 1 it is a 23 times of this component. So, it is giving significant amount of reactive power support that is required to your resistor. So, this is basically we can see the shunt filters especially, not the series filters, shunt filters provide the reactive power support at the fundamental component.

However, the series you can also prove for the series filters, it is always consumed you can just even also verifying in the similar manner. So, now, another criterion that is we have to design the filter that it should be have the cost should be minimum. Normally, the costs of the filters are 5 to 10 percent of the terminal equipment. Terminal equipment I mean that we are having your converter all other are (( )) are transformer, your line smoothing reactors, protection system etcetera; the total terminal equipment it is just filters cost basically 5 to 7 percent.

Because, you know it is looking a very simple inductor, it is looking a very simple capacitor, but if you see this capacitor requires huge of this room; the inductor you see just like a bigger than a transformer, because the value you have this inductor is required for the particular harmonics 5th, 7th etcetera. And as well as if you are going for higher and higher harmonic, the size of these filters becomes more and more larger. So, why it is so? Now, you can see this is omega n we prove here your L upon C. If you are going for this larger value, you have to increase this value or you have to decrease this value; decreasing that capacitance also this is one issue, because you are (( )) series.

Here inductance, the size of inductance value is more. So, you are going for the larger and larger size of components that is L and C and the cost becomes very very high. So, that is why we go for only the lower order of harmonics, if you are operating at the six pulse convertors then we go for 5th, 7th, 11th and 13th. If you are going for your 12th convertors, then we use tuned filter are this 11 and 13. And remaining we can just either pass it to the system or sometimes we can use the band pass filter nearby that, so that you can not going to the A C.

So, in the total I want to say that, cost of the filter is one criteria and the cost is basically a related that how much reactive power it is supporting. So, the cost of the filter total cost there are some fixed cost, there are some cost related to your inductor and this see. So, we will see how we are going to get the optimal value of the minimum cost filter design, and will see that in the next lecture.

So, in the next lecture, what I will discuss? I will discuss about the cost of the tune filters and also we will see some consideration for the design of the band pass filters, then the filter aspect will be over. And then later on, we will talk about this grounding and line design, then this module will be over. So, two more lectures I will be talking in this module and then will finish it, after that we will go for the power flow and other things, thank you.