Power Quality Improvement Technique
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Lecture – 12
Passive Filter Design – II

Welcome to our NPTEL lectures on the Power Quality Improvement Technique. Today it is Passive Filter Design. It is the second lecture on it. So, please recall. So, we left it here. We have calculated the value of the capacitor and now want to find the value of the inductor.

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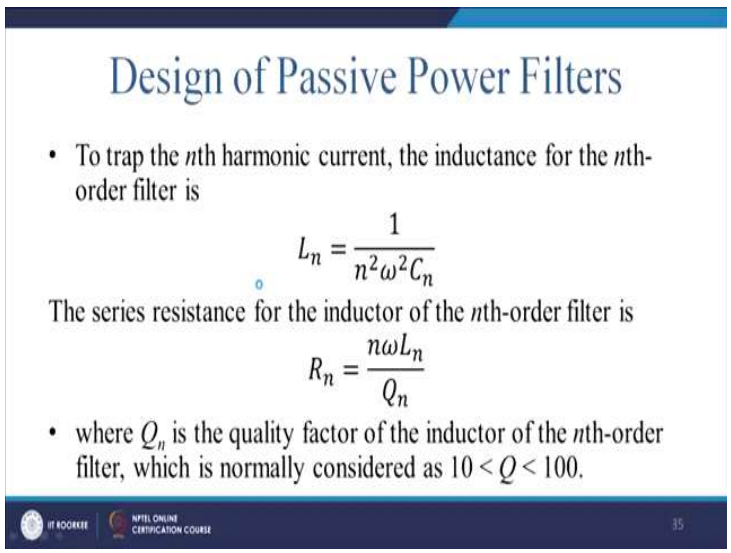

So, to trap the nth harmonic current, the inductance for nth order filter is $L_n = \frac{1}{n^2\omega^2 C_n}$. So, the series resistance of the inductor for the nth order is Rn and$R_n = \frac{n\omega L_n}{Q_n}$. So, Q is something that you will fix and you go back to the value of R and where Qn is a quality factor of the inductor of the nth filter and which is normally considered to be 10 to 100, but generally it is within 30 to 60. Now, how you design an inductor? You get the value let us say L and R.

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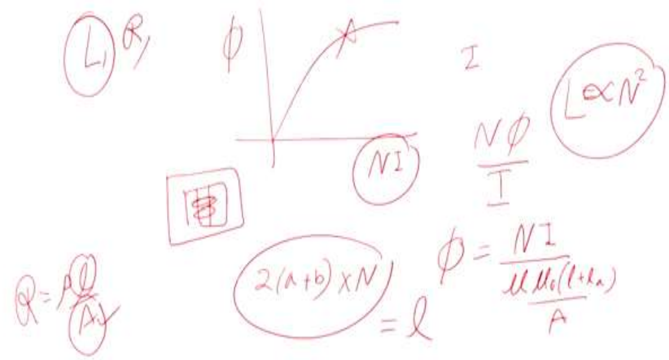

So, then there are few issues. Now inductor generally will have a rolling over effect. So, generally if you have the value of the inductor that is NI the overstate and the flux, you will find that after sometime essentially it is B vs. H graph and you would expect that it will have a saturation at this point. After saturation what happens? If you increase the value of this NI, definitely flux is not going to increase and thus the value of the inductance will decrease.

So, value of inductance will have a rolling over effect after some value of current. For this reason, we require to specify it. So, no load inductance which will measure what should be the value. Full load inductance what should be the value and generally it is able to overload it and what should be its value. Accordingly, you will choose the number of turns.

Ultimately you know that ϕ is essentially reluctance. Ultimately it is $\frac{N\phi}{I}$. So, what is ϕ? $\phi = \frac{NI}{\mu\mu_{0(l+l_a)}/_A}$, here ‘l’ is due to the air gap. So, you can see that I, I cancels out most of the cases and ultimately L depends on the geometries of it and ultimately L will be proportional to ‘N^2’ as long as ‘I’ is in linear region.

So, you know the number of turns now. From the number of turns, you have chosen a core and where you will host these wires. So, that length you know and thus it is 2(a+b). This is the periphery of this coil into number of ‘N’ gives you the length of the wire. So, then your R value is fixed that is$\rho\frac{l}{A}$. Once this ‘A’ value is fixed you have to choose the value of the ‘A’ from the AWG table and thus you get the desired resistance. In that way we will calculate the value of the resistance and sometime when there is a mismatch in between you may require to feed an external resistance to it.

Of course, you can reduce the Q factor by that. If you want to increase the Q factor then of course, you have to increase the area of the wired gauge. Now designing the second order damped filter. Generally it is required to be tuned and it should be optimally damped that mean it is very close to critically damped. We should not have a over damped entities which will make the system sluggish. The response time will be less. So, the second order damped filter.

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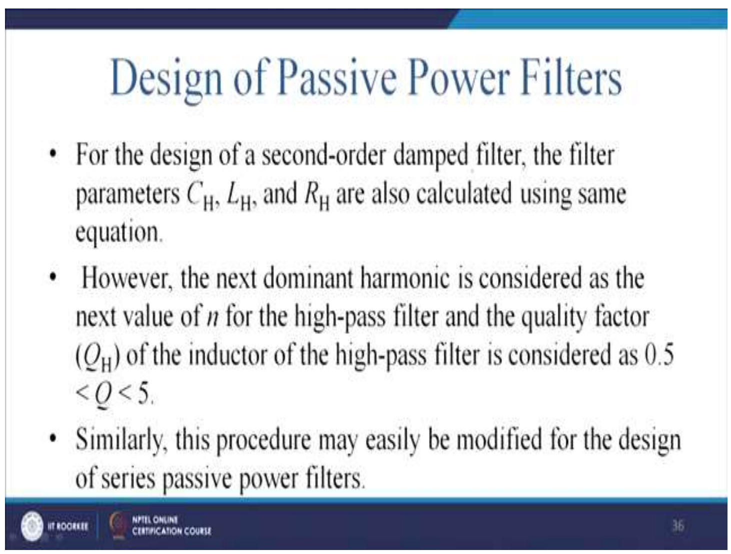

The filter parameter this C_H, L_H and R_H are also calculated by using the same equations. Now, let us comes to the next point. However, the next dominated harmonic is considered as a next value of ‘n’ for the high pass filter and its quality factor Q_H of the inductor of the high pass filter is considered between .5 to 5. So, let us switch over again. Next.

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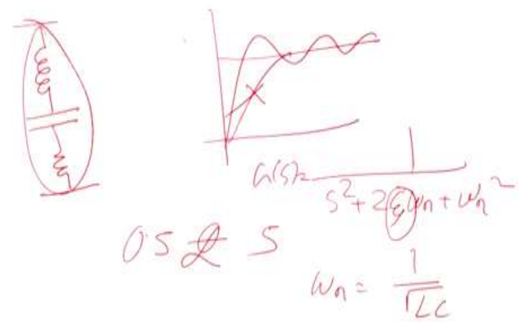

You will have a small inductor and a capacitor and a resistance. Ultimately if you have a step response and if it is a damped circuit this is the case of the under damped and this is the case of the critically damped. So, you will have these entities and for this reason you will eliminate all those higher order frequencies. You will set the cut off frequency and higher frequencies, let us say after 11, 13 and so on.

Ultimate it is a band pass filter if you look at the series, but it is connected to the shunt that automatically gives you the saving from the high frequency which is connected parallel to it and thus you require to put the value of ‘Q’ in between 0.5 to 5. And now you know that the $S^2 + 2\xi\omega_n + {\omega_n}^2$ where $\omega_n = \frac{1}{\sqrt{LC}}$.

You want a transfer function as under damped. So, there is a condition of the ‘ξ’. Generally, we require to keep the ‘ξ’ value just little above 1 and accordingly the Q factor required to be designed and having a Q factor range 0.5 to 5. So, this is the way we generally design the high pass filter. Similarly, this procedure may easily be modified to design the series passive filter. The logic will be just different. You will ultimately block it. Here you are bypassing it. There you will be blocking it.

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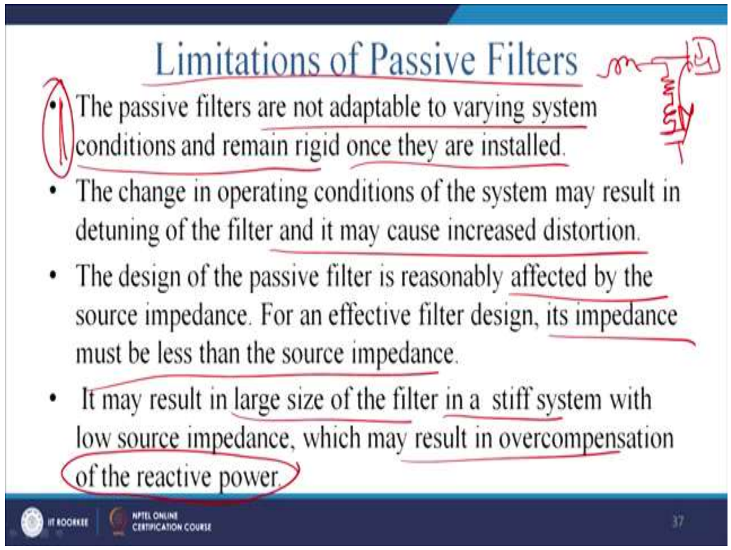

Now, let us come to the important aspect. From 1984 once Akagi proposed this active power filter solutions. We moved quite a bit up to today. This course will run in 2020. So, we have moved 36 years. So, by this time nowadays, it is a domain of totally the active power filter. This active power filter is a proven solution as well and we do not require to look back to the passive device. The cost of this passive device is also increasing because cost of the capacitors especially in India where inflations is been placed, is increasing.

Whereas by defeating inflation, because of the patent issues cost of the switch was high previously but gradually it is decreasing relatively. For this reason we are now looking after the active solution, but we cannot replace the passive filter totally and thus we have a combination of the hybrid filtering. We will discuss it in detail with the shunt active filter and what is the role of the passive filter.

So, anyway now let us discuss what is the limitations of this passive filters. So, the passive filters are not adaptable in varying system condition and remain rigid once they are installed. For example, you want to put a filter in a weak grid. We also allow the variation of the frequency as per our discussed standard within allowable range of the varying frequencies. What I am saying it is a 50 Hertz.

Nowadays due to the power grid corporation most of the problem has been solved because of the huge inertia in India. Frequencies are almost very much constant and it varies only at a very low rate of less than 0.25 Hertz from no load to the peak load. But where the deviation is quite high, there it will not function properly because we have tuned to the, 250 Hertz. If it is 2 Hertz variations automatically that will be a 10 Hertz variation to the fifth harmonic.

So, at 260 it may not work properly if you have put the sharpness quite at this point of the 250. So, it will not work and it is not flexible to the changing frequency. Thereafter changing the operating condition of the system. For example, operating condition means it may have sag, it may have a swell and thus the rating of this voltage may change and it may require to be tune properly otherwise whatever desired reactive power compensation you want, you will not get it.

Moreover, the system may result in detuning of the filter and it may cause increased distortion. That will enhance the problem instead of the mitigating the problem. The design of the passive filter is reasonably affected by the source impedance, because you are changing the source impedance. For an effective filter design, its impedance must be less than the source impedance.

Otherwise the entities will not sink into that or thus connected in a passive once, you want that and thereafter you got a source inductance. Ultimately fifth harmonic impedance should be less. Then only it will sink there otherwise it will go there. As simple as that.

It may result in large size of the filter as I told you because you want the sharpness of the resonance higher. Now value of the coil you chosen for the inductor may require to be higher in a stiff system. With low source impedance in a stiff system the source inductance is quite low which may results overcompensation of the reactive power. Ultimately you leave in a capacitive region. So, that may be one of the problems of the passive filter.

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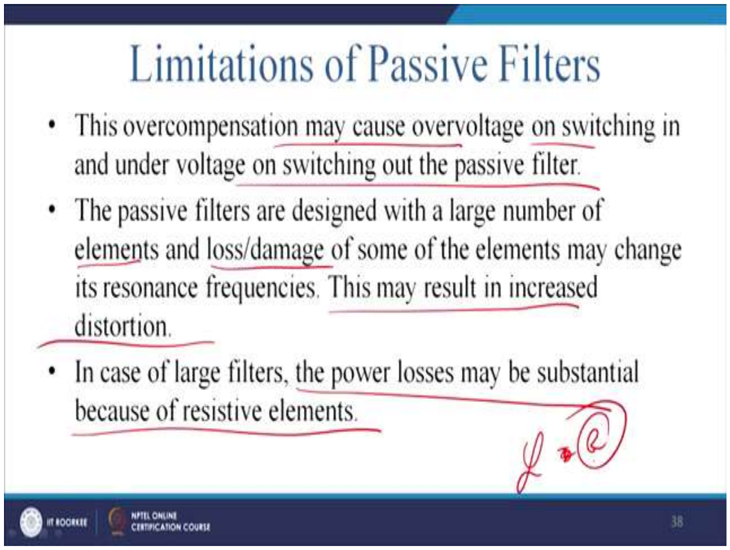

The overcompensation may cause overvoltage because once you are compensating terminating the line with the capacitive VAR the voltage will swell up. This overcompensation may cause undervoltage on switching out the passive filters. So, what happens? The overcompensation may cause overvoltage on switching on. Once you switching on this non-linear load you have to switch on this passive filter also which will jump up the voltage and once you withdraw it there will be a under voltage on switching of the passive filter.

So, voltage switching will take place, due to that overcompensation. The passive filters are designed with a large number of elements because you have seen the capacitor bank. I have shown you some pictures of the real capacitor bank placed and it occupy a huge place itself that is also a source of our good amount of real estate cost.

Think about it. If it is placed in the commercially viable place. The place will have a good amount of the real estate value. So, that has to be catered into the system other than the cost of the bill of material elements. Loss and damage of some element may change its resonance frequencies of the passive filters. That is detuning. I have not talked about it. Detune is another issue. Some of the element may change the resonance frequency and that may increase the distortion.

So, if somehow one string of the capacitor is damaged partially then the value of the capacitor will change. So, instead of the attenuating fifth harmonic it will attenuate some other frequencies. Let us say now it is been tune to 3.8. So, that again leads to the distortion of the voltage. In case of the large filters, the power loss may be substantially high because of the resistive elements. As you want some value of R to be there which will give you the losses especially in case of the series entity.

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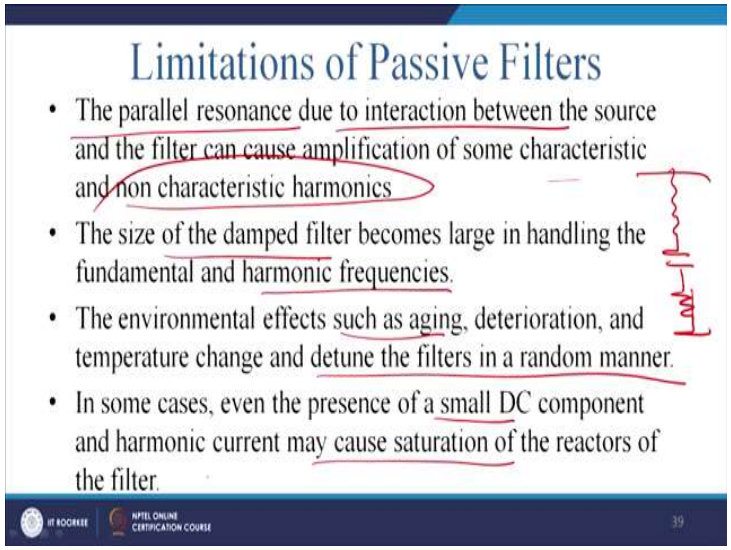

And another problem is this. The parallel resonance due to the interaction between the source and the filter can cause amplification of some characteristics of non characteristics harmonic. So, since it offers an anti-resonance. So, it will offer very high impedance to a particular frequency that may disturb the power system, which was not at all an issue in a particular case. As it will aggravate because of this parallel resonance problem.

Thereafter, another big challenge is the size of the damped filter becomes large in handling the fundamental and the harmonic frequencies. So, this is quite big issue because once you have a damped filter. Because you want that you should have L C fine thereafter you want that it to be damped. So, that takes lot of spaces because current rating has to be matched. It is not that simple one reason being ceramic resistance. So, for this reason that also is also required to be big in size for damping.

The next is the fundamental effect such as aging. This is something quite problematic because it will detune and de-rate. So, one problem will be detuned as a result instead of the fifth harmonic it will compensate some other harmonic and the value of this capacitor will also come down. So, effective compensations of the reactive power will also be less.

Due to such aging deteriorations and the temperature change and detune the filters in a random manner. So, problem lies as in the evening it will operate some frequency when temperature is less. Again in the afternoon it will operate at some other frequencies.

In some cases, even the presence of a small DC component (generally, it comes into the picture because of the triggering angle failure of the thyristors or little mismatch between the triggering angle of the thyristor) and harmonic current may cause saturation of the reactor of filters. So, inductor may saturate, the flux value will saturate and value of the inductor will degrade further. So, once current flows no change into it will be occurring. This is one of the biggest problems.

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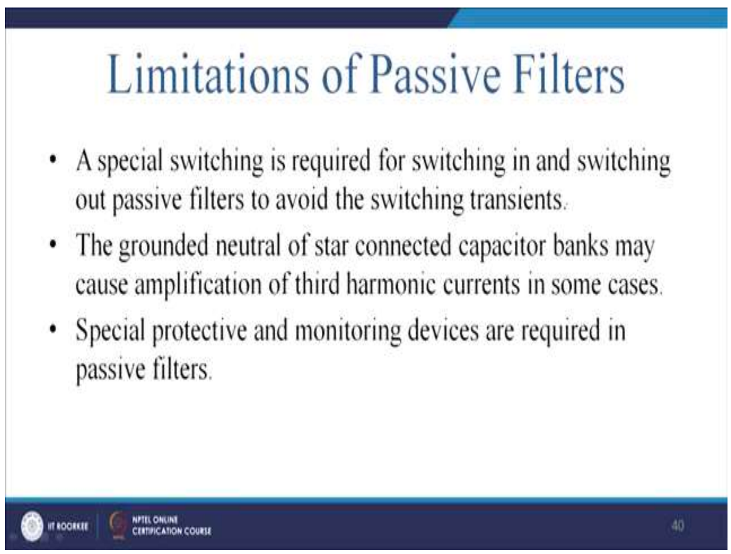

Thereafter, special switching is required for switching in and switching out passive filters to avoids the switching transient. We have discussed this in detail. We have a short of time here for this I cannot discuss here. Inserting capacitor in the facts devices. Please see those applications. Once you insert a series capacitor (SVC). So, where you can enter? If it is already that capacitor, generally you cannot always have that discharging totally.

So, you require to enter the capacitor bank when it is sinusoidally varying, when the supply voltage and the capacitor voltage matches. Also, you generally take it out because there is a problem of capacitor current and the voltage being 90-degree phase shifted. So, it is not advisable to take it out at the '0' crossing or at a peak because for one it is '0' crossing for others it is peak.

You will say that, look I will take it out in the ‘0’ crossing of the voltage which may be fine but current is at peak. So, inductor will create a problem. For this reason, what we do? We wanted to take it out or insert these filters when voltage levels are same. Then we will insert with the nominal value of the current. Not at the peak value of the current.

So, that is something we require to do. It should not be placed blindly otherwise you will have a transient and the sustain oscillation and to remove the sustain oscillation you will require to damp out. Another problem is that the grounded neutral, generally it happens in the star connected network. The grounded neutral of the star connected capacitor banks may cause amplifications of the third harmonic current in some cases and thus current will flow and third harmonic voltage will build up into the system. So, that we require to take care.

Another issue is there. Special protective and monitoring device are required because mainly this, transients and also if it is sarge affected and if it is having other problem. So, it requires to bypass the system and for this reason we require to have a protective and the monitoring relays to ensure that it is functioning properly.

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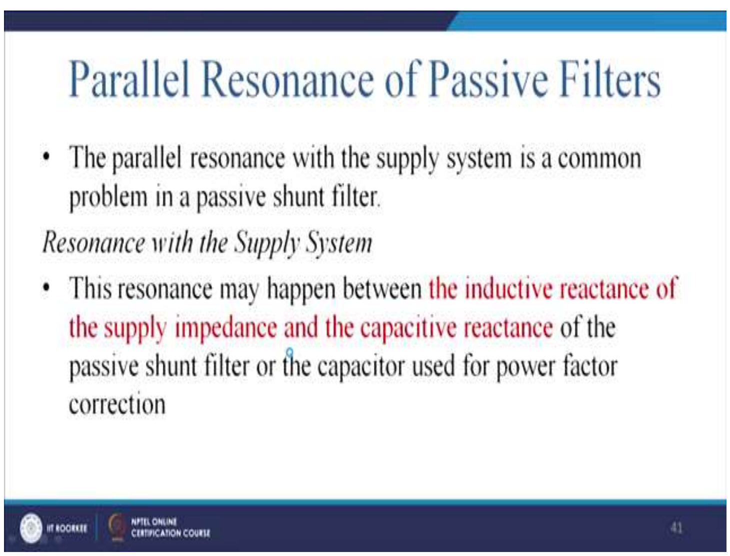

Parallel resonance with the supply system is a common problem in a passive shunt filter. So, that is the anti-resonance and thus it offers high impedance. Your admittance is minimum, then impedance will be high. So, what happened? With the resonance of the supply system this resonance may happen between the inductive reactance of the supply impedance and the capacitive reactance (sometime occurs with the leakage reactance of the transformer and the capacitor bank.

This is totally unknown phenomenon sometime) of the shunt passive filter or the capacitor used for the power factor correction. So, this is also one of the element that we will solve some problem on and I will give you this in assignments and we see that how detrimental it is.

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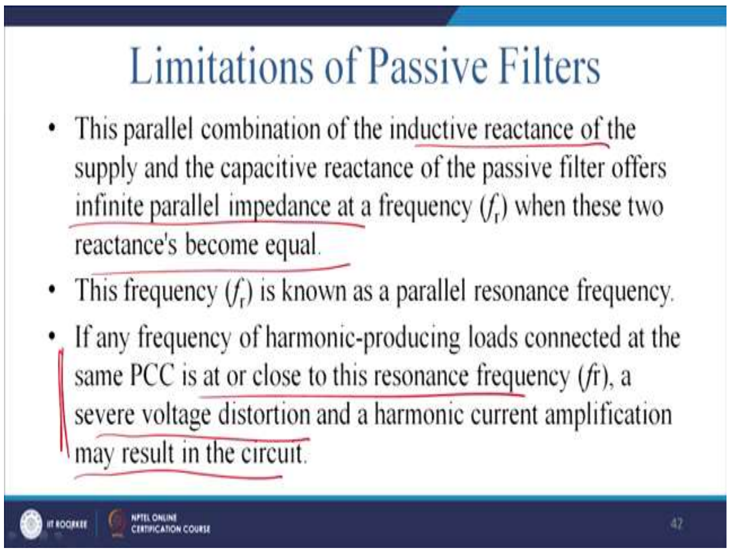

And moreover, this parallel combination of the inductive reactance of the supply and the capacitive reactance of the passive filter offers infinite parallel impedance. That is also very detrimental at the frequency f_r when this two reactance becomes equal. So, we say that this frequency f_r is known as the parallel resonance of the frequency and this behaves like open circuit corporation. You have condition. You have studied the waves in open circuits and thus it will be an open circuit for the harmonics.

So, any frequency of the harmonic producing load connected at the same PCC is at or close to the resonance frequency (if it is anti parallel resonance), a severe voltage distortion (because of the reflecting wave and that is not a fundamental at that particular frequency) and a harmonic current amplification may occur that may results malfunction of the relay sometime. So, this situation we require to avoid and we require the relay (nowadays it is mainly digital relay) to have that sensitivity to operate and monitor at this condition.

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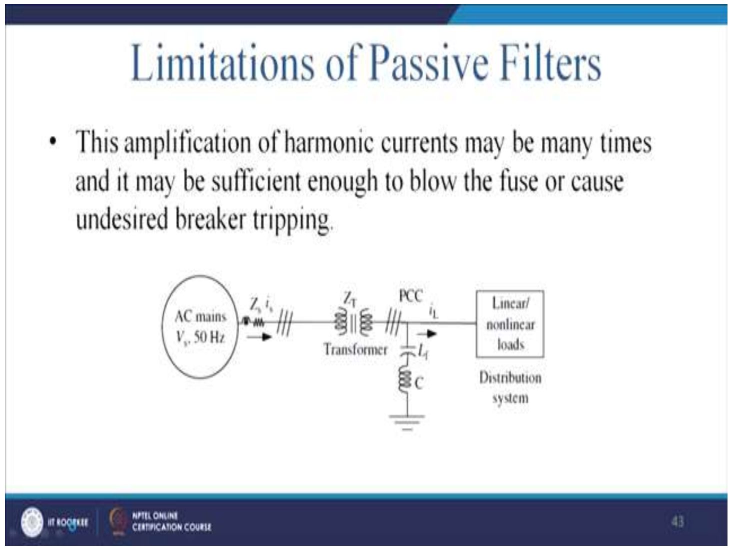

And this is one example of it. This amplification of the harmonic current may be many times and it may be sufficient enough to blow out the fuse or cause the circuit breaker to trip or relay to malfunction. This is a 50 Hertz supply thereafter the transformer, thereafter PCC. You have a non-linear load.

This leakage reactance and this capacitance may set to a resonance and due to that resonance (it is generated by the fifth harmonic) there will be amplifications of the fifth harmonic resonance and high fifth harmonic current will flow and it may cause to the malfunction of the relay.

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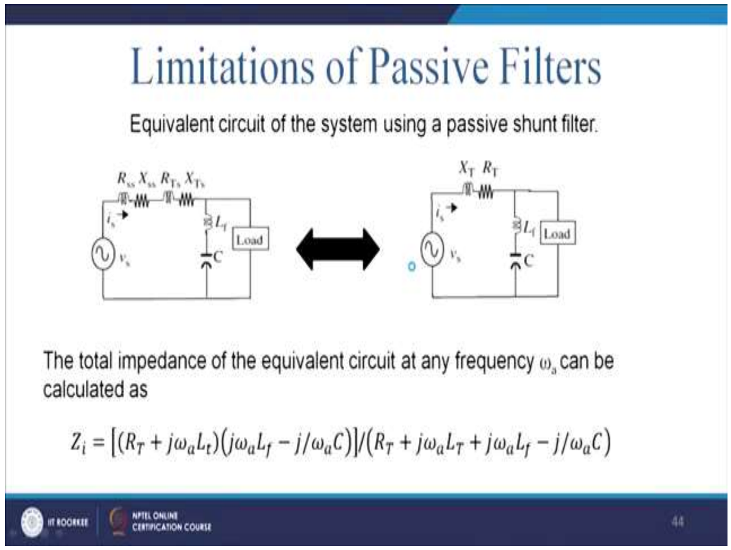

This equivalent circuits can be like this. So, you have a R_S, X_S that is a source part of it. Thereafter this is the leakage part of transformer and this is a filter and ultimately if you combine, you just neglect this part because being negligible source inductance in a steep source. So, X_T, R_T and L_f, C_f let us have and thus what happen, the total impedance of the equivalence circuit ω_a can be this and it may be at resonance for any particular frequency accidentally.

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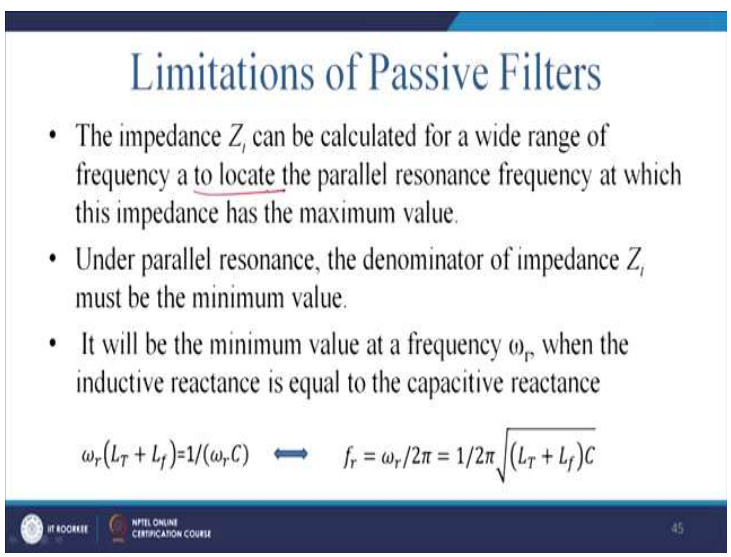

So, Z_i can be calculated for a wide range of the frequency to locate parallel resonance frequency at which this impedance has the maximum value. Under the parallel resonance, the denominator of the impedance Z_i must be the minimum value. It will be minimum value at the frequency ω_r, when the inductive reactance is equal to the capacitive reactance. So, equate it. So, you get the value of the ω_r and if ω_r is fifth harmonic then great.

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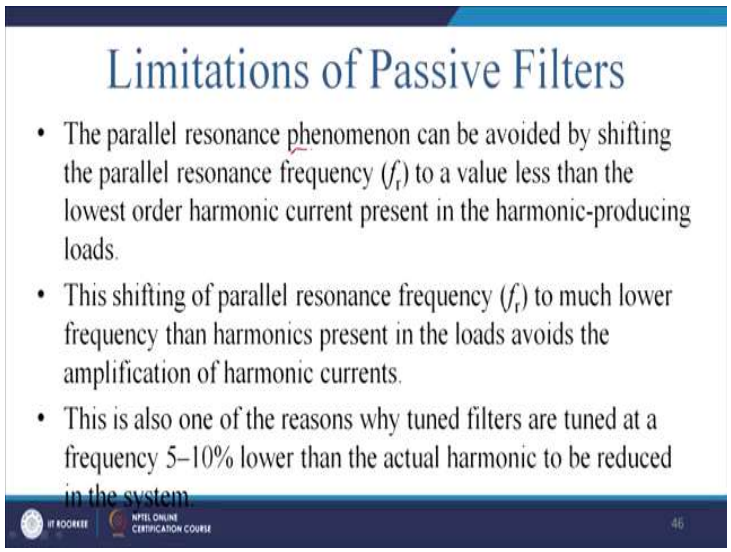

The parallel resonance phenomenon can be avoided by shifting the parallel resonance f_r to a value less than the lowest order harmonic current presents into the harmonic producing loads. So, that is the one way we require to check. So, it should not match. The shifting of parallel resonance frequency (f_r) to much lower frequency than harmonic present in the loads avoids the amplification of harmonic currents.

This is the way this problem is being truckled. So, you should not be close to the harmonic generating frequency. This is also one of the reasons why tuned filters are tuned at 5 to 10 percent lower than the actual harmonic to be reduced in the system and some effect may come from the leakage reactance, source inductance, stray capacitance. So, it will add up your value.

Thank you. This is how we proceed with the passive filter. Thank you for your attention. I shall continue the discussion with the other topic of the power quality.