Power Quality Improvement Technique

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Lecture – 10
Passive Filter – II

Welcome to our NPTEL lectures on the Power Quality Improvement Technique. We are continuing to discuss the Passive Filter. This will be your second lecture. So, we are discussing about the passive shunt filters. So, this kind of network, this RC network. We will say it is a first order system and it will give you a 20 dB decade.

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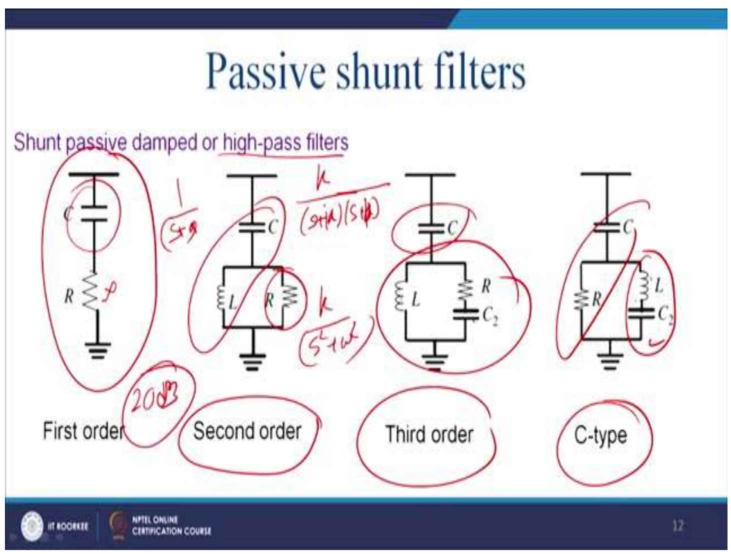

And of course, this is it's transfer function. So, ultimately you can see that, if you connect a load parallel to it, this impedance will go down with the increasing frequency and thus it is a high pass filter.

So, for this reason shunt damped or the high pass filter: it will generally eliminate the high pass filters and DC part will be there. Thereafter, it can have a second order filter. It will give you a 40 dB decay and generally you will have a transfer function of $\frac{k}{(s+a)(s+b)}$. It can have a complex conjugate also.

So, these will essentially set a 40 dB decay and this is also mostly ‘a’ and ‘b’ are same. So, it will have a complex conjugate and generally it will have $\frac{k}{(S^2+\omega^2)}$, this kind of entity if it is in an undamped quantity. Otherwise if since you have added a resistance it is a damped quantity.

So, you can expect that. So, the roots will be complex conjugate also, but you can split it like this. Roots will not be same. So, this will give you the 40 dB decay of this high pass filter. So, it will have a very sharp decay and this is the third order filter. So, you got a L and C, this combination will give you a 40 dB decade and with that this will be another 20 dB. So, total will be the 60 dB decay.

And this is the C type filter. This is a special kind of filter. Here you can see the L and C. You can go back. We have talked about the L and C filter for the single tune. So, this part is essentially the single tuned filter. It has been tuned to a particular frequency and this is essentially this. So, it is a combination of this high pass and a particularly tuned filter.

So, this type of filters is said to be the C type filter. You want to eliminate switching frequency and for that this filter. Apart from that you want to eliminate 5th harmonic. So, due to that this will have this L and C, then this kind of combination is said to be the C type filters.

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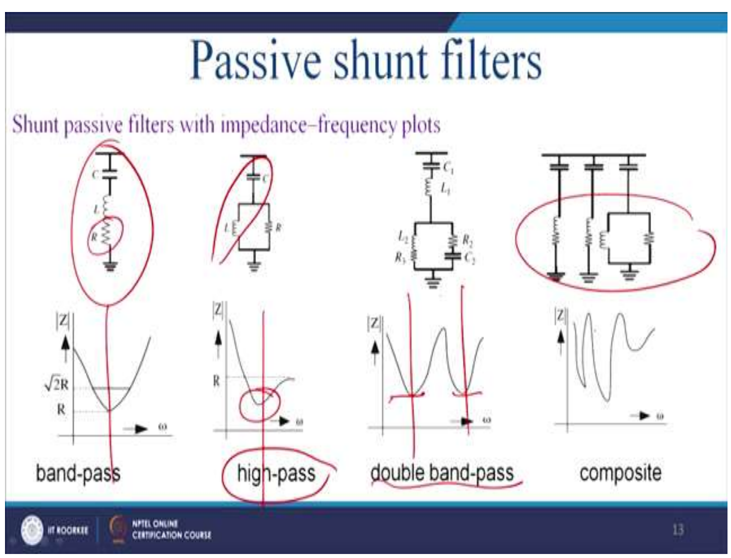

Let us see how it will behave. So, you have the band pass filter and ultimately this will sink to this particular 'ω' and it will give you the anti resonance. So, particular value of the 'ω' and you required to damp it properly. Otherwise there will be a very sharp anti resonance.

Similarly, you can have a high pass filter with this combination and thus response will be like this. So, first of all there will be notches. So, this is an impedance, so admittance will be maximum at that point and thereafter it will reach there and this is a doubled band pass filter.

So, you will have the maximum admittance here and minimum admittance on opposite position. So, it is a minimum impedance and this is a minimum impedance and when we got a minimum impedance, so it will be a sink to the 5th harmonic or 7th harmonic. So, you can eliminate both.

And you can have a composite, so you have this and this. Thereafter, this then you can eliminate any other frequencies like this. This will be a zigzag line. Passive series filters are connected in series. Now let us talk about the series passive filters.

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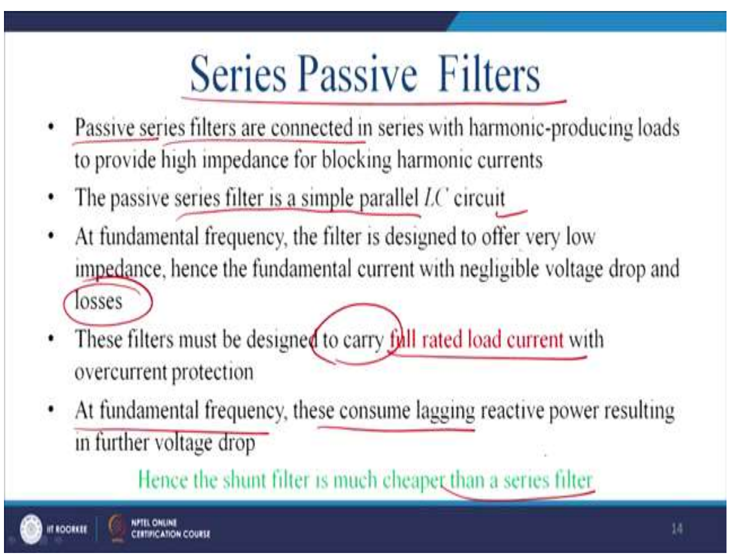

We generally prefer the shunt passive filters because of the anti resonance and you by pass this. You provide the sink for the high frequency. So, just reverse is required to do in case of the series passive filter. Let us see. Also, there is a problem of the transient because you can have a series resonance. So, that will increase the value of the current.

The passive series filters are connected in series with the harmonic producing load to provide high impedance for blocking harmony currents. So, it will not allow 5th harmonic to flow into the grid. The passive series filter is a simple parallel LC circuit. It is quite easy. At fundamental frequency, the filter is designed to offer very low impedance, hence the fundamental current with negligible voltage drop and the losses are also negligible.

But problem lies since it is in series. It sieges a whole current through it. So, it will see the full rating of the current and that is what it is. So, this filter must be designed to carry full rated current with the over current protection. So, this is one of the major drawbacks of the series filters. Its rating required to be higher. At fundamental frequency this consumes lagging reactive power resulting further drop into the system. For this reason, you do not use it. Hence that shunt filter is much cheaper than the series filter and it has this demerit.

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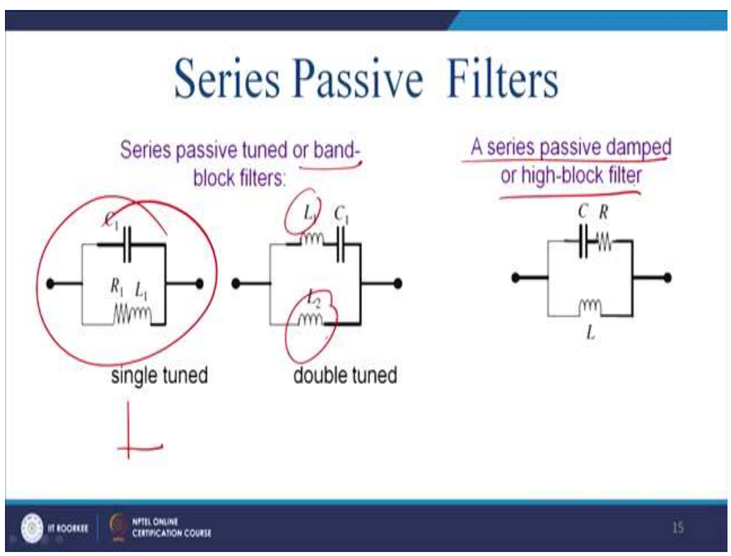

So, this is one example. You refer to the facts devices also. So, TCSC and all those devices, series compensation devices. It is an extension of the serious passive filter. So, series passive filter tuned or band block filter, this is C_1 and this is R and L_1, this is L_1 and C_1 and this is single tuned, it can block 5th harmonic. It can block 5th and 7th harmonic. And this is a series passive damped high block filter. It will allow this low frequency to pass, but will block the high frequency. That is the way it should operate.

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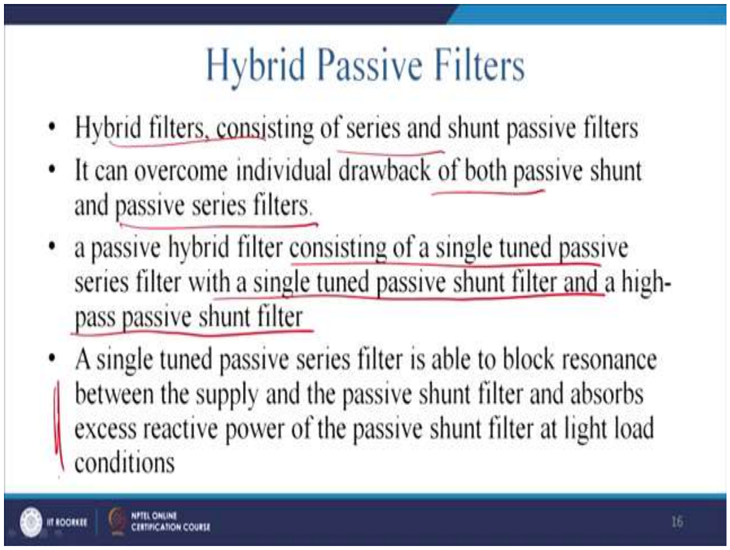

Now, you can have a hybrid passive filter. Of course, you can have a combination of it. Sometime T filter, pi filters. These are the topologies we are very frequently use. So, hybrid filters, consisting of series and shunt passive filters. It can overcome individual drawback of both passive shunt and the passive series filters.

Passive filter's rating is less, but there is a problem of the anti resonance and in case of the series filter, it sieges the total rating and the cost is high. The passive hybrid filter consisting of a single tuned passive series and a single tuned passive shunt and a high pass passive shunt filter. So, these permutations and combinations are possible in it. So, you can have many combinations.

So, single tuned passive series filter is able to block resonance between the supply and the passive shunt filters and absorbs excess reactive power of the passive shunt filter at light load conditions. So, this is the demerit of the shunt filter that can be eliminated by the combination of the shunt and the series filter.

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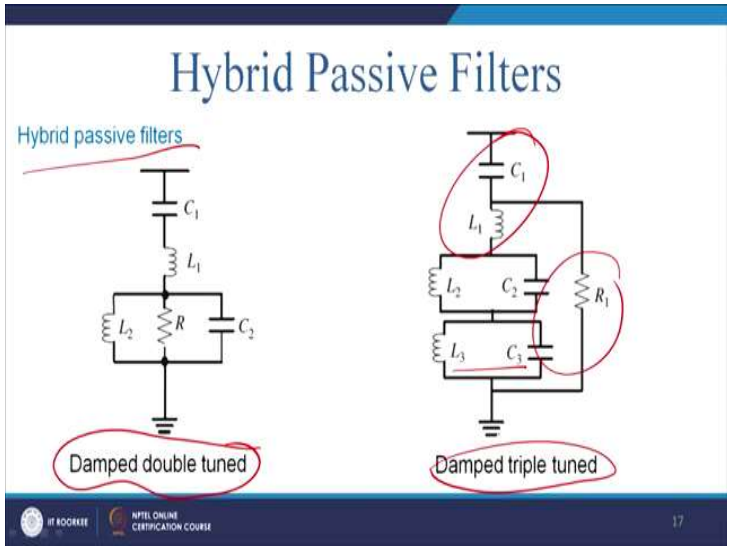

So, this is the combination of the hybrid passive filters. So, you can have a series filter with that you can have a shunt filter and this is double tuned. Similarly, you can put it like this L_1, C_1, this will give you combinations of this one. L_2, C_2 will give you some combination, L_3, C_3 and thereafter you can have a RC network which will bypass the switching mainly. So, those kinds of combinations are possible here.

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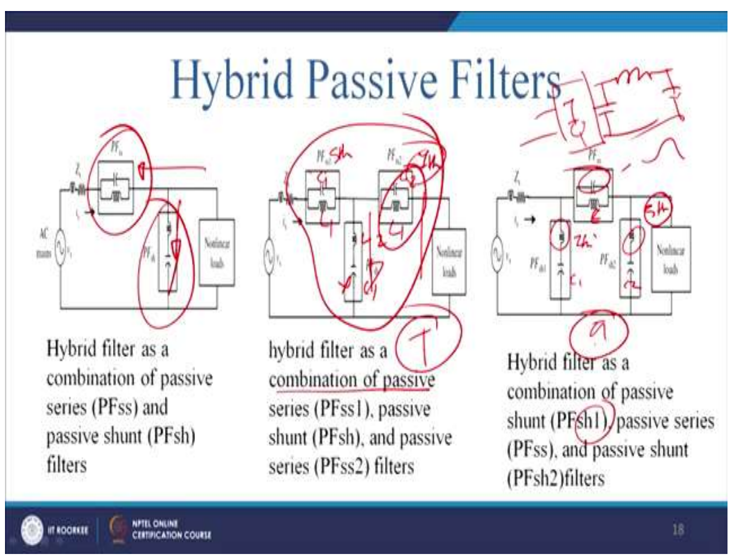

So, this is one of the combinations I am showing you. The hybrid filter as a combination of the passive series and passive shunt. So, this one is a passive series and this one is a passive shunt. You have a non-linear load. So, it will block maybe the 5th harmonic.

So, 5th harmonic will not be able to pass on this direction and it will provide the path for the 5th harmonic to sink, ultimately 5th harmonic will be drastically reduced. Hybrid filter as a combination of the passive series (PFss1), passive shunt (PFsh) and the passive series (PFss2) filters. So, this is called the T network. So, that is what I was saying. This network is called the T network and there is also an advantage of it. So, this L_1 and this L_1 and this C_1 forms a network and this C_1, this C_2 and this L_2 forms another network.

So, ultimately this L_1, L_2 and C_1 can be combined to eliminate a particular harmonic. This itself can be tuned to eliminate a particular harmonic and this can block a particular harmonic. This also blocks a particular harmonic and this combination can allow to sink a particular harmonic. So, these has enough capabilities. So, inside it this can provide high impedance, let us say the 7th harmonic. This can provide the high impedance for the 5th harmonic individually and moreover these combinations can allow this L_1, L_2 and C_1 to be a sink for the 5th harmonic. Same way C_1, C_2 and L_2 can be a sink for the 7th harmonic.

So, you are not allowing the 7th harmonic to pass through it and whatever you are getting will be trapped here. So, in that way you can improve your power quality problem. Same way this is called pi network. We are using the pi network from the rectifications of the circuits because in your diode bridge rectifier you put these two kinds of capacitors and in between there is an inductor. So, it is not new for you, previously as well you have dealt with diode bridge rectifier. You are studying this circuit form may be basic level of engineering.

So, here also the same thing. So, this network is called the pi-network this network is called the T-network. The hybrid filter is a combination of the passive shunt (PFsh1) and the passive series (PFss) and the passive shunt (PFsh2) filters. So, same way you have this C_1, C_2 and this L. It can eliminate a particular frequency and same way this L, this L and C will also behave as a band pass, low pass and many combinations is possible also.

Here, we generally prefer this network over this because you can provide let us say this is a sink for the 5th harmonic and it is little bit of band pass filter so, you actually provide high impedance to the both 5th and 7th harmonic. And here you provide sink to the 7th harmonic, but here you have trapped the 7th harmonic, but it is not getting a path to flow. Here you have provided the drainage for the 5th harmonic.

So, and also if you see the component count, here component count is less. So, any way it has its own advantage and disadvantage. We can go into the detail when you will design this for a particular problem.

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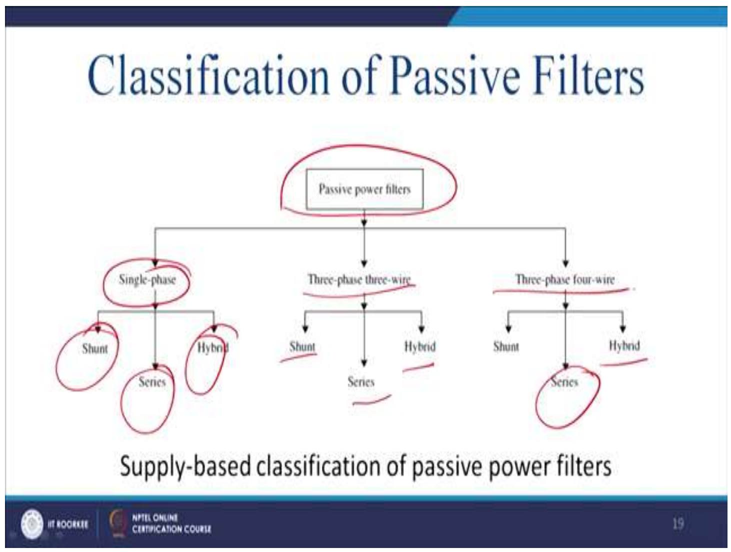

Now, based on our discussion, passive power filters can be based on the phases. You can have a single phase, that is put into the distribution system and a shunt, series and the hybrid. And you can have in a transmission system mainly in HVDC line and others that is for the three phase three wire system and you can have a shunt also series and hybrid similarly and you can have a three phase four wire system in 440-volt line.

So, you can have a shunt. That is connected in between the or line to the neutral. All the combination we will see. Series its fine because it will be in the line, but hybrid we can see the combination. We can put it between two lines also you can put with the line to the neutral.

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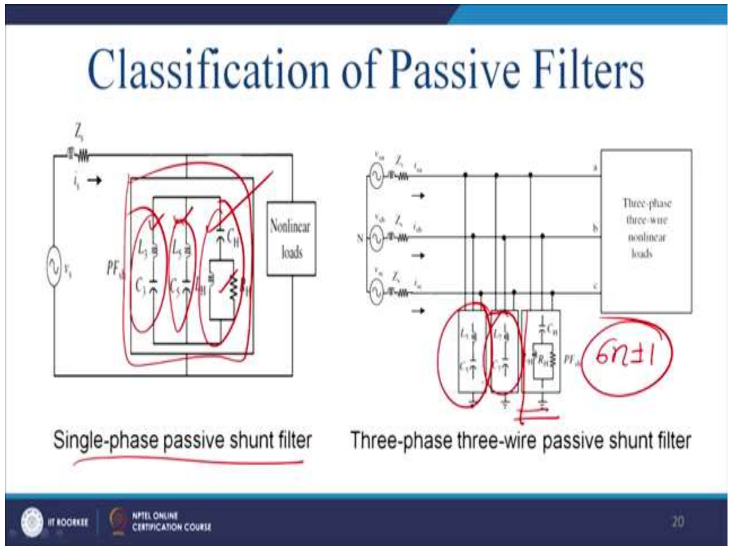

Now, this is one of the examples of the single-phase passive shunt filter. So, here this is your source impedance and you can see that. This is the block. Inside it you have put that filter. This has been tuned to the particular harmonic. This has been tuned to the particular harmonic and this is a combination of harmonic. We already discussed this. 5th, 7th there after all the higher order harmonic can sink into the system. So, this is the way of doing it. So, you will have a 3rd harmonic.

So, for this reason this filter has to be the sinking path for the 3rd harmonic. This is a filtering path for the 5th harmonic and all the higher order harmonic above 5th will be sinking through this high pass filter because it will sink all the hyper frequencies. Same way, since it is a three phase three wire system you have a harmonic content is $(6n \pm 1)$. That is your first. Thereafter, 5th, 7th, 11th, 13th. So, for this reason, it is in a star combination.

So, it is connected in between three lines and it will be tuned to the 5th harmonic. Same way, this will be tune to the 7th harmonic and all the other harmonics will be eliminated by this filter above 7th harmonic.

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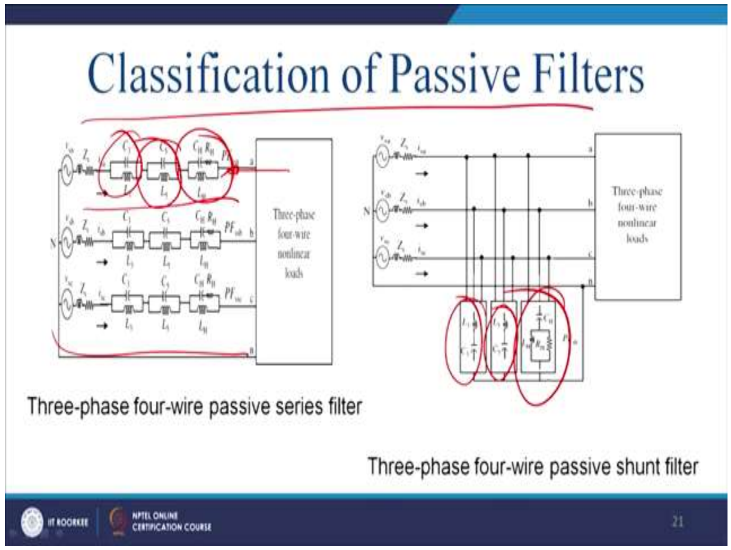

Similarly, we can have classifications of the passive filters based on the series network also. This can eliminate third because it is producing the harmonic source. So, it will not be able to flow here and this will have a 5^{th}. This will have all the high frequencies.

So, only fundamental current will flow and others will generate it and similarly this one for the other phases and this one will have a neutral aspect of it. This is the way of connecting three phase four wire system with the passive. You see the component count and thus will appreciate the shunt active power filter. So, you require huge number of components.

Similarly, we can do it with the passive filter. So, you have, this is the 3rd harmonic, thereafter this is 5th harmonic. This is the combinations of all the higher order harmonic and that is the feeding.

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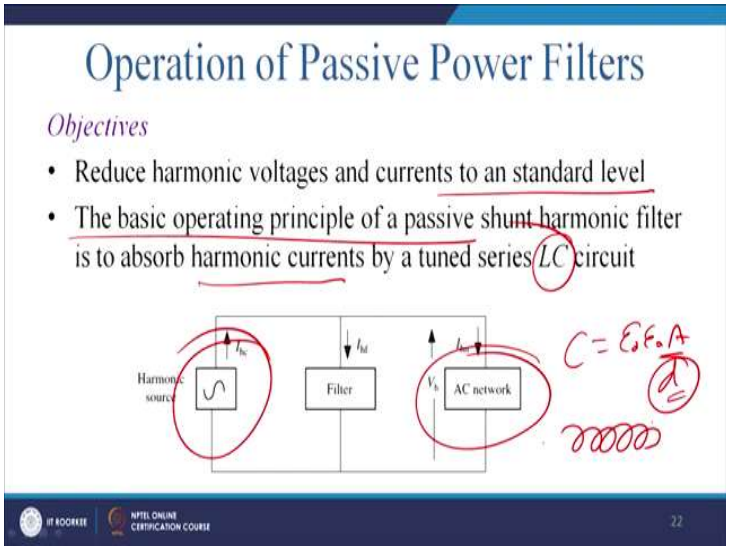

So, this will provide the path for sinkage for the higher harmonic. Now, objective: the operation of the passive filters. How it is been done? you have some harmonic sources and thus it will sink the harmonic here and you have an AC network that will be free from the harmonic. That is the way it has been designed.

So, reduction of the harmonic voltages and current to a standard level. The basic operating principle of the passive shunt harmonic filter is to absorb harmonic currents by a tuned LC circuit. That is the way we do it. But problem of the LC filter is derating. We have not come into the discussion this derating. The value of the capacitor will gradually reduce since $C = \frac{\varepsilon_0 \varepsilon_r A}{d}$. What happens you know; you got a dielectric in between and gradually the dielectric strength will start decaying because 'd' is in micrometers in other words it is very thin and also inductor, it depends on the rating of the current.

These wires are varnished. So, even varnished still if you keep it into the raw weather, that is what it is subjected to be, this varnish will go out. And thus, what happens? It will de-rate and the value which your designing, after sometime you will find that it is not able to mitigate that particularly tuned and if the sharpness is very high, then it will fail to operate properly.

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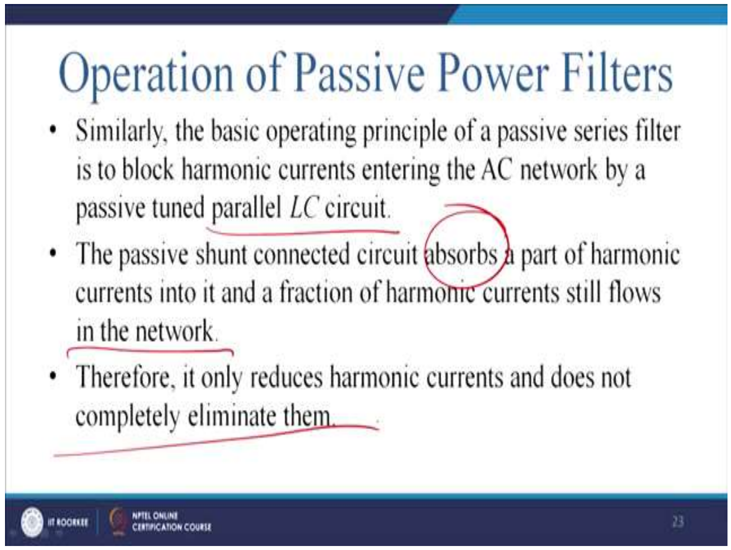

So, similarly the basic operating principle of a passive filters is to block harmonic currents entering to a AC network by a passive tuned parallel LC filter. The passive shunt connected circuit absorbs a part of harmonic currents into it and a fraction of harmonic currents still flows into the network.

And therefore, it only reduces harmonic currents and does not completely eliminate them but we have read the standard of the power quality. We do not say that we require to eliminate them. It is acceptable up to some level after that it is dangerous.

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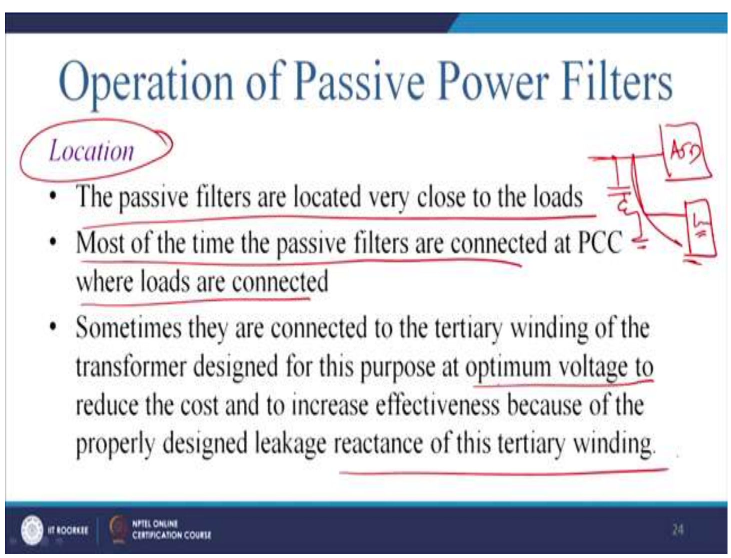

So, if you can keep below it, you can work with it and also this is something very important the location or placing of the passive filter. Where you will place? That nowadays done by the harmonic load flow study and you have a saddle point of the particular harmonic in a system, because we have considered a one-line system practically it is not so. It is a multi-bus system and you required to run the load flow study.

From the load flow study, you required to find the saddle point where the strength of the 5th harmonic is maximum in a particular bus and in that bus, you will connect the particular filter. So, in that case we are assuming that it is only a single bus system. The passive filters are located very close to the loads that has to be something we require to say. We have to put it. We have to trap them very close to its origin. You should not allow it to propagate. Otherwise a lot of interference will come.

For example, you have an adjustable speed drive and parallel to it, there is another load and if you connect a passive filter here. This is ASD and this is the linear load maybe a motor without a switching frequency. Then what happens? This 5th harmonic, which is sinking here will also flow. So, it will interact with this linear load.

So, for this reason we say that most of the time passive filters are connected at the point of common coupling. We will discuss it in details in case of the shunt active power filter, where loads are connected and sometimes they are connected to the tertiary winding of the transformer designed for this purpose at optimum voltage to reduce the cost and to increase the effectiveness because of the properly designed leakage reactance of this tertiary winding. That we will see. That we do not want the inductance in the transformer. That will be lossy one.

If we see that there is a sufficient value of the inductance in a transformer, it is due to the leakage of the flux and that we do not want. A good designed transformer should have a very low leakage reactance. And for this reason, we want another winding that will be a tertiary winding with the high leakage inductance and with that the capacitor will be connected and its rating will be low also. In that way we can give you a solution.

Anyway, we shall continue this discussion in our next class from this. That is the location of the transformer, location of the placing of the transformer of the tertiary winding along with these passive filters. Thank you for your attention. I shall continue this discussion of the passive filter in the next class as well.