

Power Quality
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Lecture - 17
Passive Power Filters

Welcome to the course on Power Quality. We will cover today the topic on Passive Power Filter.

In last lecture we covered the non-linear loads and the problems they cause, including increased rms current, increased losses, low system efficiency, and poor power factor.



It causes derating of the distribution system, distortion in voltage waveform at PCC and interference to communication system.

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INTRODUCTION

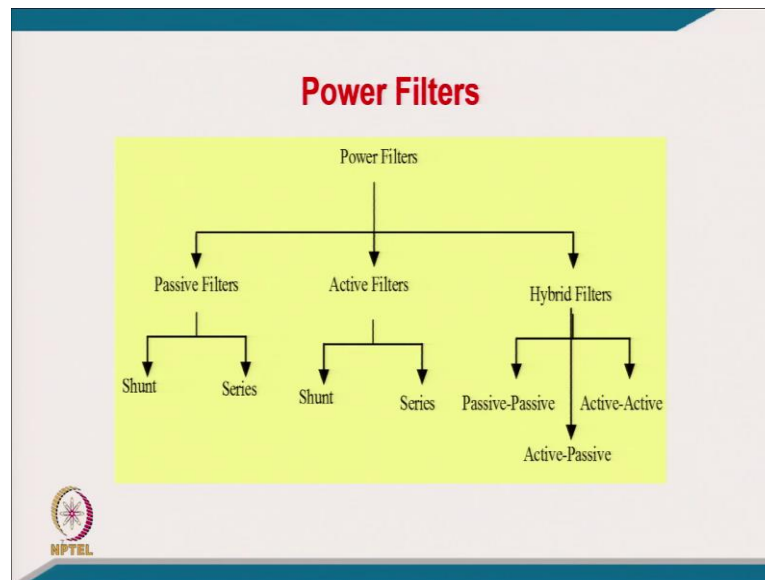
•Solution are

- ✓Traditionally **power passive filters (PPF)**
- ✓Active Shunt Filter
- ✓Active Series Filter
- ✓Hybrid Power Filter



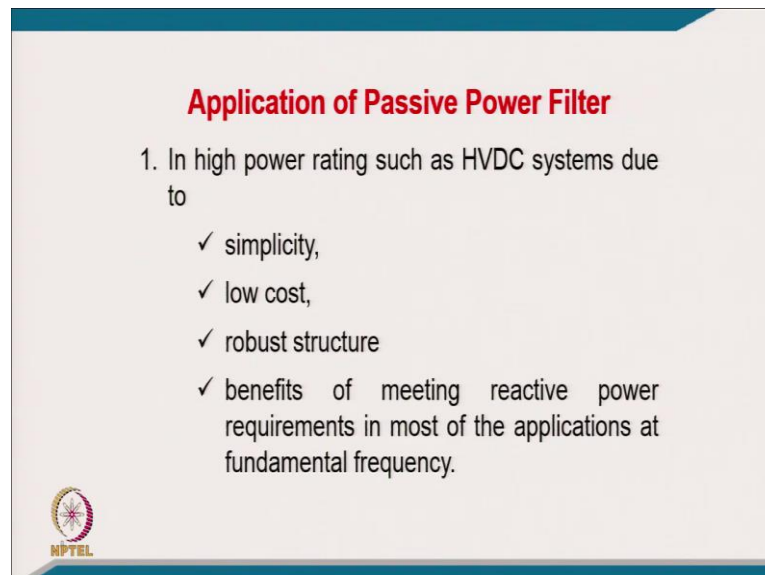
And the solution of course, for these problems which are caused by non-linear load in the distribution system are use of passive power filters, active shunt filter, active series filter and hybrid power filter.

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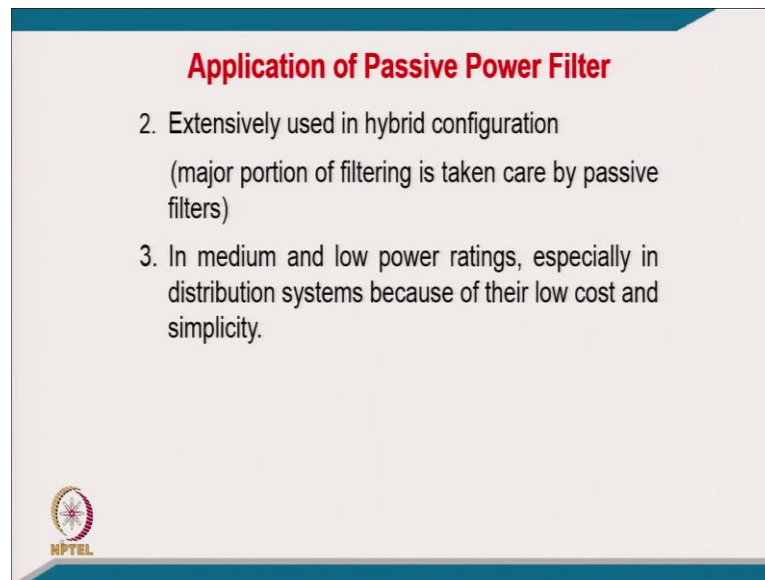
This is the broad classification of the power filter which are used for mitigating the power quality problem in the distribution system or even part of the transmission system like HVDC or other kind of converter where you have a power quality problems caused by harmonics generated by the different converters and non-linear load line.

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Passive power filter are used in high power rating such as HVDC, due to its simplicity, low cost, robust structure and benefits of meeting reactive power requirements at fundamental frequency in most of the applications.

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Application of Passive Power Filter

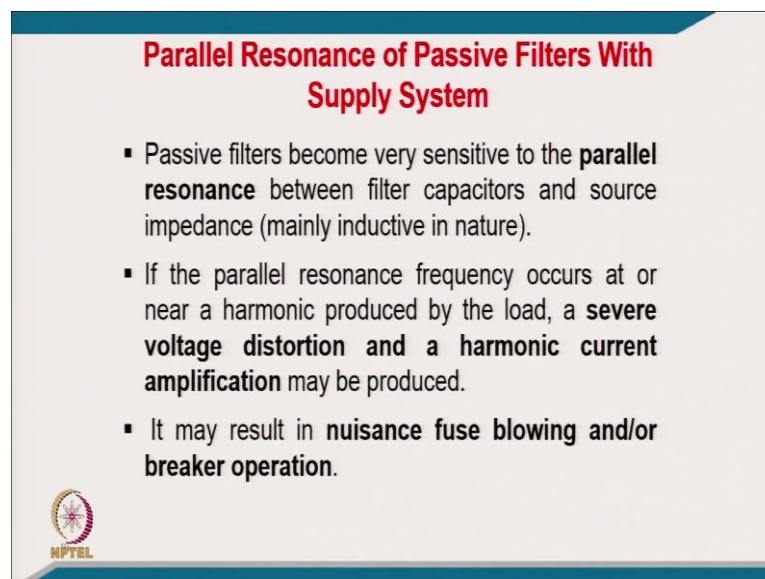
2. Extensively used in hybrid configuration
(major portion of filtering is taken care by passive filters)
3. In medium and low power ratings, especially in distribution systems because of their low cost and simplicity.



Passive power filters are extensively used in hybrid configuration. Major portion of filtering is taken up by passive filters. Hybridization may be using additional active shunt or active series filter.


These are especially used in medium and low power rating distribution system because of their low cost and simplicity.

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Parallel Resonance of Passive Filters With Supply System

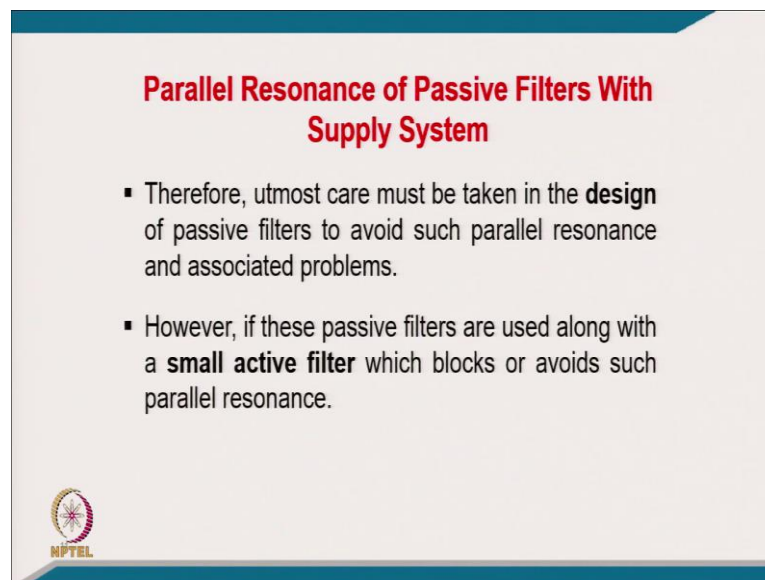
- Passive filters become very sensitive to the **parallel resonance** between filter capacitors and source impedance (mainly inductive in nature).
- If the parallel resonance frequency occurs at or near a harmonic produced by the load, a **severe voltage distortion and a harmonic current amplification** may be produced.
- It may result in **nuisance fuse blowing and/or breaker operation**.



One of the major problem with passive power filters is the parallel resonance with the supply system. The passive filters are very sensitive to the parallel resonance between


the capacitors of passive filter and the source impedance which is highly inductive in nature. And if the parallel resonance frequency occurs at or near a harmonic produced by the load, a severe voltage distortion and harmonic current amplification may be produced and it may result in nuisance fuse blowing and or breaker operation.

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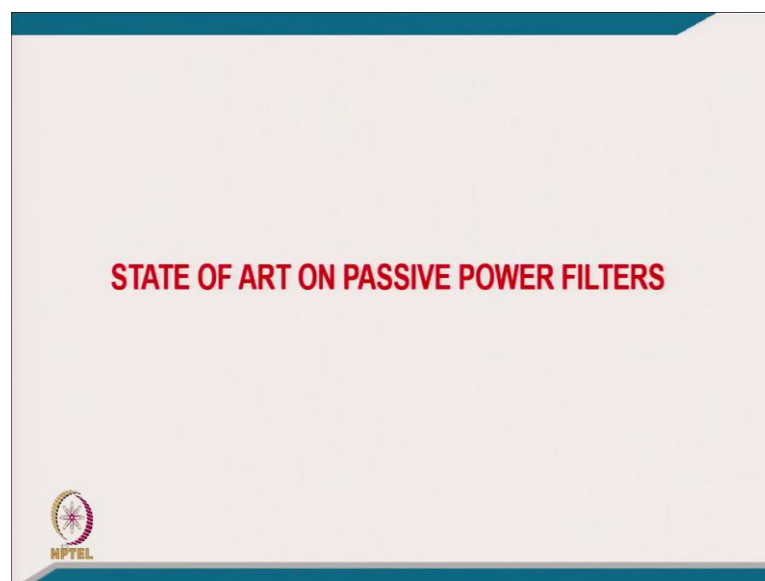
Parallel Resonance of Passive Filters With Supply System

- Therefore, utmost care must be taken in the **design** of passive filters to avoid such parallel resonance and associated problems.
- However, if these passive filters are used along with a **small active filter** which blocks or avoids such parallel resonance.




Therefore, utmost care must be taken in the design of passive filters to avoid such as parallel resonance and associated problems.

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STATE OF ART ON PASSIVE POWER FILTERS



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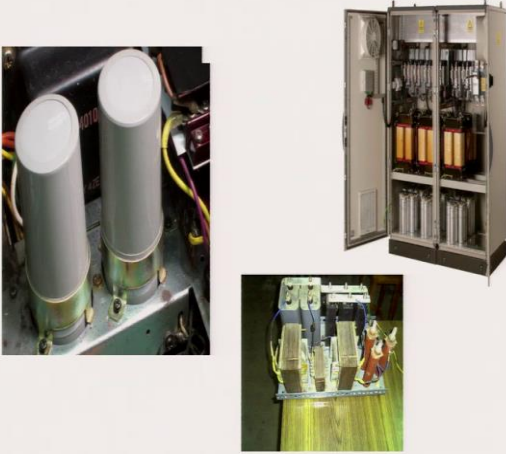
- **Shunt passive filters have been considered more appropriate**
 - ✓ to mitigate the harmonics currents and
 - ✓ partially to meet reactive power requirement of these loads and
 - ✓ to relieve ac network from this problem especially current fed types of nonlinear loads.
- In voltage fed types of loads, passive series filters are considered better for blocking of harmonics currents.



Shunt passive filter have been consider more appropriate to mitigate the harmonic currents and meet the reactive power requirement of loads. In voltage fed type of load passive series filter are considered better for blocking the harmonic.

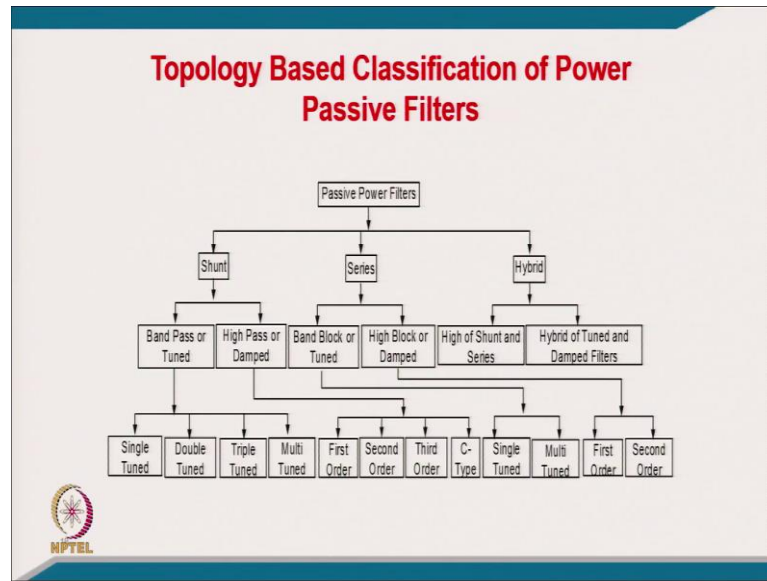
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Power filter



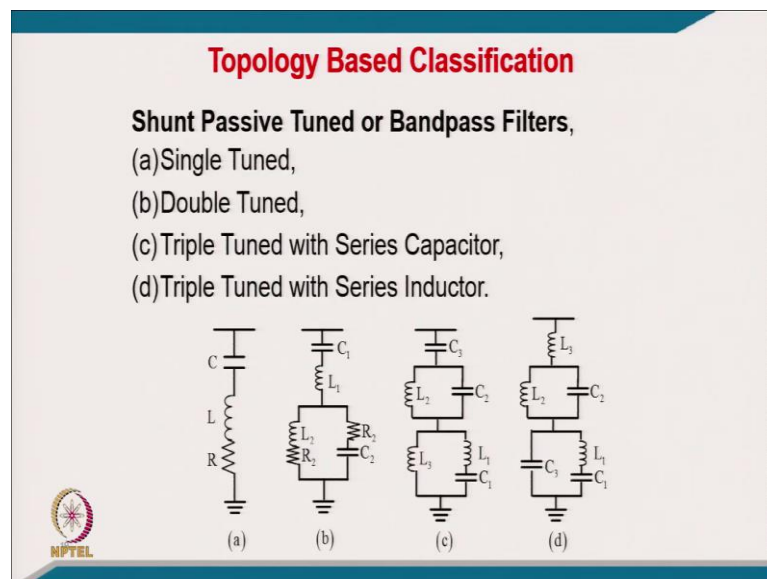
Passive power filters consist of AC capacitors and inductors.

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A broad classification of passive power filter is provided here.

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Well coming to each individual category, let us first discuss about shunt passive tuned or band pass filter. It can be like a single tuned, double tuned, triple tuned with series capacitor or triple tuned with a series inductor.

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Topology Based Classification

Series Passive Tuned or Bandstop Filters,

(a) Single Tuned,
(b) Double Tuned Bandpass and Bandstop Filter.

(a) (b)

Coming to series passive tuned or bandstop filter. It can be also single tuned or double tuned.

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Topology Based Classification

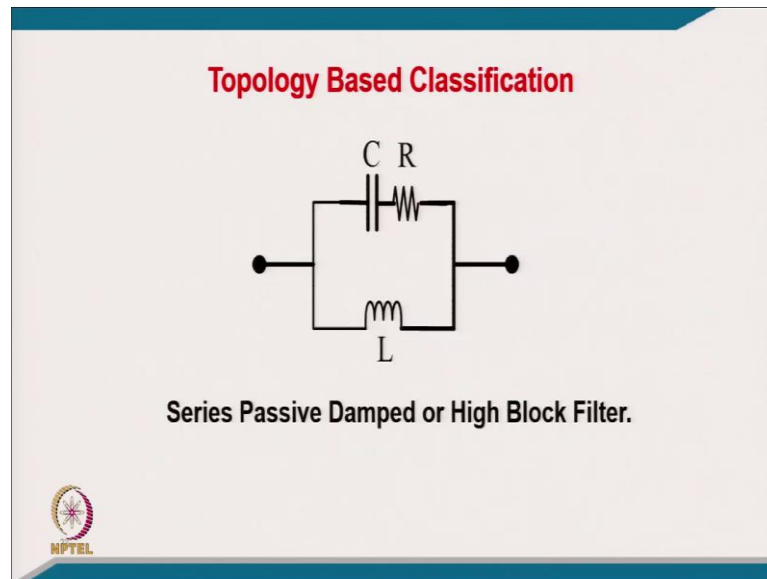
Shunt Passive Damped or High-Pass Filters

(a) First Order,
(b) Second Order,
(c) Third Order,
(d) C-Type Filters.

(a) First order (b) Second order (c) Third order (d) C-Type filter

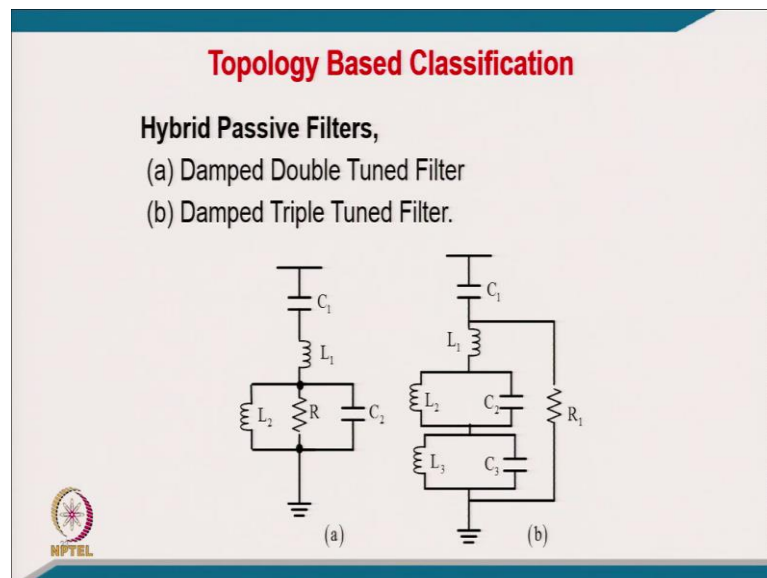
High pass means, all higher order harmonic will pass through and that it can again be first order, second order, third order or C-type filter. C-type filter is normally used in very high rating applications like HVDC also.

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Coming to damped filter for eliminating the higher order harmonics current. The inductor size is small and will take a very small voltage drop at fundamental frequency.

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Well coming to the topology-wise classification of the hybrid passive filter. Hybrid passive filters can be damped double tuned filter or damped triple tuned filter.

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Connections Based Classification

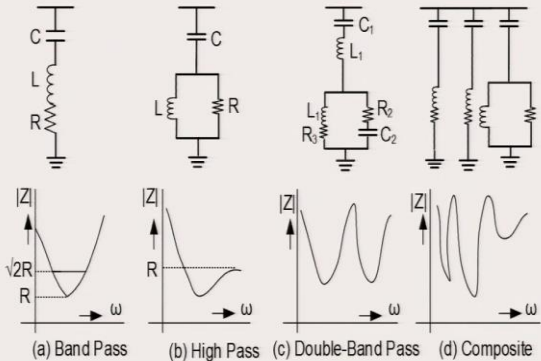
- Series filters
- Shunt filters and
- Hybrid filters (use a combination of both)



For connection-wise classification, it can be like a series filter, shunt filter and or a combination of both.


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Shunt Filters



(a) Band Pass (b) High Pass (c) Double-Band Pass (d) Composite

Common Types of Passive shunt Filters with Impedance-Frequency Plots.

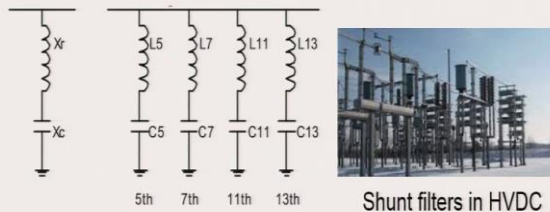


Now coming to classification of shunt filter, it can be band pass, high pass, double band pass and composite filter.

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Shunt Filters

- Passive shunt filters are connected in parallel with harmonic producing loads
- They provide low impedance paths for harmonics currents.



Well coming to the passive shunt filter, they are connected in parallel with the harmonic producing load. And they provide low impedance path for harmonic currents because they are tuned corresponding to that.

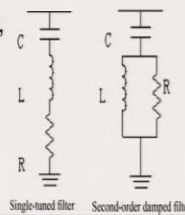
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Types

- **Notch filter** also known as single tuned filter.
- **Double tuned** or double band pass filter. (high voltage applications)
- **High pass filters**, also know damped filters

Shunt Passive filters have following problems


- ✓ resonance with source impedance,
- ✓ fixed compensation and
- ✓ poor power factor at light loads




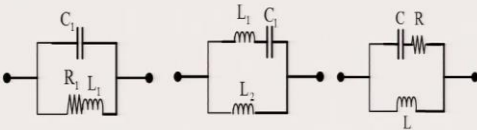
The types of shunt filters are described in the above screenshot.

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Series Filters



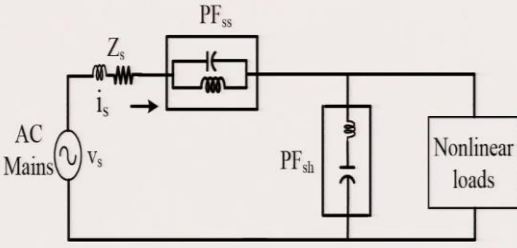
- They provide high impedance for blocking harmonic current
- At fundamental frequency, the filter is designed to offer very low impedance,
- These are used in small power ratings in single-phase system to block dominant third harmonic current.




Now, coming to the series filter, they provide the high impedance for blocking harmonic current. At fundamental frequency the filter is designed to offer very low impedance.

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Hybrid Filters

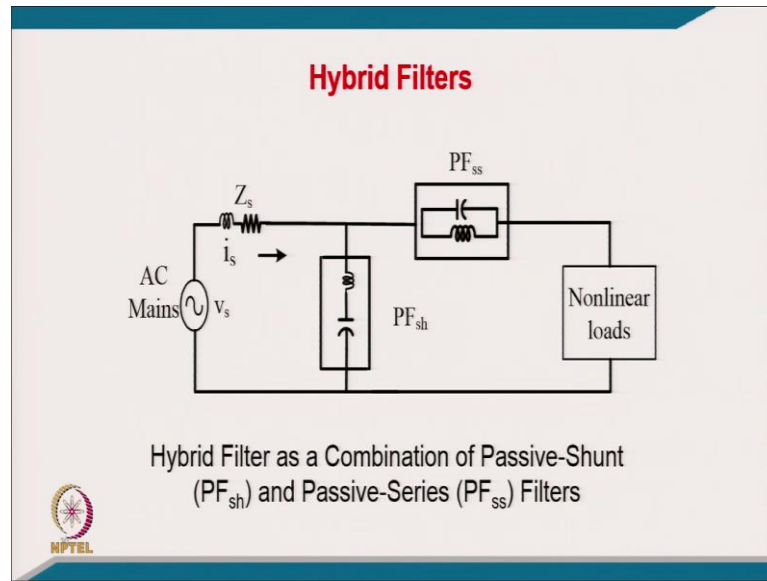


Hybrid Filter as a Combination of Passive-Series (PF_{ss}) and Passive-Shunt (PF_{sh}) Filters



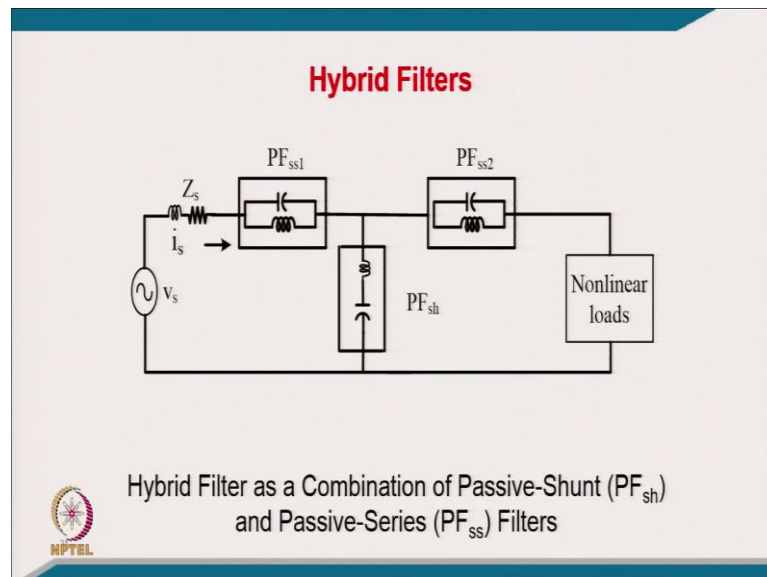
Hybrid filter can be used for single phase two-wire systems, three-phase three-wire systems or three-phase four-wire systems. This is a basic configuration with a passive filter in series and passive filter in shunt with a non-linear load.

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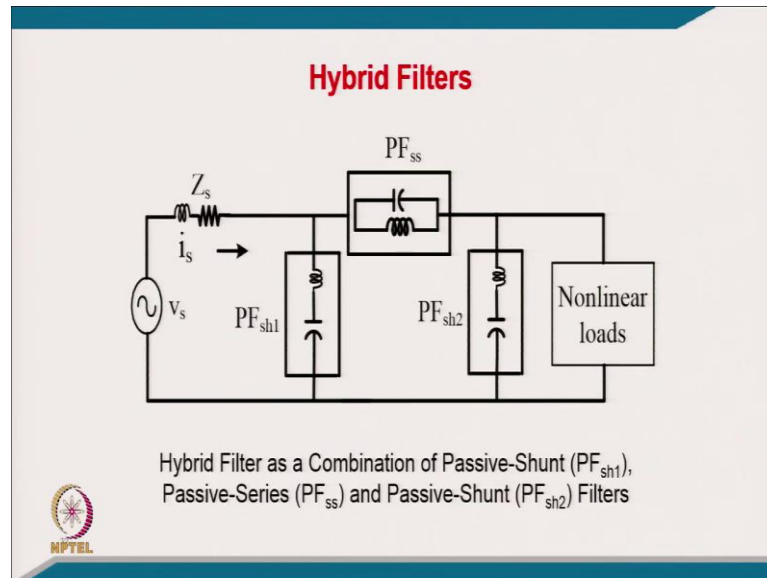
Coming to another configuration, the passive series is put on load side.

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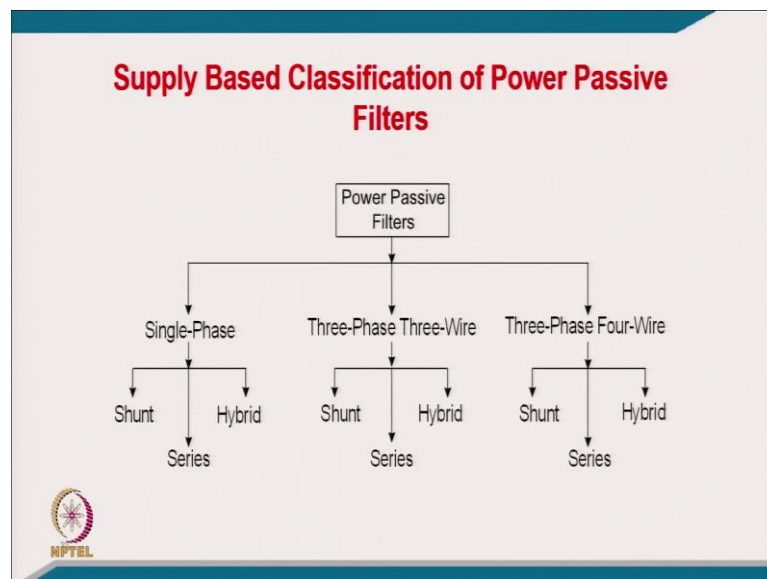
There can even be three passive filters as shown.

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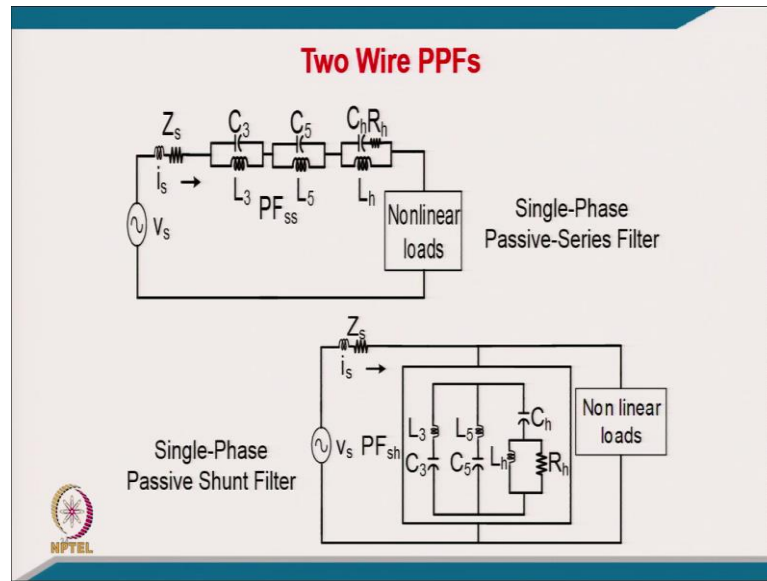


Here there is one passive series and two passive shunt filters.

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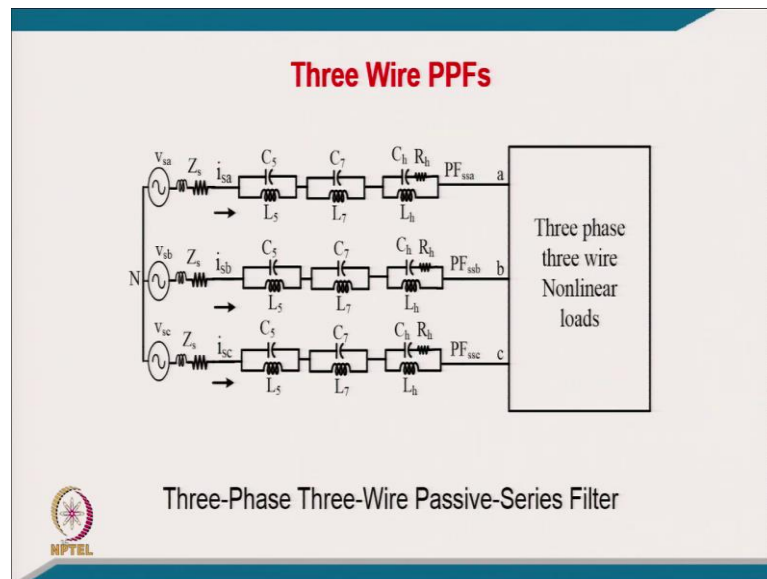


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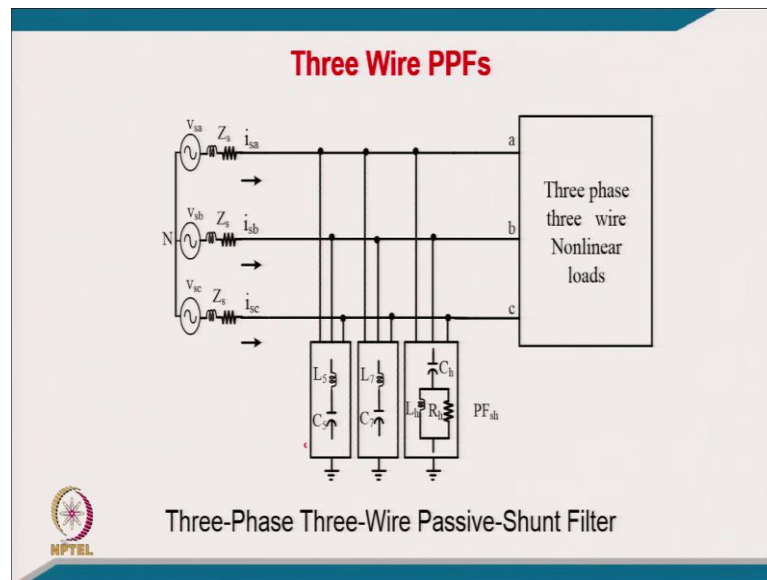
First case of supply based configuration is the two-wire topology.

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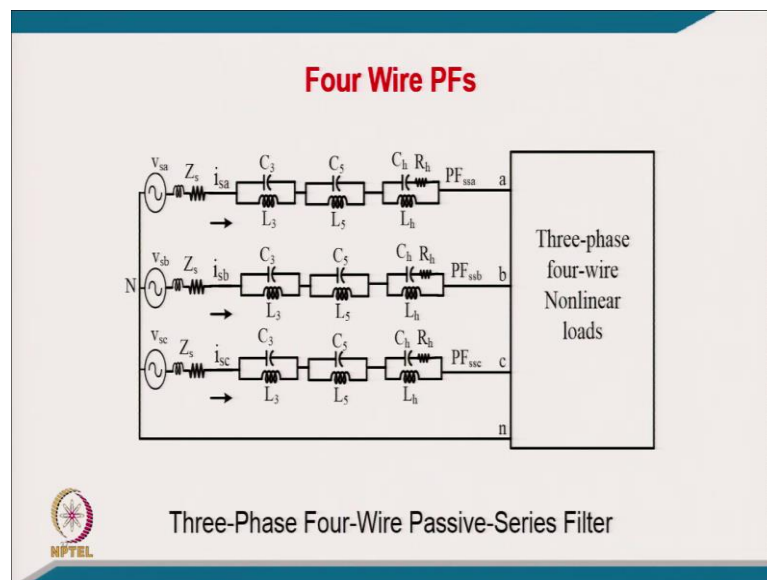
And then we have the three-phase three-wire configuration with series filters.

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Similarly we have the shunt filter where you have a 5th, 7th, and then high pass. They are normally used with a current fed loads.

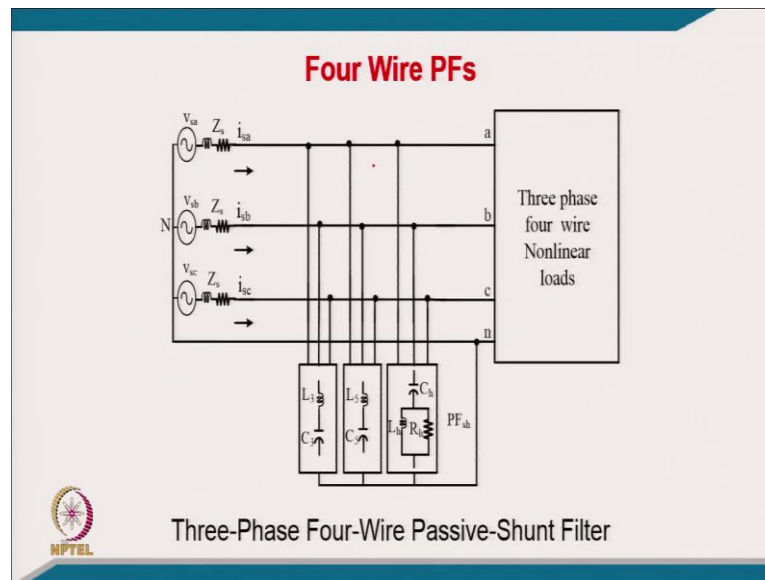
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Well this is typically your three-phase four-wire series filter configuration.

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And then here is three-phase four-wire shunt filter configuration.

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The basic principle of operation of passive power filters may be explained through their objectives, locations, connections, quality, sharpness, rating, size, cost, detuning, applications and other factors.

Objectives

- The main purpose of passive shunt filters is to reduce harmonics voltages and currents in ac power system to an acceptable level.
- The basic operating principle of passive shunt harmonic filter is to suck/absorb harmonics currents in low impedance path realized using a tuned series LC circuit.

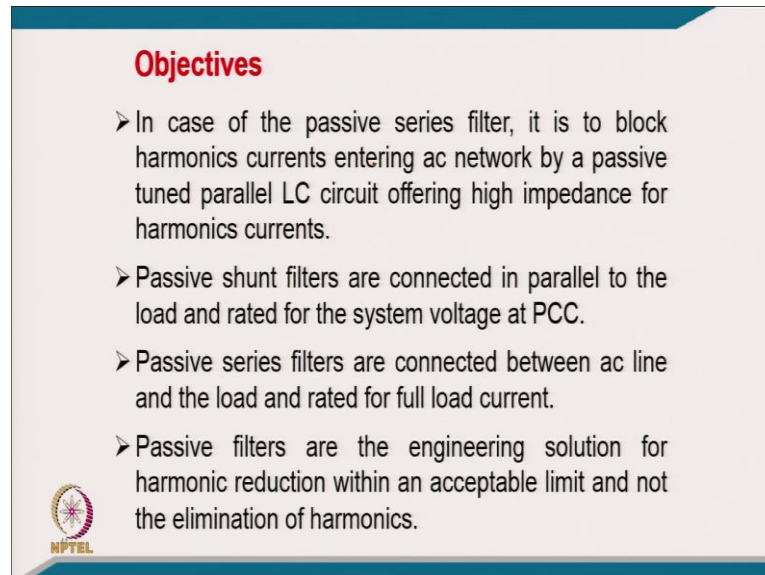
The NPTEL logo is visible in the bottom left corner.

The basic principle of operation of passive power filters may be explained through their objective, location, connections, quality, sharpness, rating, size, cost, detuning, applications and other factors.

[The main purpose of passive shunt filters is to reduce the harmonics voltage and current in the ac power system to an acceptable level. And the basic operating principle of


passive shunt harmonic filter is to absorb harmonic current in low impedance path using a tuned series LC circuit.

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Objectives

- In case of the passive series filter, it is to block harmonics currents entering ac network by a passive tuned parallel LC circuit offering high impedance for harmonics currents.
- Passive shunt filters are connected in parallel to the load and rated for the system voltage at PCC.
- Passive series filters are connected between ac line and the load and rated for full load current.
- Passive filters are the engineering solution for harmonic reduction within an acceptable limit and not the elimination of harmonics.

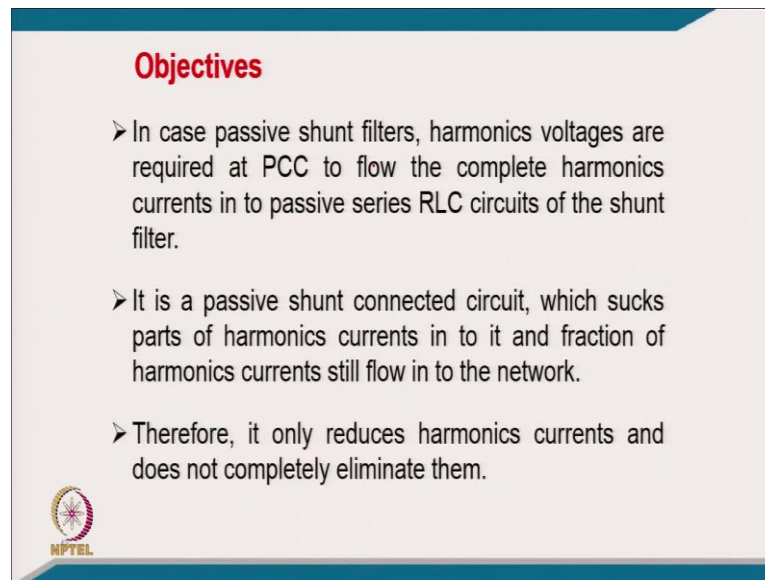
 NPTEL

In case of passive series filter, it is to block the harmonic currents entering into ac network by passive tuned LC circuit offering a high impedance for harmonic currents. While, the filter should not draw any fundamental current from the supply as they are put in shunt.

At fundamental frequency they behave as a capacitive network and give the leading reactive power which is required by most of the current fed kind of non-linear load.


Passive shunt filters are connected in parallel to the load and rated for the system voltage at PCC. And passive series filters are connected in between ac line and the load and rated for full load current.

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Objectives


- In case passive shunt filters, harmonics voltages are required at PCC to flow the complete harmonics currents in to passive series RLC circuits of the shunt filter.
- It is a passive shunt connected circuit, which sucks parts of harmonics currents in to it and fraction of harmonics currents still flow in to the network.
- Therefore, it only reduces harmonics currents and does not completely eliminate them.

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The passive filters are located very close to the load either on ac or dc lines. And most of the time these passive filters are connected at PCC where the loads are connected; however, sometime they are connected in tertiary winding of transformer designed for this purpose at optimum voltage to reduce the cost and to increase the effectiveness because they are popularly designed the leakage reactance of tertiary winding.

Moreover, these passive filters may be used for high voltage harmonic producing loads which require transformers and tertiary winding of the same transformer is designed to use these passive filters like.

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- **Connection and Configuration**
 - These passive filters are used in shunt, series and hybrid configurations.
- **Connection and Configuration (Shunt Filter)**
 - The passive shunt filters are tuned at slightly low frequency at which they suck harmonics current.
 - For multiple harmonics, multiple tuned series RLC circuits are used to absorb these harmonics currents.
 - However, voltage harmonics are also reduced at PCC due reduced harmonics currents flowing in to ac network and less harmonics voltage drop at PCC resulting in reduction in harmonics voltages.

Coming to the type of connection and configuration: these passive filters are used in shunt, series and hybrid configuration.

And the passive shunt filter are tuned at a slightly lower frequency at which they absorb the harmonics.

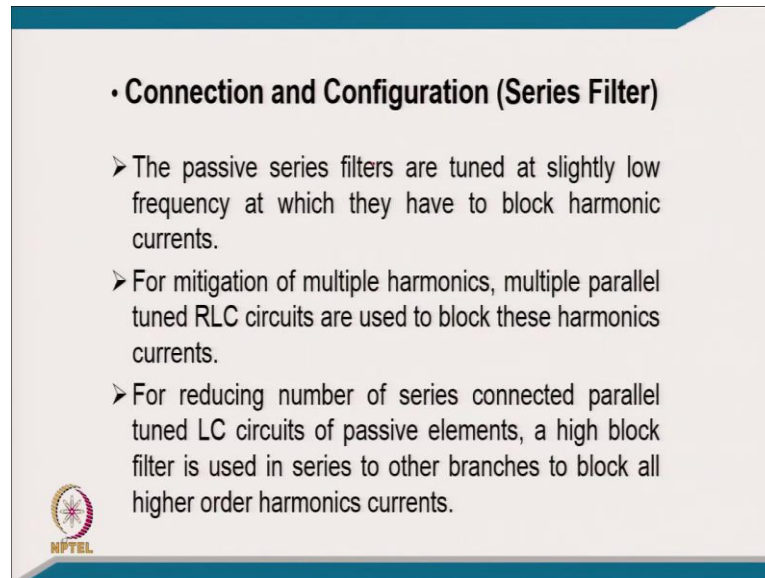
Like typically, 5th harmonic filter is tuned at 4.7.

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- **Connection and Configuration (Shunt Filter)**
 - Moreover, low frequency current (Fundamental) is mainly confined to through the inductor.
 - These passive shunt filters **provide leading reactive power at fundamental frequency, which is fortunately an additional requirement** of large rating ac-dc converters for which these filters are used.

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• Connection and Configuration (Series Filter)

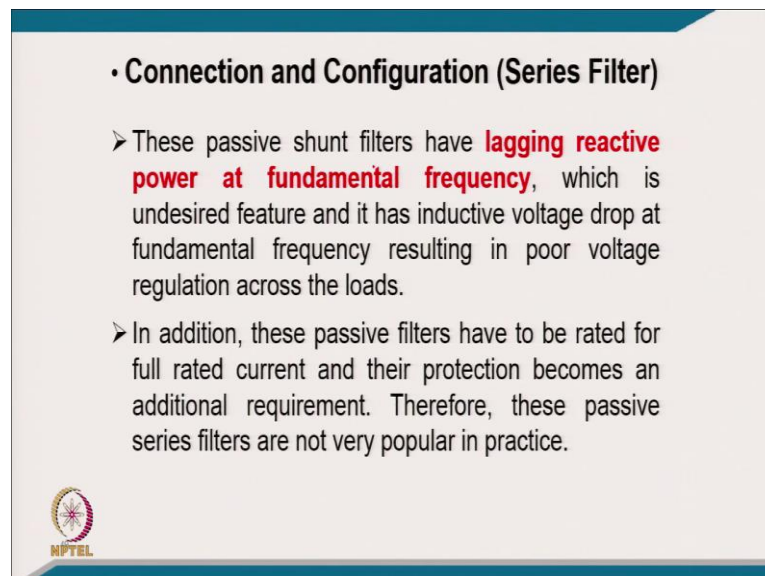
- The passive series filters are tuned at slightly low frequency at which they have to block harmonic currents.
- For mitigation of multiple harmonics, multiple parallel tuned RLC circuits are used to block these harmonics currents.
- For reducing number of series connected parallel tuned LC circuits of passive elements, a high block filter is used in series to other branches to block all higher order harmonics currents.



And coming to like a series filter connection: the passive series filters are tuned at slightly low frequency at which they have to block harmonic current. And for mitigation of multiple harmonics multiple parallel tuned RLC circuits are used to block these harmonic current.


And for reducing the number of series connected parallel tune LC circuit of passive element a high block filter is used in series with other branches to block all higher order harmonics current and they are connected all in series.

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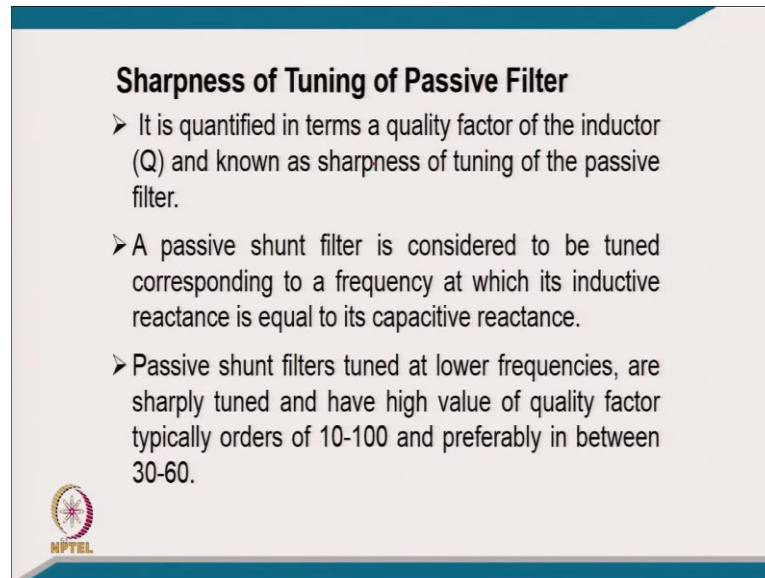
• Connection and Configuration (Series Filter)

- These passive shunt filters have **lagging reactive power at fundamental frequency**, which is undesired feature and it has inductive voltage drop at fundamental frequency resulting in poor voltage regulation across the loads.
- In addition, these passive filters have to be rated for full rated current and their protection becomes an additional requirement. Therefore, these passive series filters are not very popular in practice.




Passive shunt filters having a lagging reactive power at fundamental frequency which is undesired features and it has inductive voltage drop at fundamental frequency resulting in poor voltage regulation across the load. In addition this passive filter have to be rated for full current and their protection becomes an additional requirement. Therefore, these passive series filters are not very popular in practice.

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Sharpness of Tuning of Passive Filter


- It is quantified in terms a quality factor of the inductor (Q) and known as sharpness of tuning of the passive filter.
- A passive shunt filter is considered to be tuned corresponding to a frequency at which its inductive reactance is equal to its capacitive reactance.
- Passive shunt filters tuned at lower frequencies, are sharply tuned and have high value of quality factor typically orders of 10-100 and preferably in between 30-60.

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Sharpness we explain with the help of quality factor of the inductor or of the circuit and passive shunt filter it considered to be tuned corresponding to a frequency at which the inductive reactance is equal to capacitive reactance.

And passive shunt filter tuned at lower frequencies are sharply tuned and have higher value of quality factor typically order of 10 to 100 and preferably between 3 and 30, so, that quality factor is quite high. And quality factor is high means the resistance is small and if resistance is small, loss is also small.

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Sharpness of Tuning of Passive Filter

- Other types of passive shunt filters, known as damped filters and high pass filters, are tuned for high frequencies and they have low value of quality factor typically orders of 0.5-5 and preferably between 1-2.
- These high pass passive filters offer low impedance over a broad band of frequencies bandwidth.

And of course, other type of passive shunt filters known as damped filter with a high pass filter are tuned for a high frequencies and they have low value of quality factor typically order of 0.5 to 2.

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Cost of Passive Filter

- The cost of the passive filter is reasonable and sometimes it reaches 15% to 20% of the equipment for which it is used therefore the design of passive filter has to consider the cost factor in to account while designing these passive filters.
- Moreover, it has some power losses, which also must be considered in its design. The cost of the passive filter may also be partially supplemented to the reactive power supplied by it.
- These filters are sometimes designed based on minimum cost filter.

And coming to the cost of this passive filter, cost of this passive filter is the reasonable and sometimes it reaches 15 to 20 percent of the equipment for which it is used.

Therefore, the design of passive filter has to consider the cost in account while designing the passive filter. Moreover, it has some power losses which also must be considered in

its design. The cost of passive filter may also be partly supplemented to the reactive power supplied by it. Well, these filters are sometime designed based on minimum cost filter.