Power Quality
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Module - 07
Lecture - 23
Active Series Power Filters

Welcome to the course on Power Quality. Here we will like to cover Active Series Power Filter.

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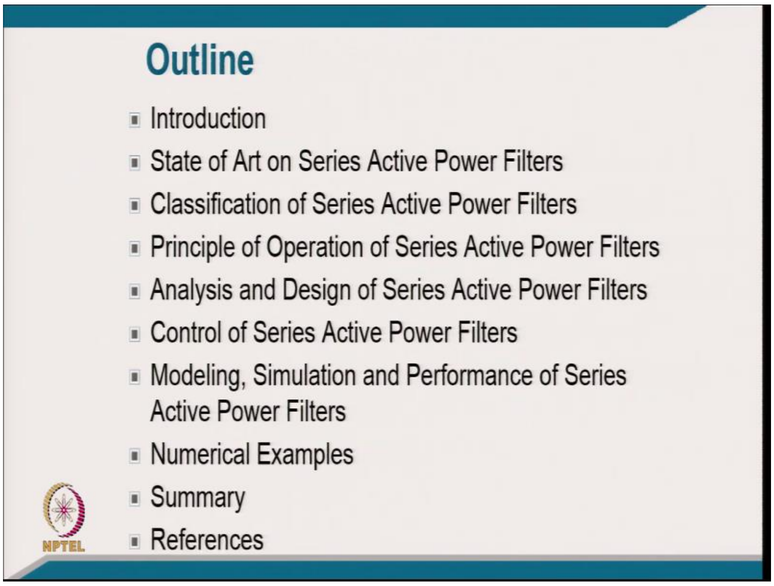

The outline of the lecture, first we will explain the Introduction on Series Active Power Filter. Then we will talk about state of art on series active power filter, then classification of series active power filter, then the principle operation of series active power filter. And analysis and design of series active power filter, control of a series active power filter, modeling and modeling simulation and performance of series active power filter, numerical examples, summary with references.

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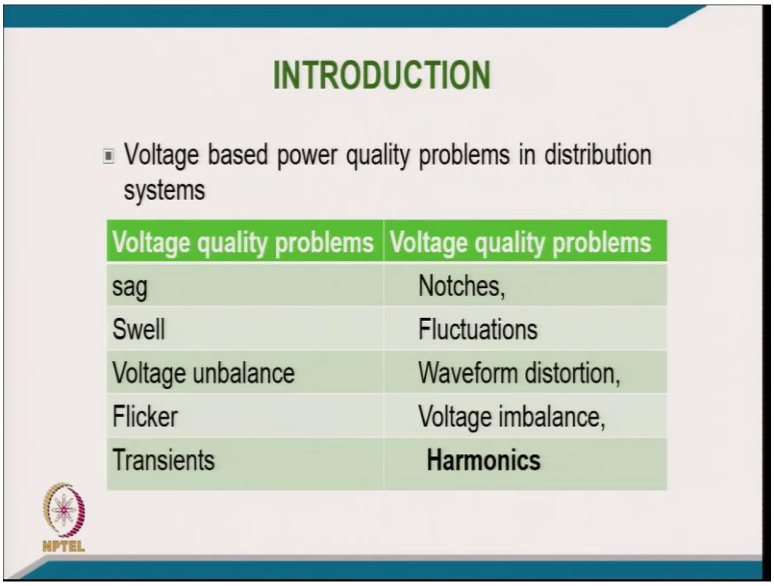

Voltage based power quality problems in distribution system are voltage sag, voltage swell, voltage unbalance, voltage flicker, voltage transient, voltage notches, voltage fluctuations, voltage waveform distortion. For dealing with these we use the series active filter.

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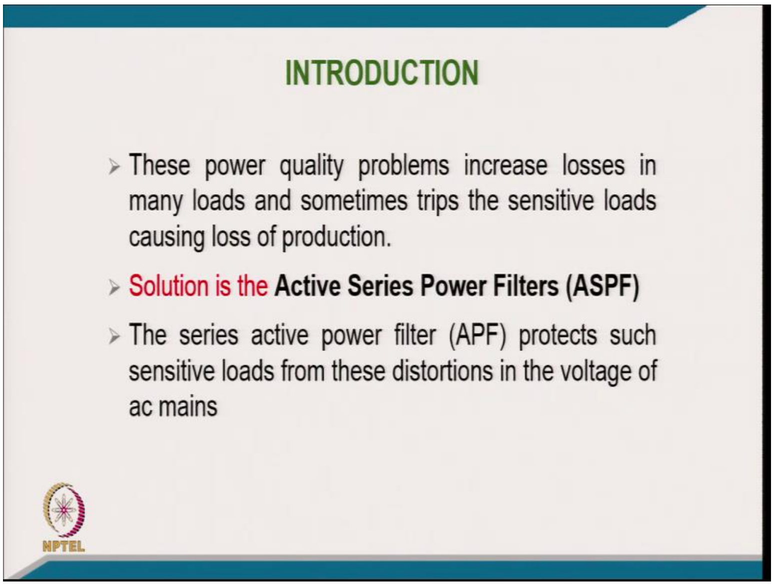

These power quality problems increase losses in many loads, and sometime trip the sensitive load causing the loss of production. Series active power filter protects such sensitive loads from these disturbances in the voltage of AC mains.

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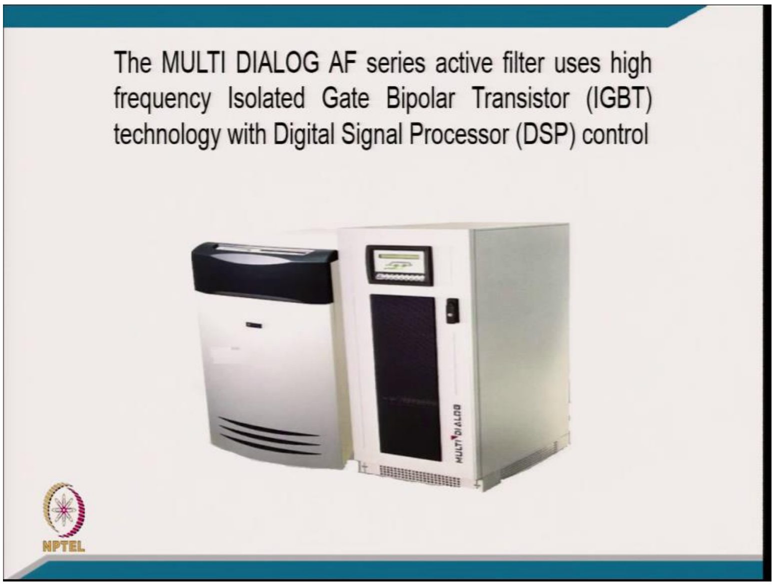

The active series filter uses the high frequency IGBT technology with the digital signal processor control.

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Now, coming to classification of active series filter power filter.

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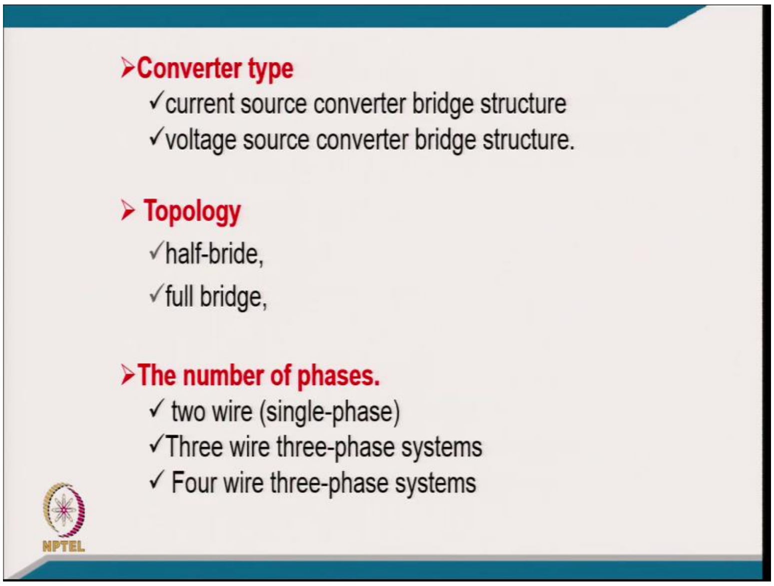

First classification is on converter type: whether the current source converter bridge structure or voltage source bridge structure is used. Topology wise: whether we use half bridge or full bridge. Based on number of phases: two wire single-phase, three wire three-phase system or four wire three-phase system.

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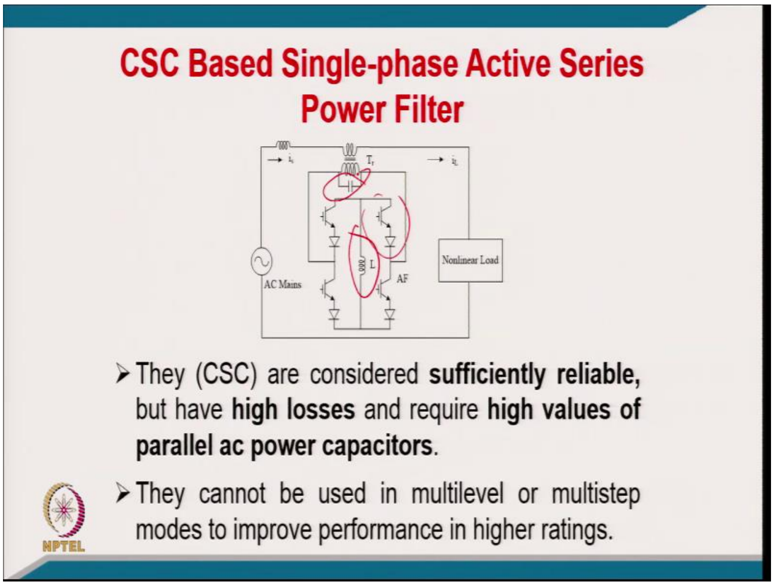

Coming to the first type of convertor classification. The current source converter based series active power filter. There is a series connected injection transformer. We are typically injecting the voltage harmonics or voltage magnitude with this current source inverter. And current source inverter I mean you have a dc link inductor as the energy storage element.

This certainly creates a problem of large size, cost, weight, and losses. And the device here needs a negative reverse voltage blocking capability which your IGBT do not have, therefore we have to use the series diode.

These current source converter are considered sufficiently reliable, but have high losses and require high value of parallel AC power capacitors. And they cannot be used in multilevel or multistep modes to improve the performance in higher rating.

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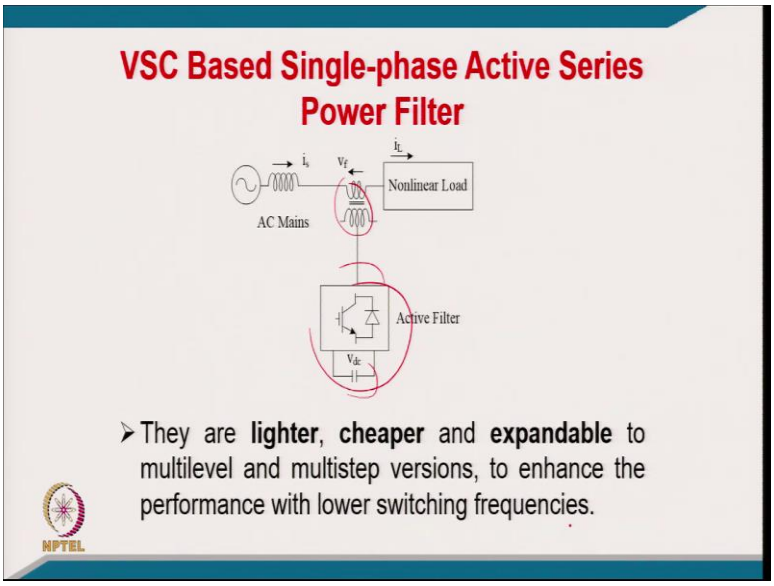

This is the voltage source based single-phase active series filter. In voltage source inverter, you have an IGBT with anti-parallel diode, and well, losses are low because either IGBT will conduct or diode will conduct. Thus compared to the current source, losses will be less in the switching devices. And then, on dc link we have an electrolytic capacitor as energy storage element.

This also have a small size, low cost and a small losses. But of course, they are also you need the injection transformer.

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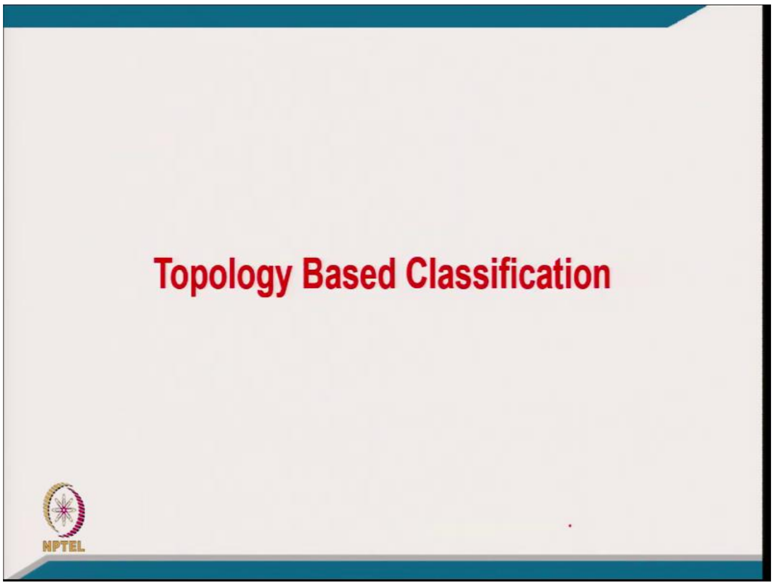

And coming to the classification on topology based classification.

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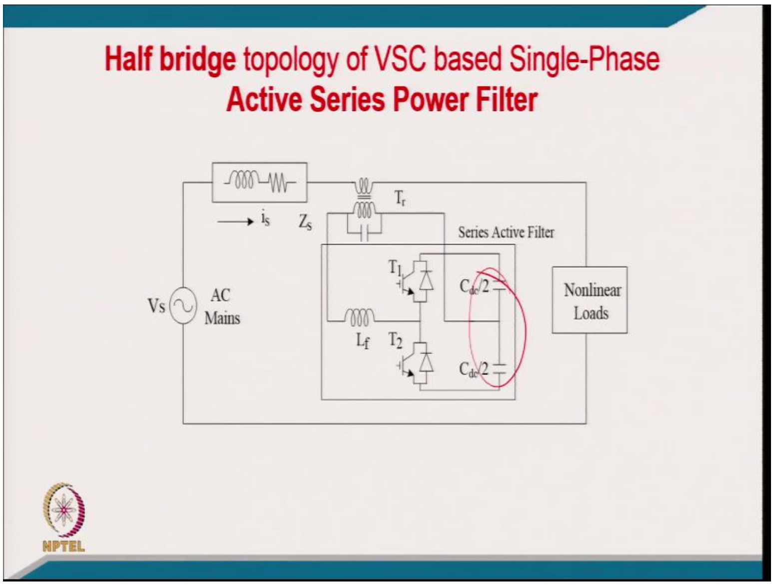

You can use this voltage source converter also with the half bridge. The only drawback is that these capacitor required quite high value, because the whole current will flow through these capacitor.

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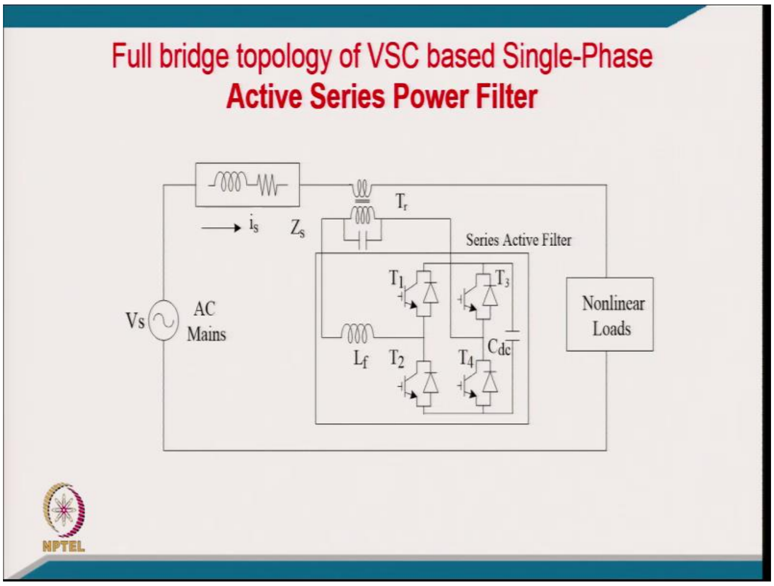

Then, this is the bridge structure which is preferred for series active filter.

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Coming to the supply based supply system based classification.

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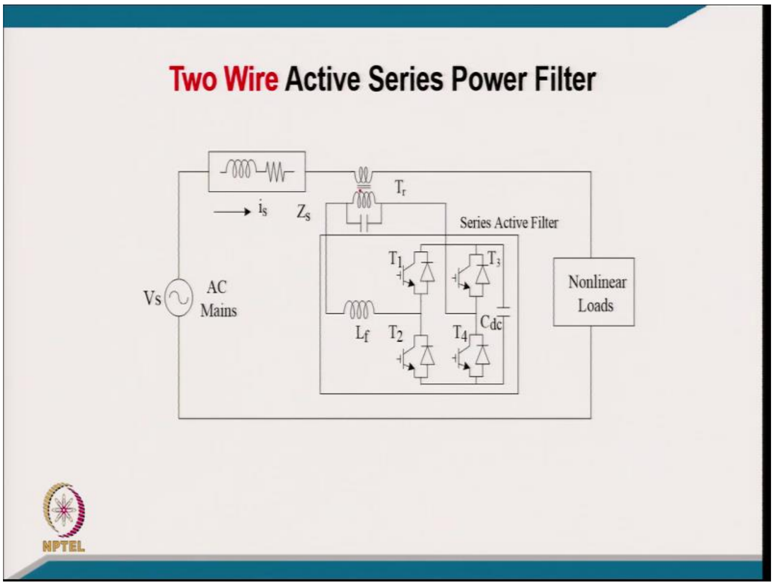

This is a single-phase two wire active series active filter, with the bridge structure.

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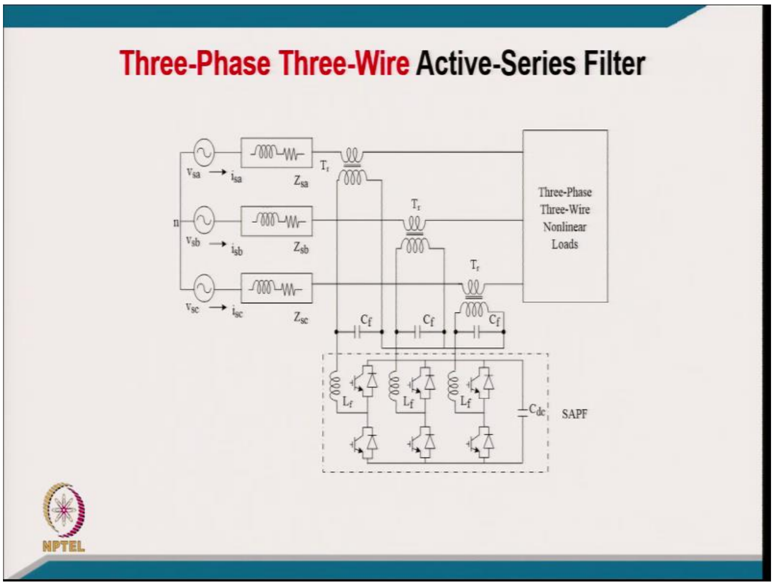

And this is three-phase three wire with a self-supporting bus.

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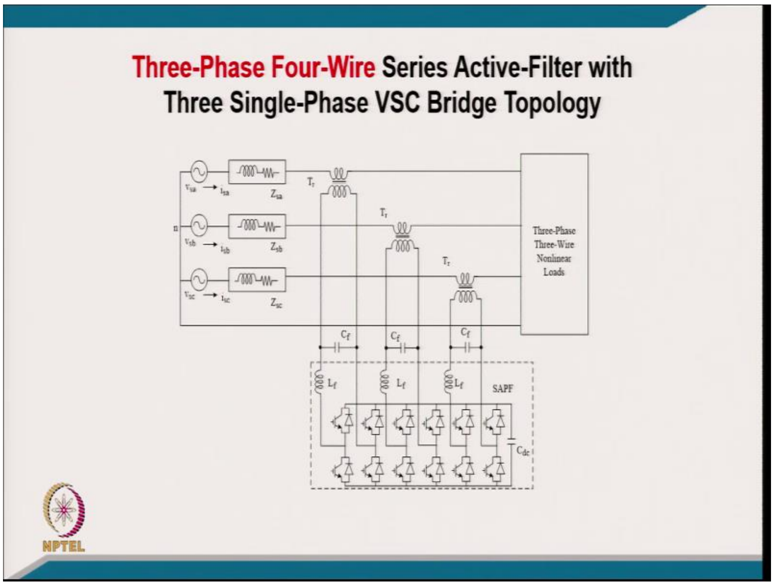

And this is the three-phase four wire configuration.

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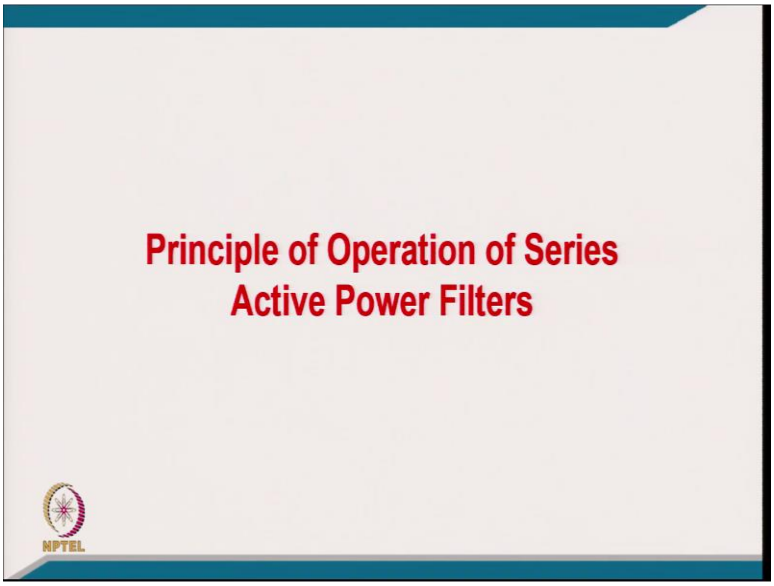

Coming to principle of operation of the series active power filter.

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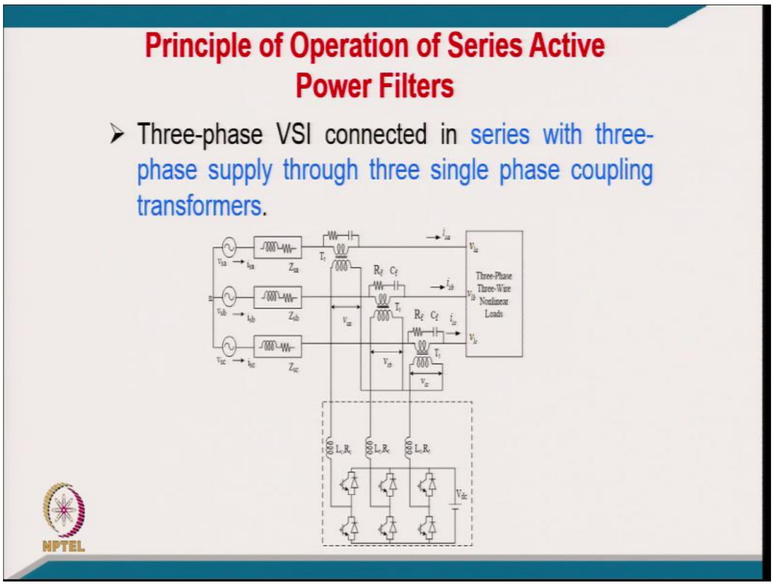

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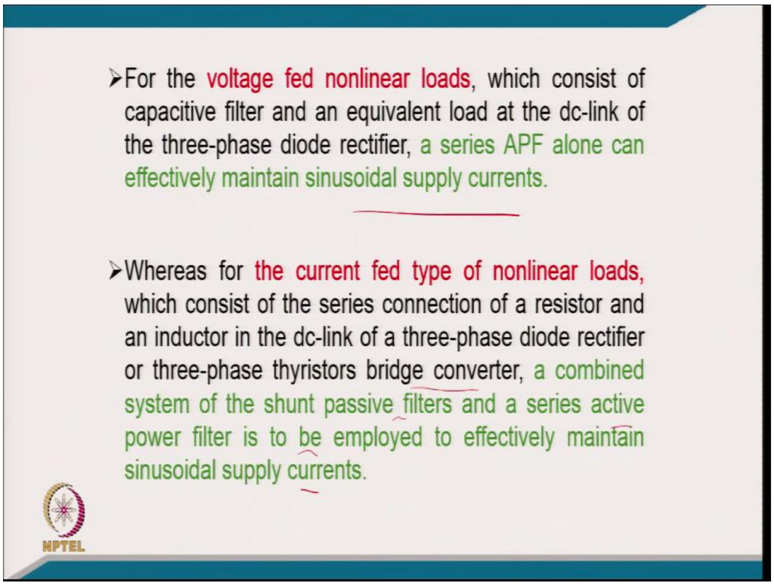

And it can be a very specific solution for the voltage fed non-linear load which consist of capacity filter and equivalent load at the dc link of the three-phase diode rectifier a series active filter can also effectively maintain the sinusoidal supply current.

Whereas, the current fed kind of non-linear load, which consist of series connection of a resistor and inductor at the dc-link of three-phase diode bridge rectifier or thyristors bridge converter a combined system of shunt passive filter and series active filter is to be employed to effectively maintain the supply current. So, that load is not really affected by that. But a series filter will be forcing the entire harmonics current into the shunt passive filter. Series filters are typically used for a small rating in those applications also.

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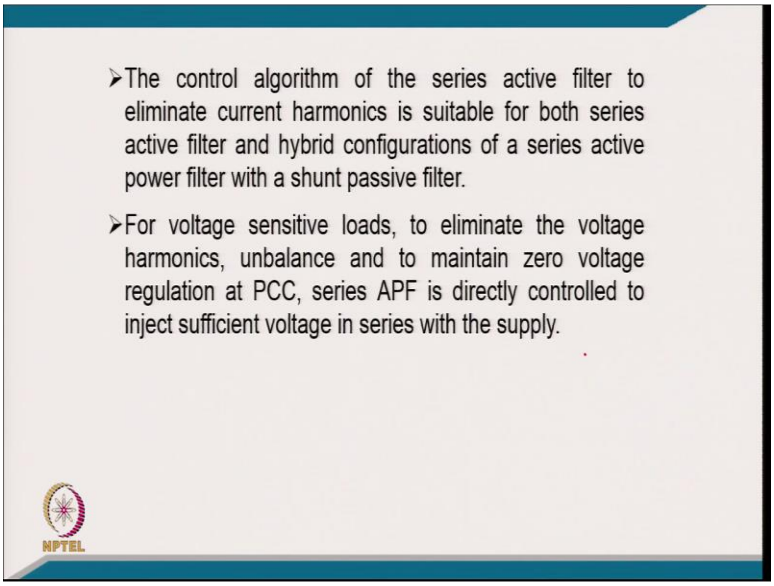

The control algorithm series active power filter is to eliminate current harmonics and is suitable for both series active power filter and hybrid configuration of series active filter and with shunt passive filter. For voltage sensitive load, to eliminate the voltage harmonics, unbalance and to maintain zero voltage regulation PCC, a series active filter is directly controlled to inject sufficient voltage in series with the supply.

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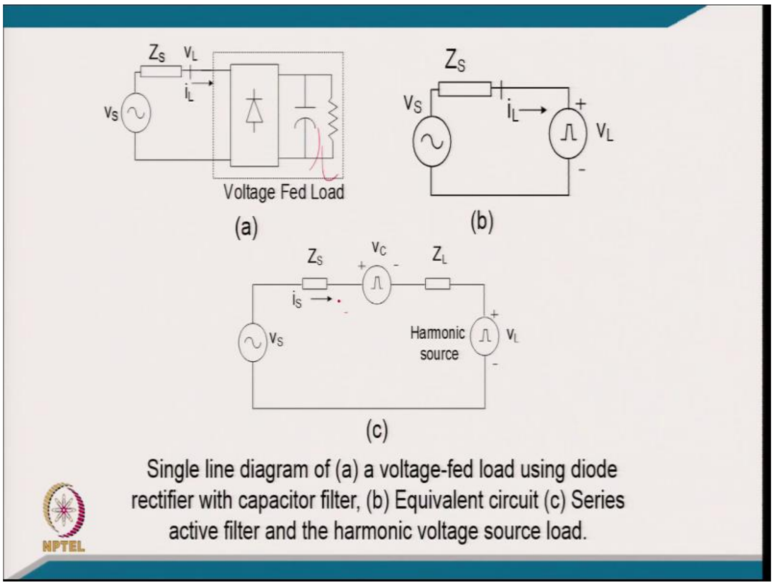

Single line diagram of (a) a voltage-fed load using diode rectifier with capacitor filter, (b) Equivalent circuit (c) Series active filter and the harmonic voltage source load.

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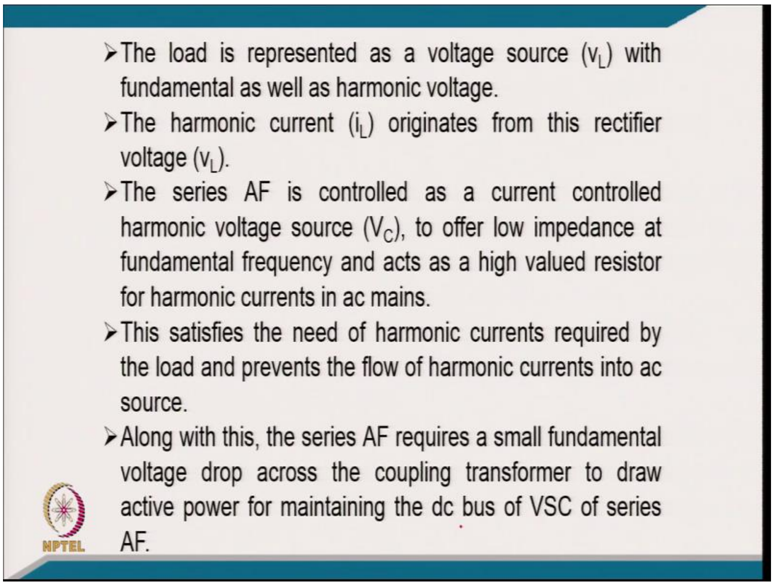

The load is represented as a voltage source with a fundamental as well as a harmonic voltage and the harmonic currant originate from this rectifier voltage. And the series active power filter is control as a current control harmonic voltage source to offer low impedance at the fundamental frequency and acts as a high value resistor for harmonic current in the ac mains.

This satisfy, the need of harmonic currents required by the load and prevents the flow of harmonic currents into the ac source. And along with this a series active power filter requires a small fundamental voltage drop across the coupling transformer to draw active power for maintaining the dc bus of voltage source converter which normally realize with help of control like.

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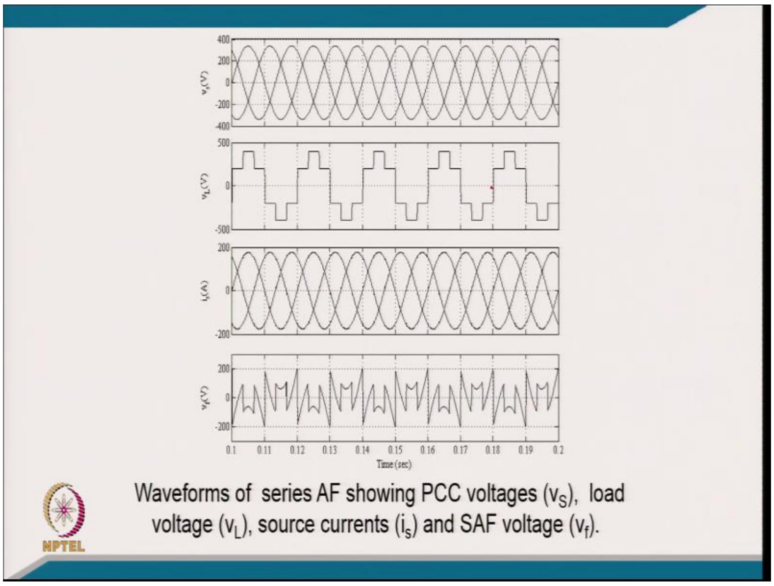

The screenshot shows the simulated performance.

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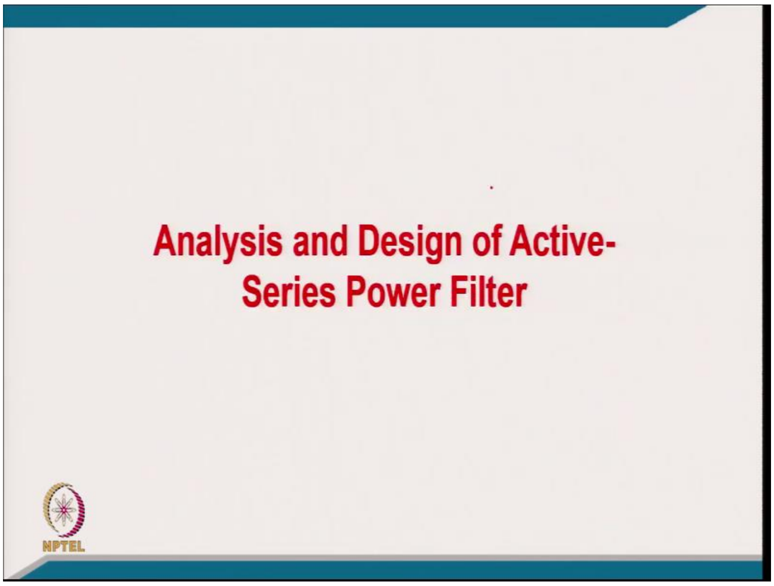

Coming to analysis and design of series active power filter.

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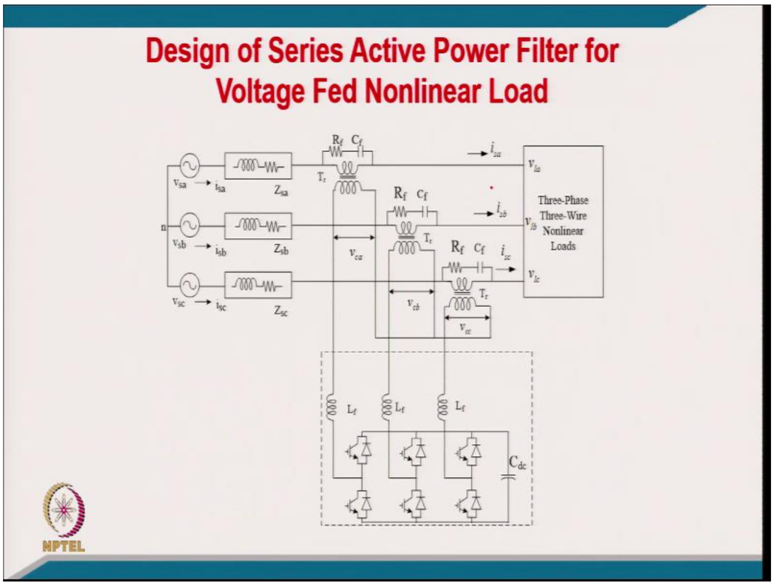

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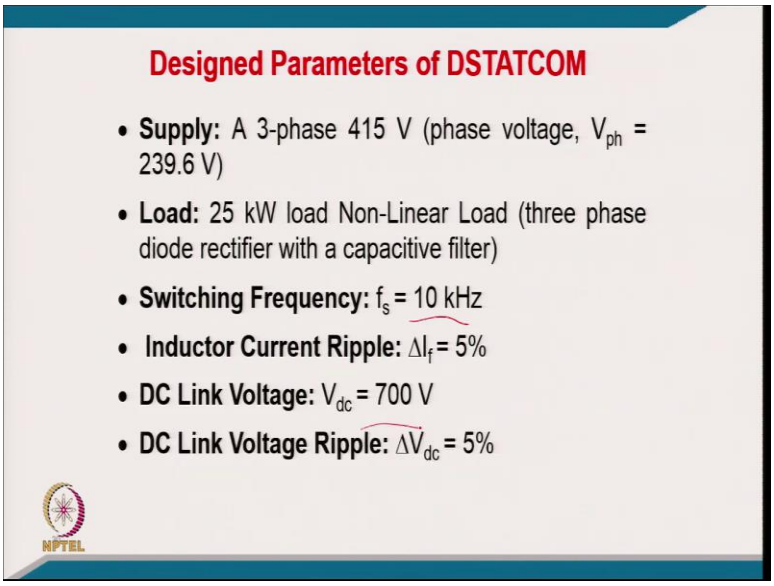

The screenshots herein describe the design procedure for the series active power filter.

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- **Design of VSC of Series Active Power Filter**

The design of the series active power filter is based on the dc bus voltage of the three-phase rectifier load. The series active power filter is operated for eliminating harmonics in the supply currents and hence it injects only harmonics voltage. It is clear that the fundamental component of load voltage is the PCC voltage as the series AF injects the harmonic component of the load voltage. Hence the fundamental component of load ac voltage is as,

$$V_{LL} = (\sqrt{6}/\pi)\, V_d = 0.779^* \, V_d$$

For a given line voltage of 415 V and a dc load voltage, V_d of 540 V.

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- **Design of VSC of Series Active Power Filter**

The voltage rating of the series AF is obtained from the difference of PCC and load voltages and hence the SAF voltage is calculated as,

$$V_f = \sqrt{(1/\pi)\left\{ \int_0^{\pi/3} (V_{ph}\sqrt{2}\sin\theta - V_d/3)^2 d\theta + \int_{\pi/3}^{2\pi/3} (V_{ph}\sqrt{2}\sin\theta - 2V_d/3)^2 d\theta + \int_{2\pi/3}^{\pi} (V_{ph}\sqrt{2}\sin\theta - V_d/3)^2 d\theta \right\}} = 75.6415 \text{ V}$$

$V_{ph} = 239.6$ V, $V_d = 540$ V

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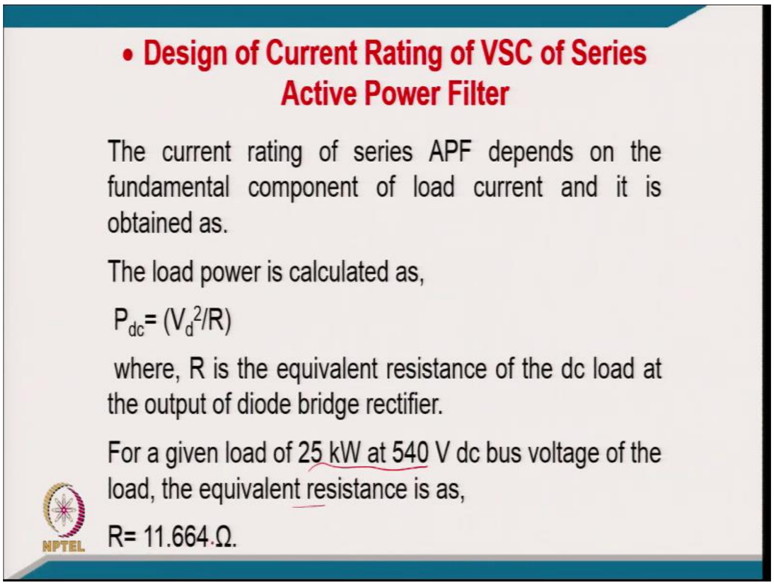

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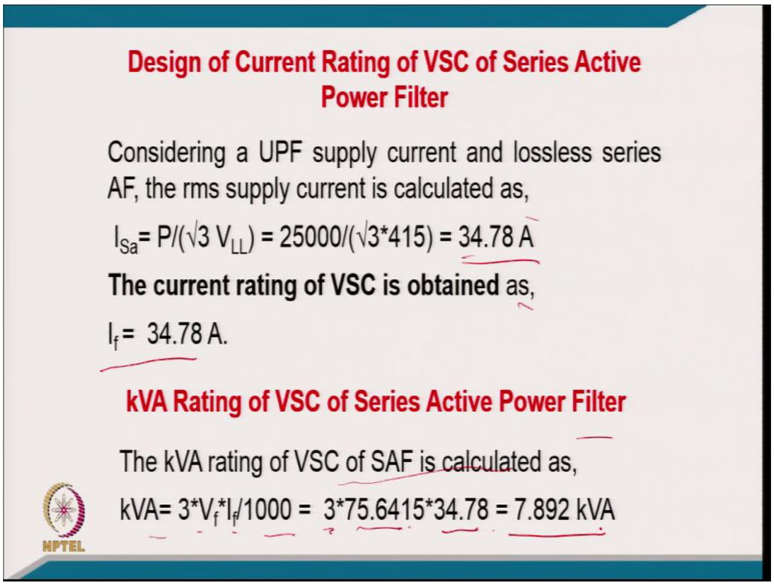

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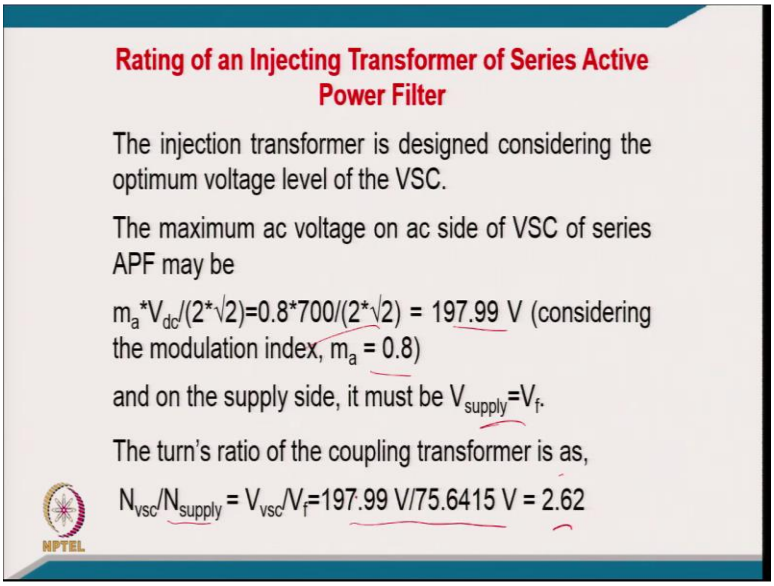

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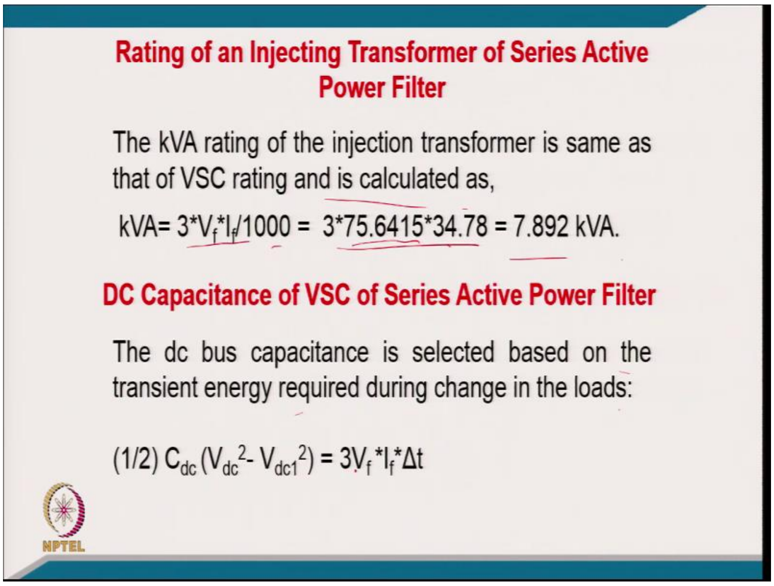

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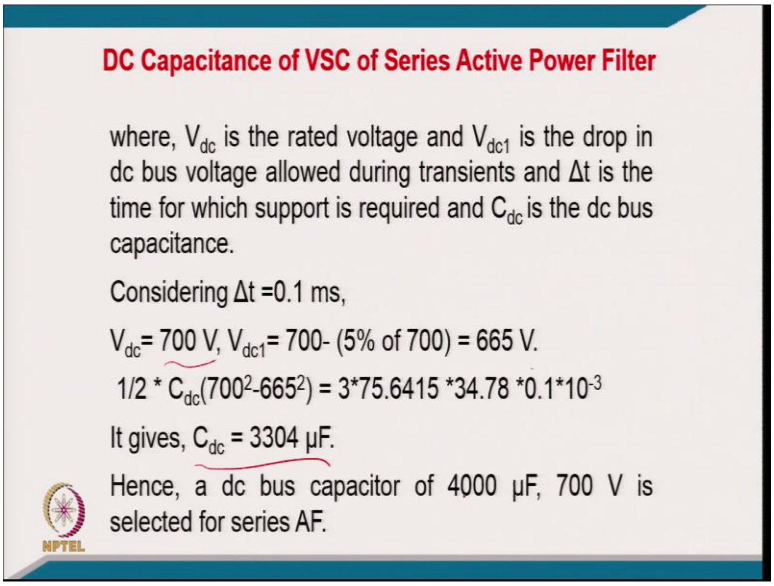

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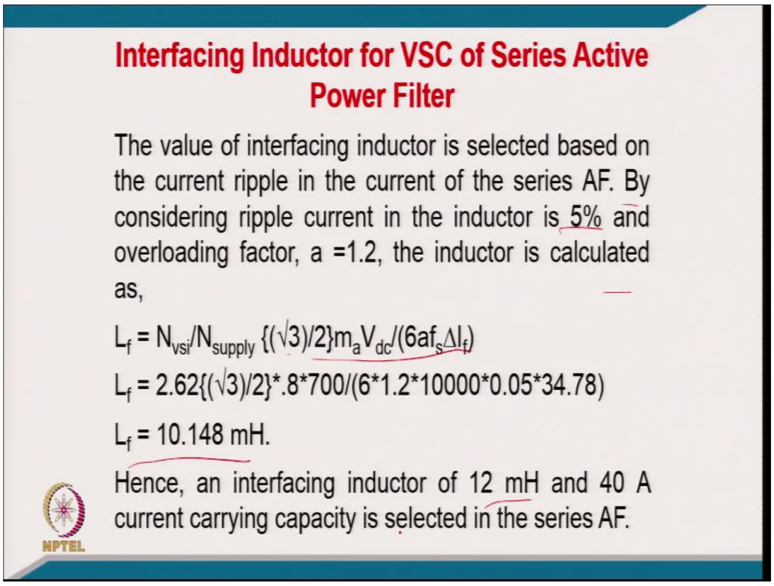

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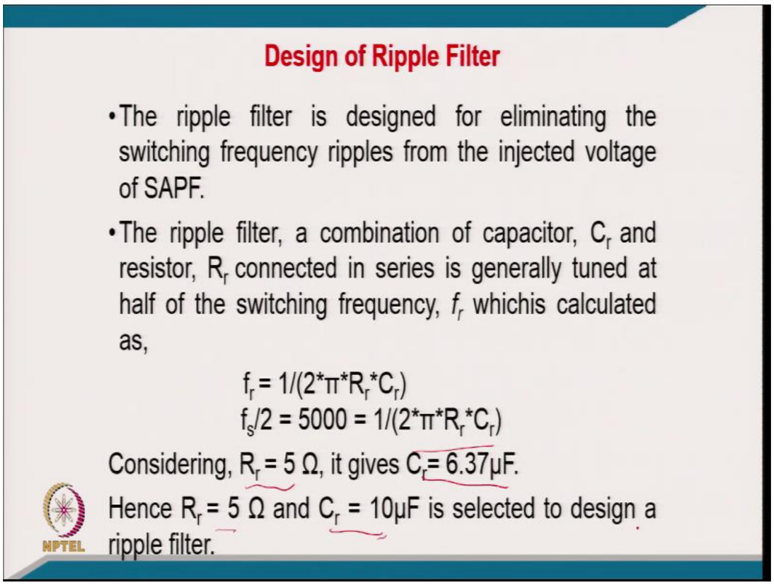

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The control algorithm used for series active power filters for elimination of voltage harmonics is described in the screenshots herein.

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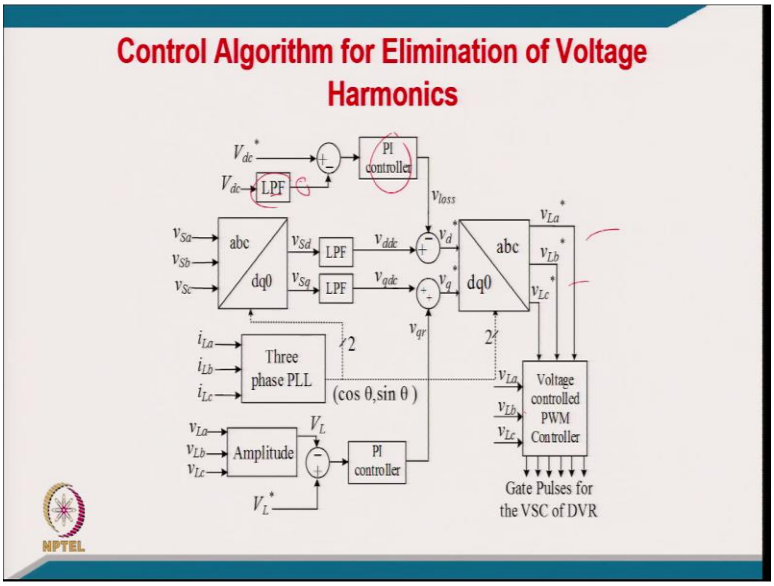

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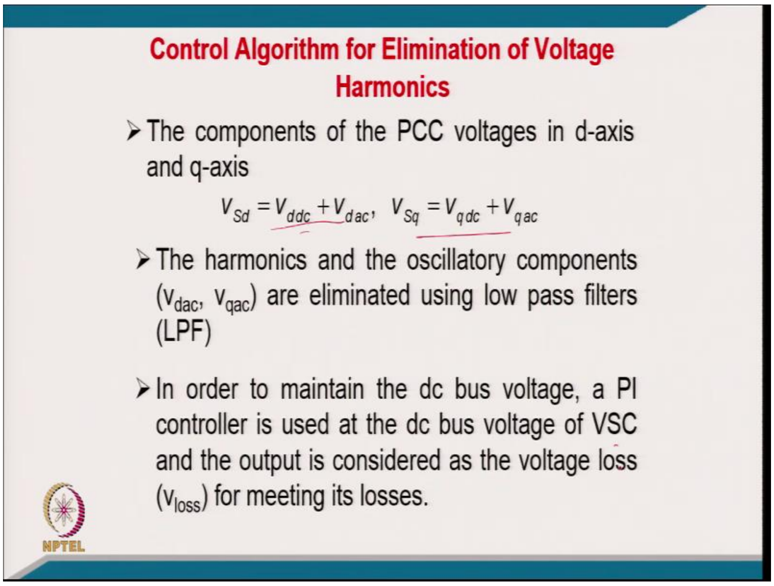

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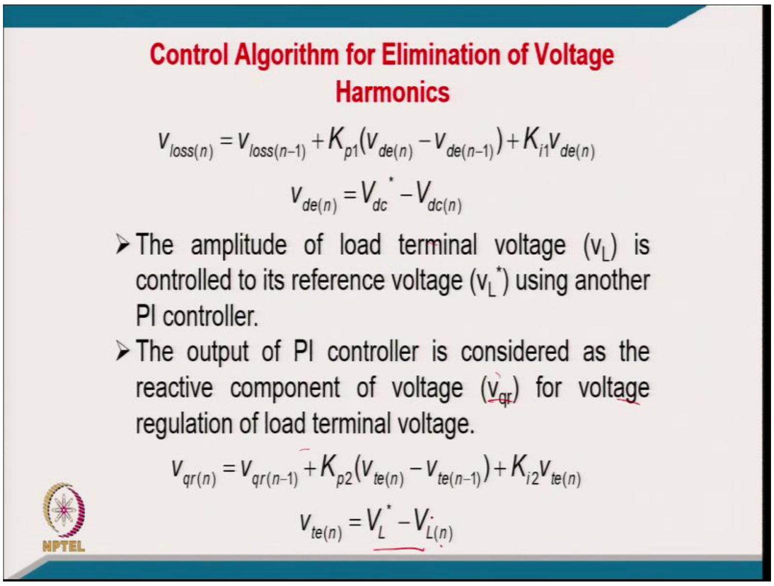

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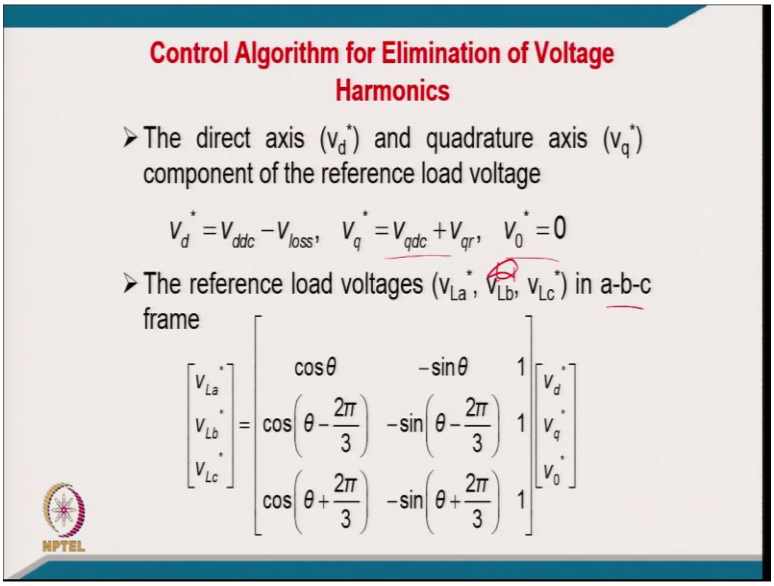

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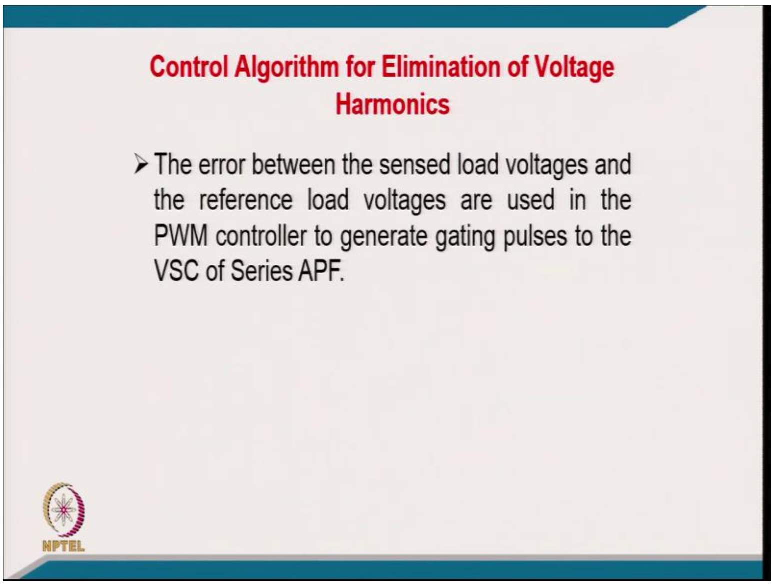

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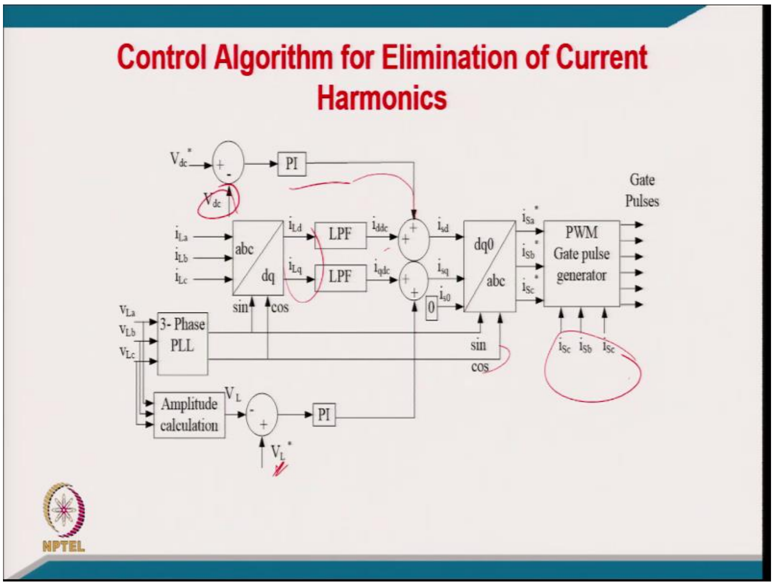

The control algorithm used for series active power filters for elimination of voltage harmonics is described in the screenshots herein.

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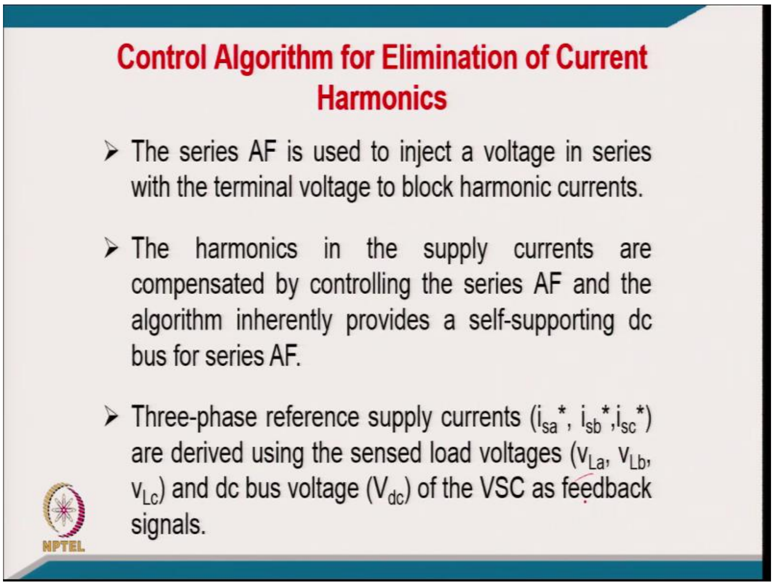

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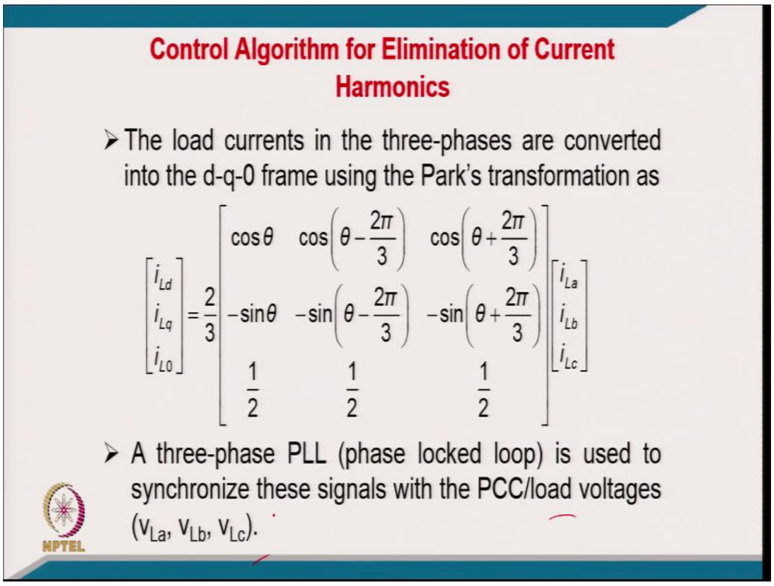

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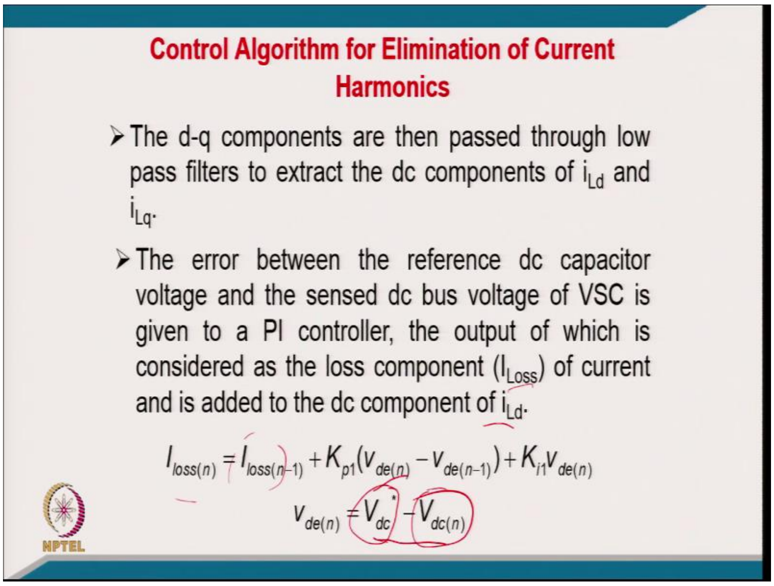

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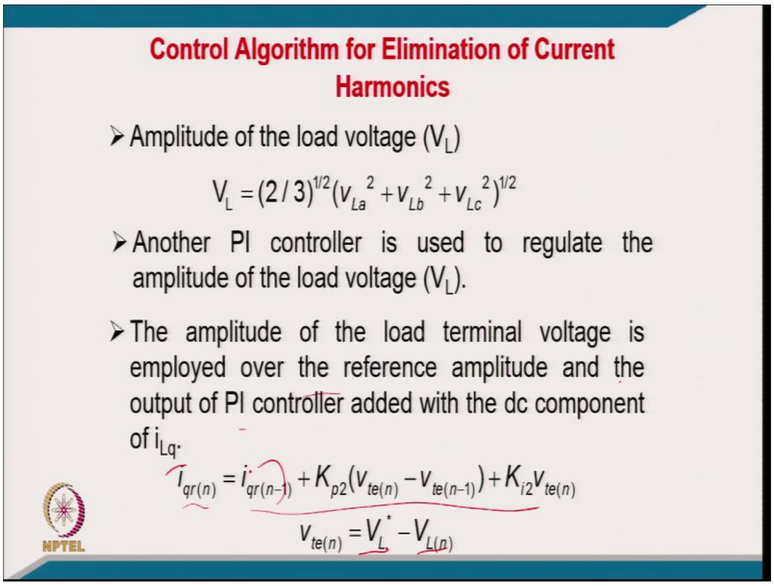

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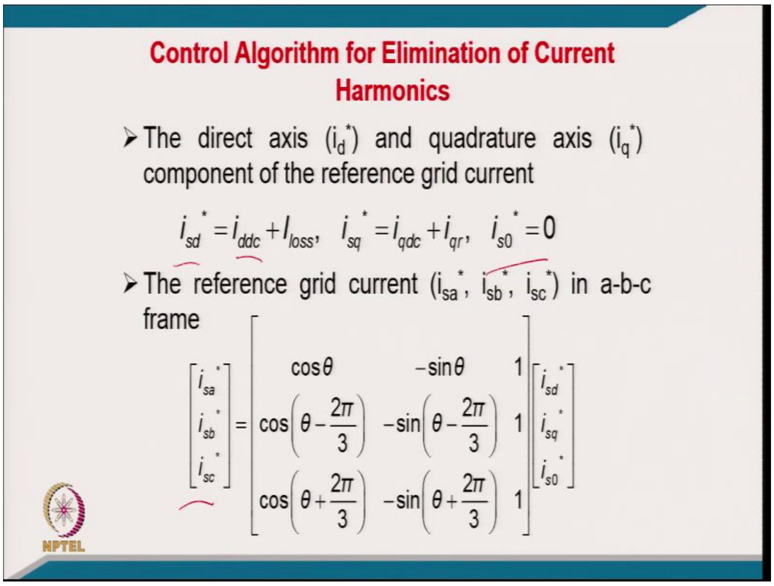

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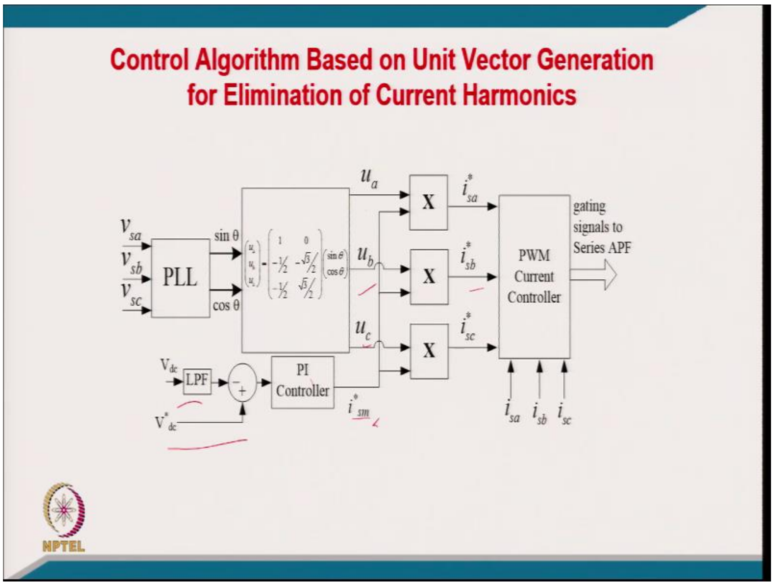

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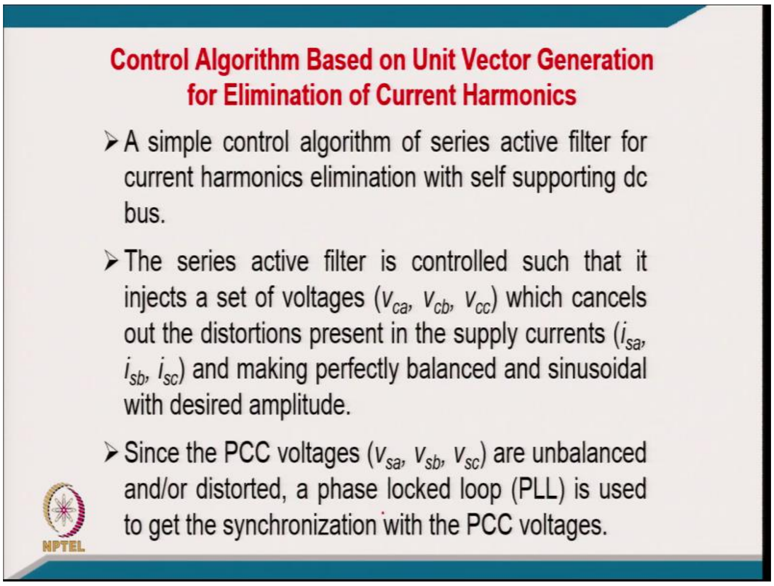

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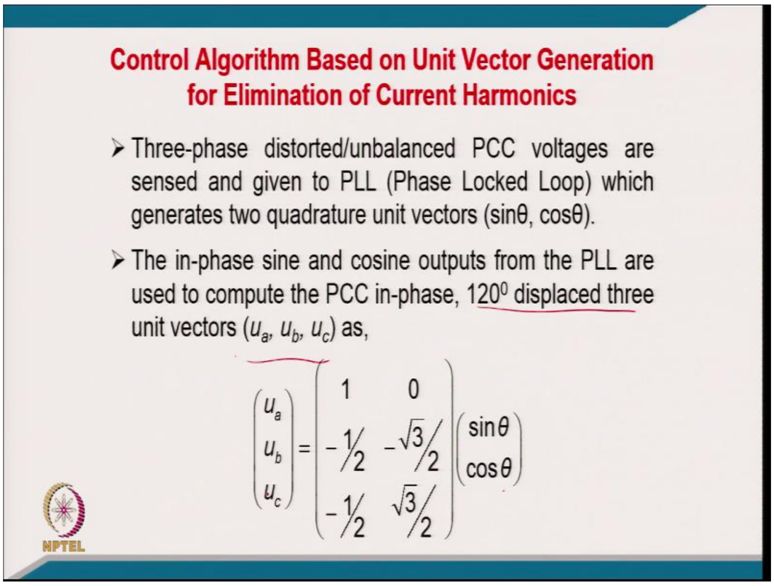

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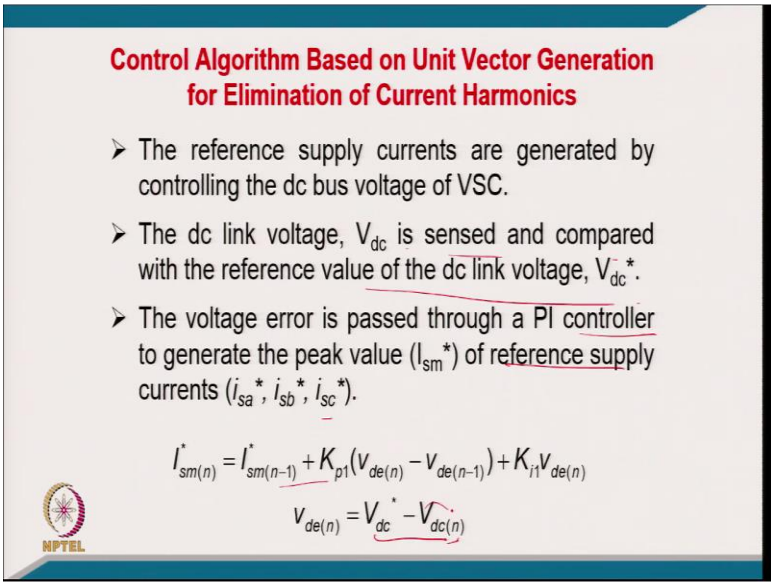

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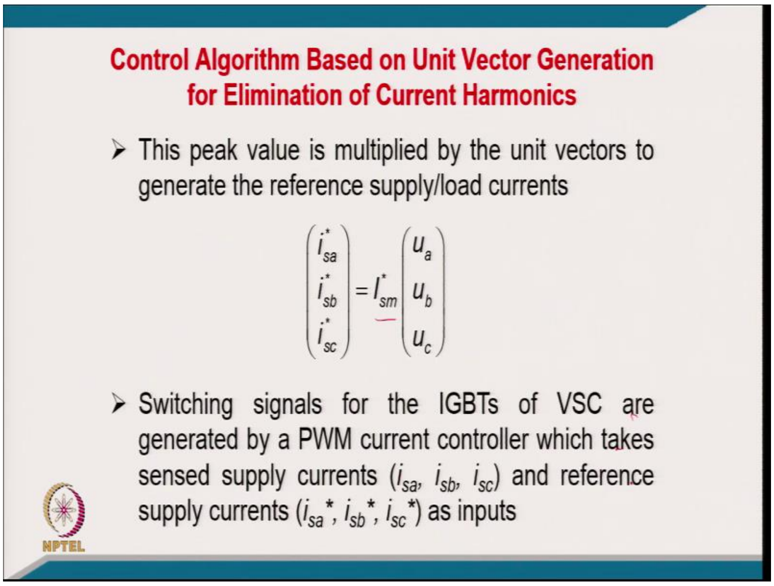

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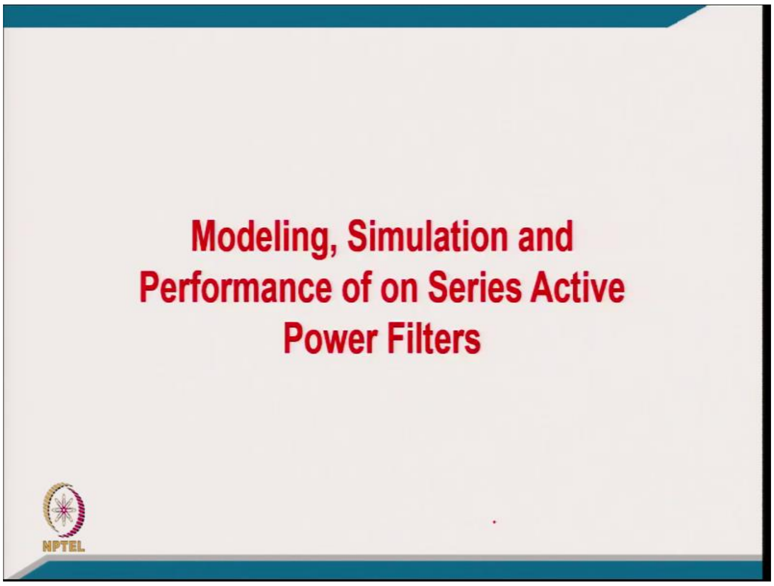

The modeling and simulation performance of series active power filter is presented in the screenshots herein.

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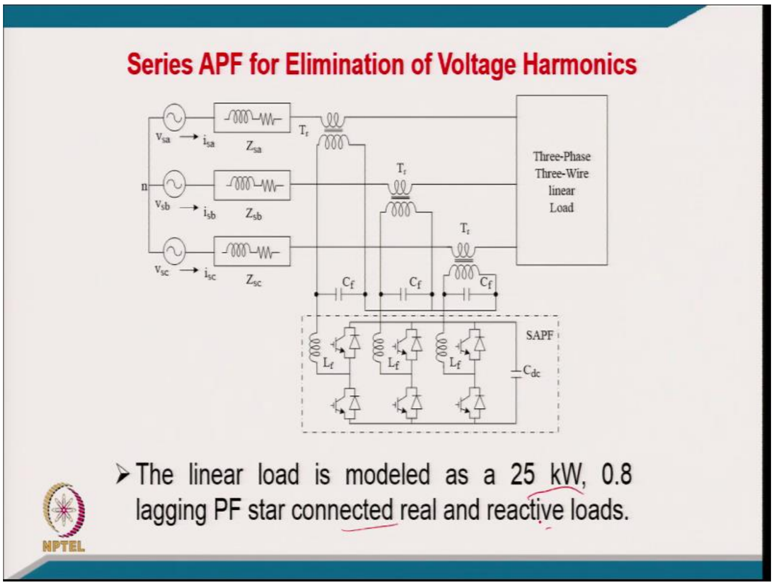

This is the circuit of three-phase three wire series active filter with a linear load of 25 kilowatt 0.8 lagging power factor. The supply voltages are distorted.

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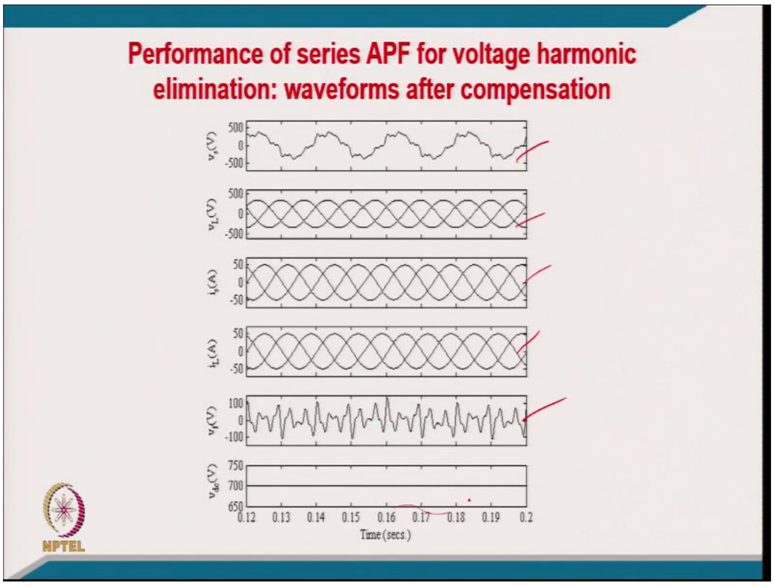

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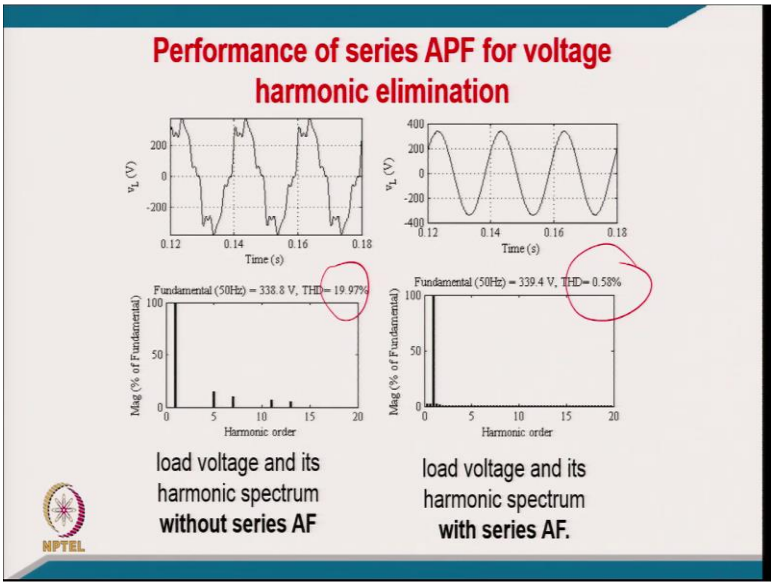

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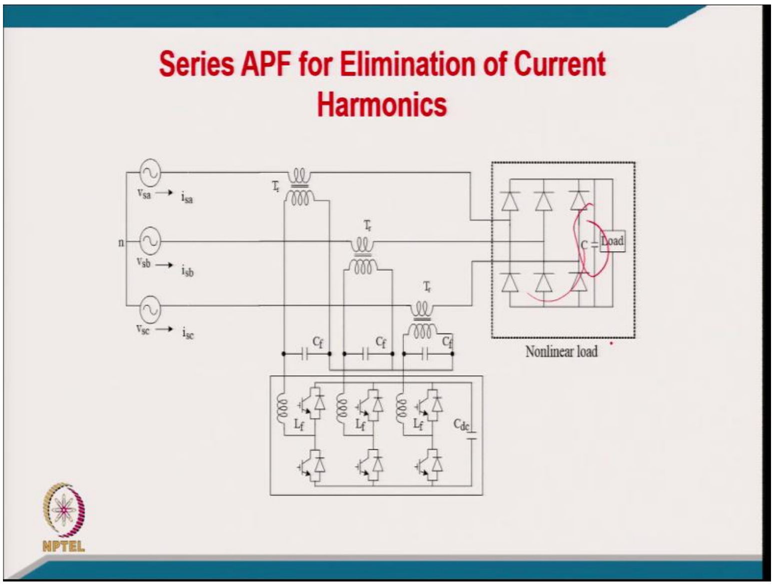

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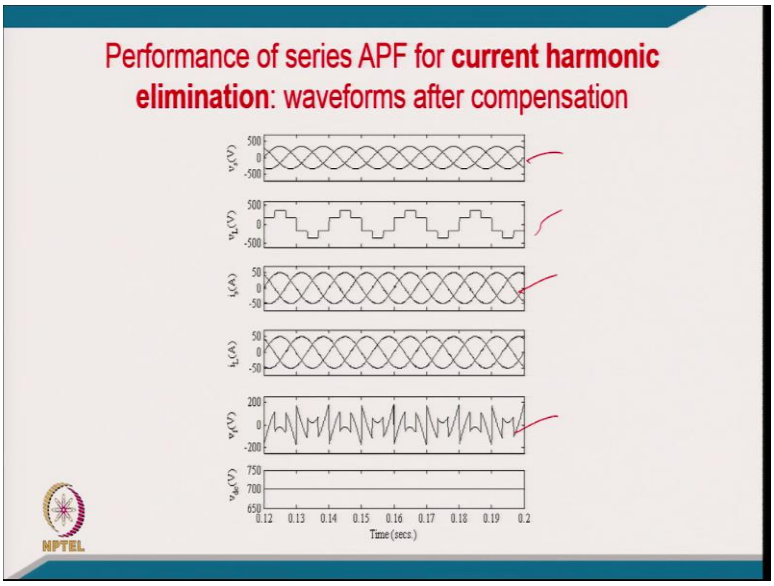

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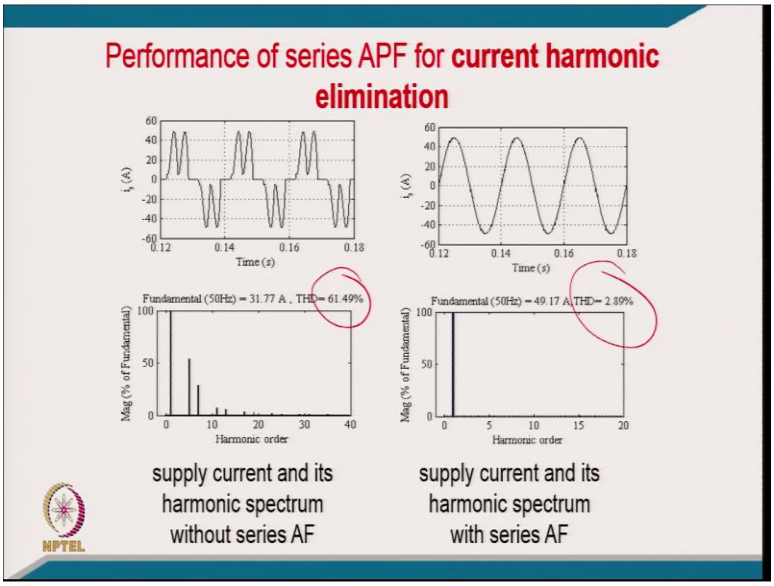

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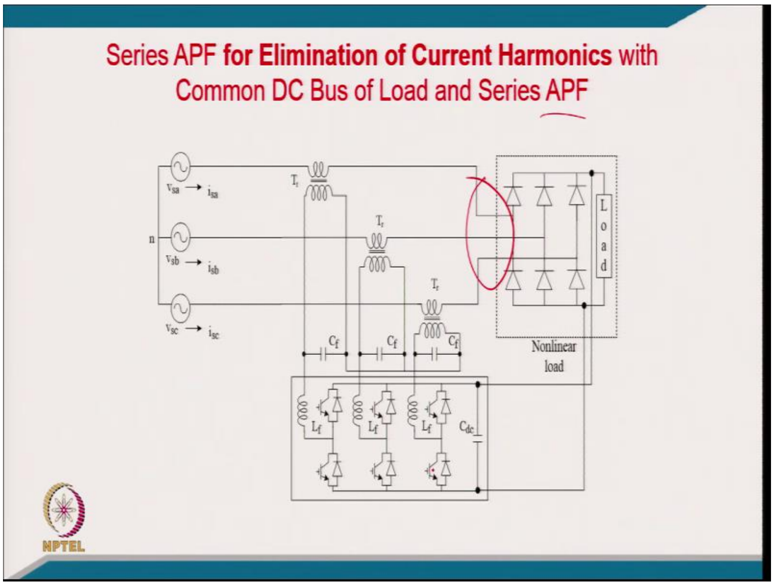

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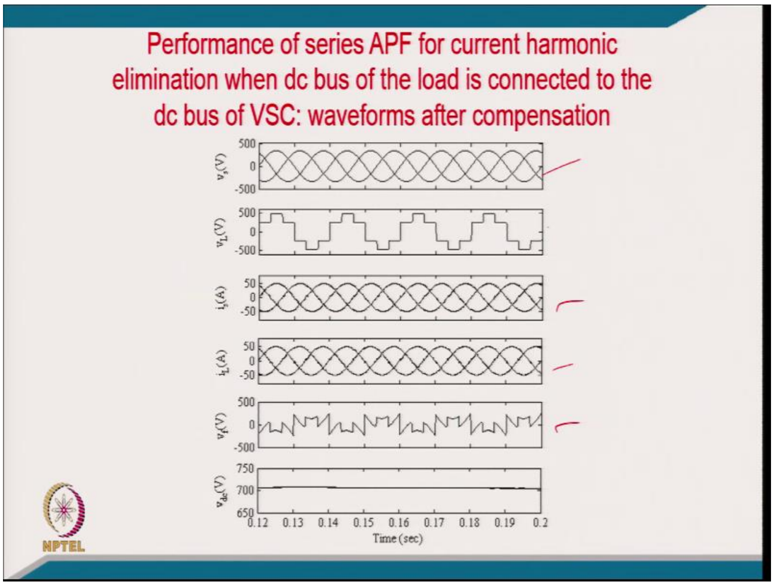

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