Power Quality
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Lecture - 21
Shunt Active Power Filters (contd.)

Welcome to the course on Power Quality. We will discuss the control operation of the Shunt Active Power Filter. We classify these control algorithm into two categories.

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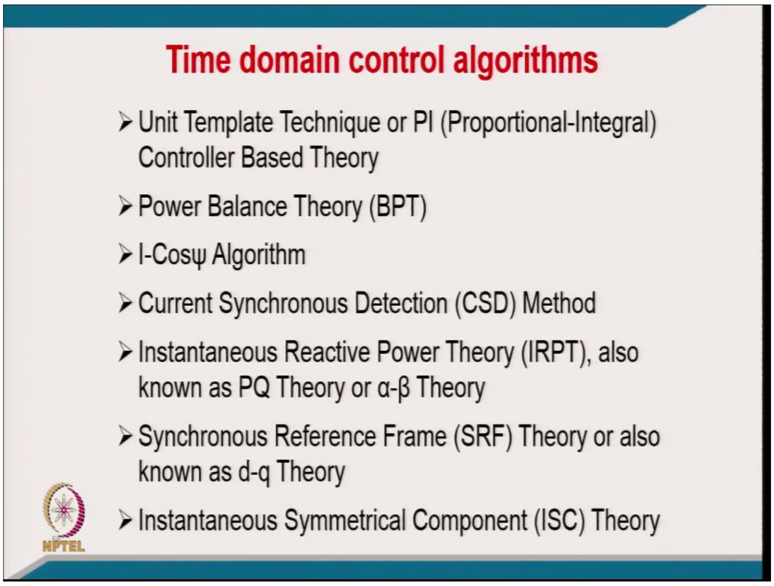

First category is the time domain control algorithm. Few examples are

- Unit template based algorithm or PI controller based algorithm
- Power balance theory based control algorithm
- I-cos phi algorithm
- Current synchronous detection algorithm
- Instantaneous reactive power theory also known PQ theory or alpha-beta theory.
- Synchronous reference frame theory also known as a d-q theory, or as symmetrical component theory.

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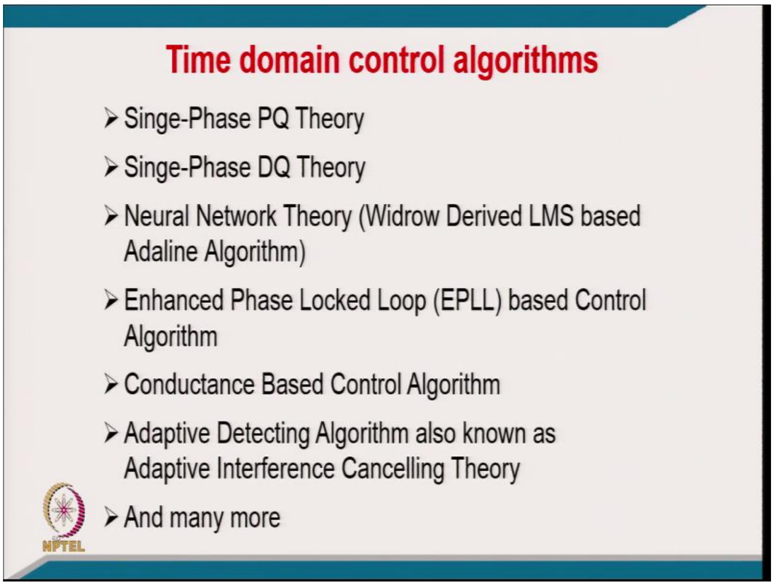

- Single phase PQ theories
- Single phase DQ theory
- Neural network theory
- Least mean square based Adaline algorithm
- Enhanced PLL based control algorithm
- Conductance based control algorithm.

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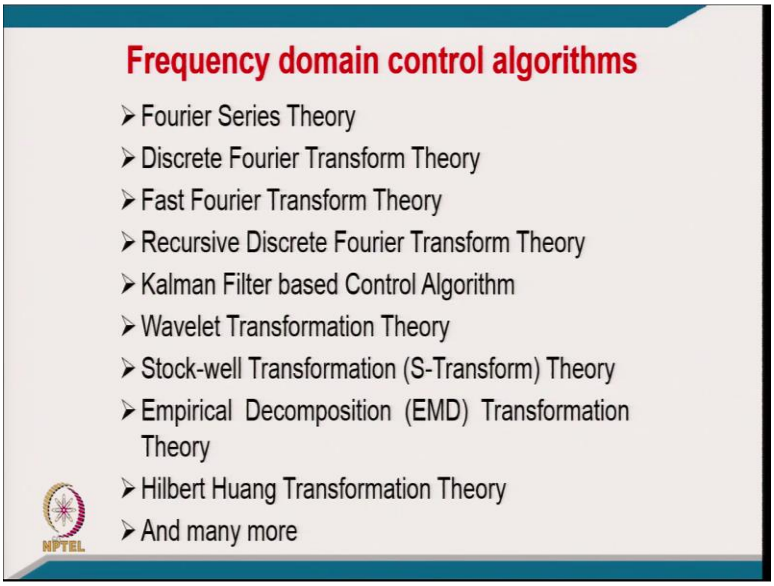

The second category is the frequency domain control algorithms like

- Fourier series theory
- Discrete Fourier transform theory
- Fast Fourier transform theory
- Recursive Discrete Fourier transform theor
- Kalman filter based control algorithm
- Wavelet transformation based theory
- Stock-well transformation based theory
- Empirical decomposition transformation theory
- Hilbert Huang transform theory

We cannot discuss all of them, but here we will discuss only a couple; just to give you an idea.

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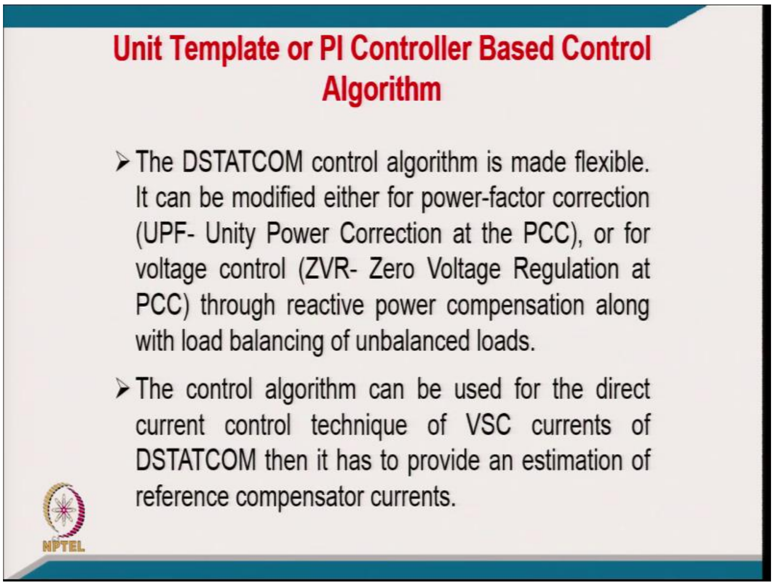

Here, DSTATCOM control theories are made flexible. It can be modified for power-factor correction or voltage regulation. Zero voltage regulation through reactive power compensation with load balancing and harmonic elimination.

This control algorithm can be used for direct current control of voltage source converter current.

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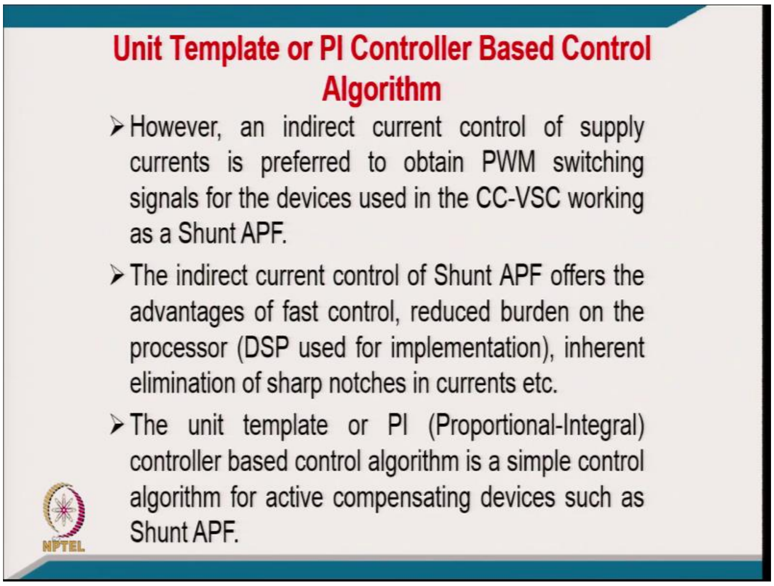

However, an indirect current control of supply current or grid current is generally preferred. The indirect current control of shunt active filter offers the advantage of fast control, reduced burden on the processor for the implementation and inherent elimination of sharp notches in the current.

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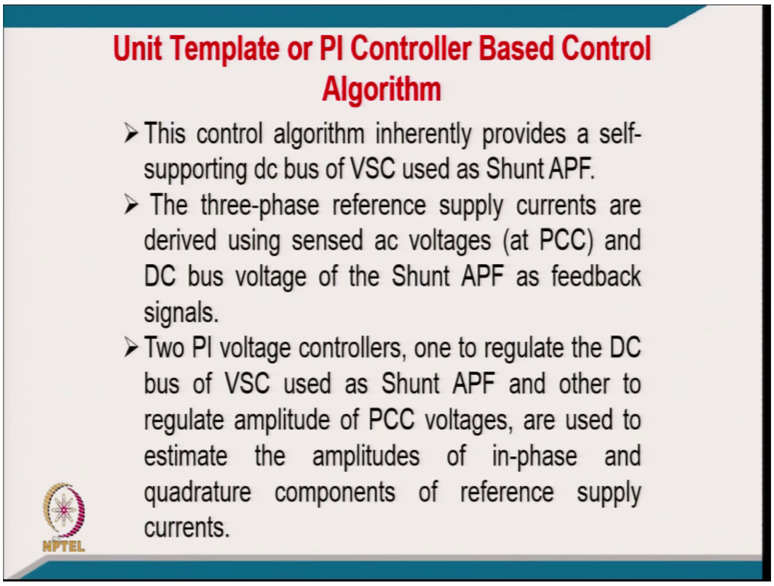

The unit template or PI controller based control algorithm is simple control algorithm for active compensating devices such as shunt active filter. The control algorithm inherently provides a self-supporting dc bus used for shunt active power filter. And, the three-phase reference grid current are derived using a sensed ac voltage DC bus voltage of the shunt active filter as a feedback signal.

The two PI controller; one to regulate the DC bus of voltage source converter used as a shunt active filter and other to regulate the amplitude of PCC voltage are used to estimate the amplitude of in phase and quadrature component of reference supply current.

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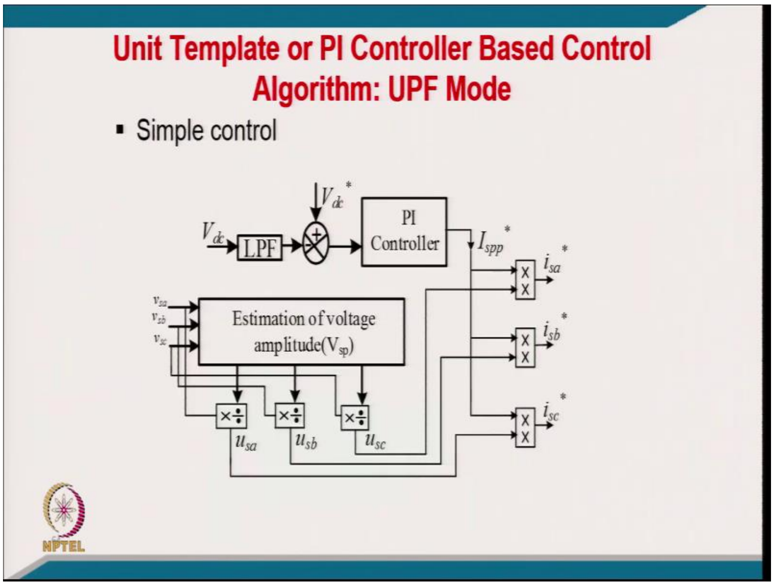

These is the block diagram of the control scheme. The following screenshots represent the expressions used in the control strategy.

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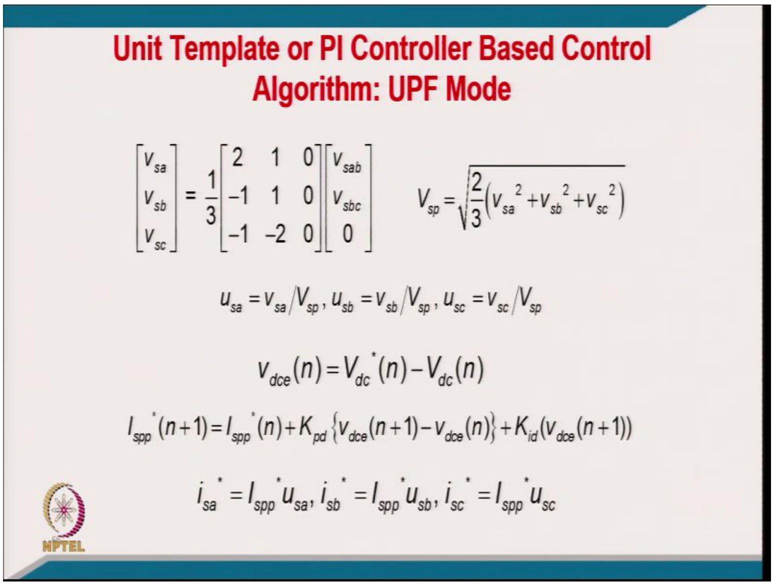

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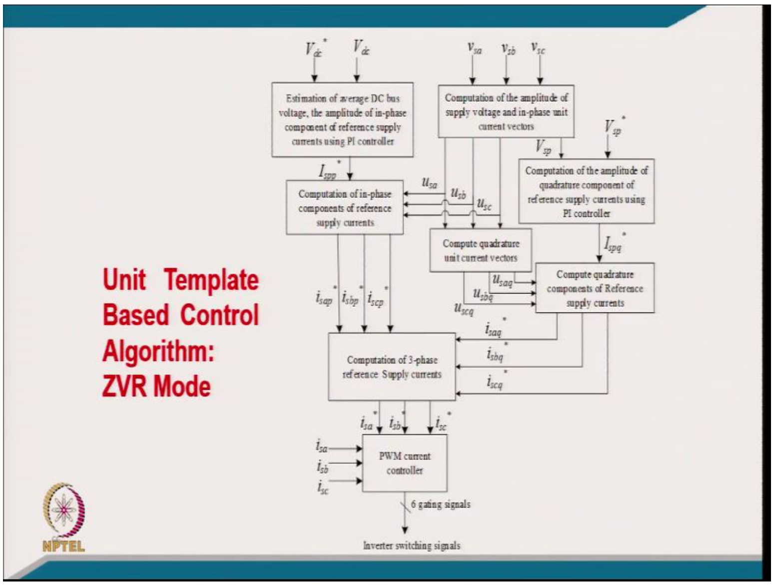

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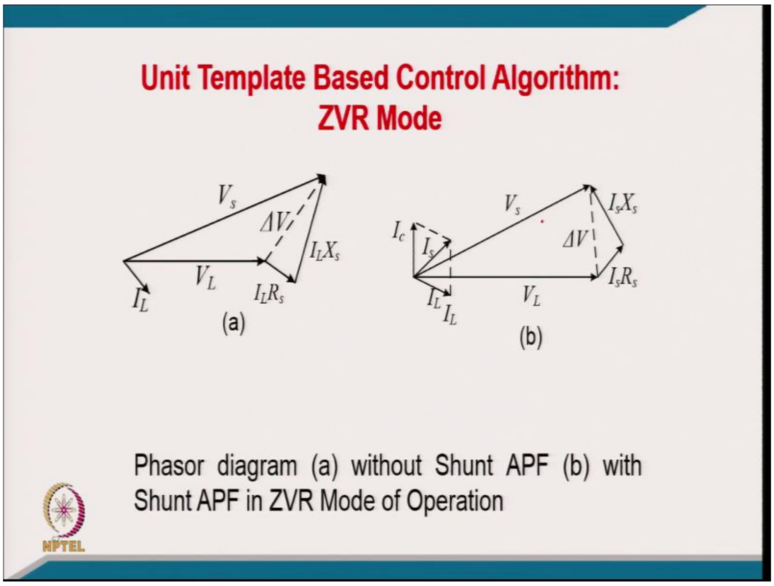

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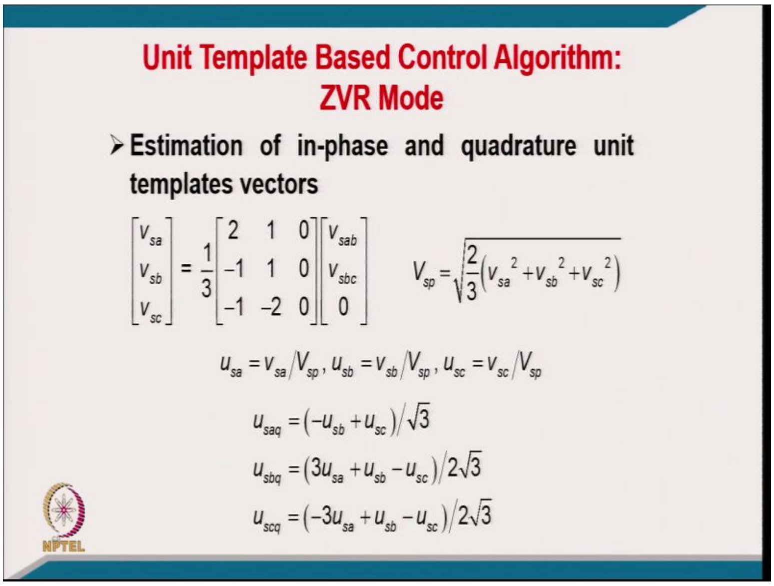

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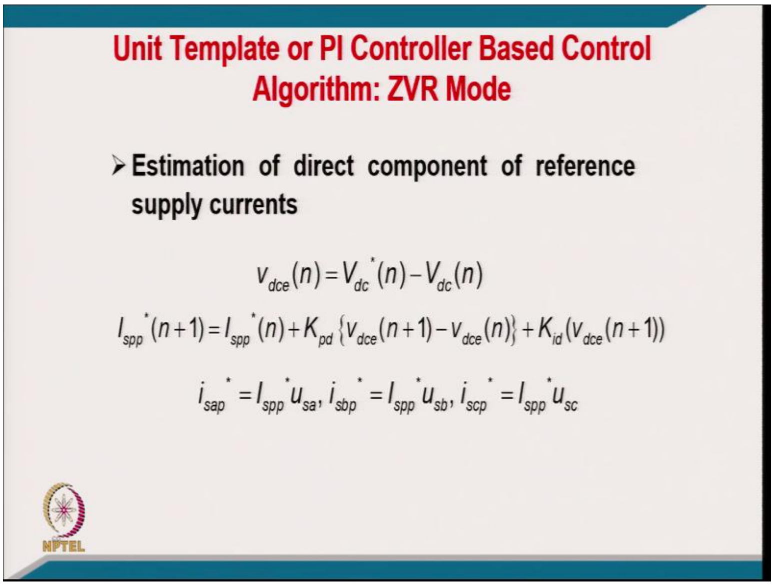

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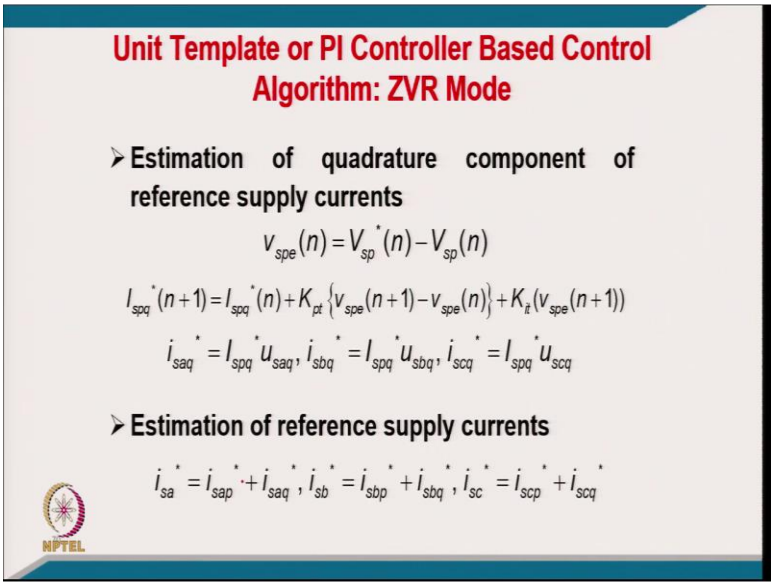

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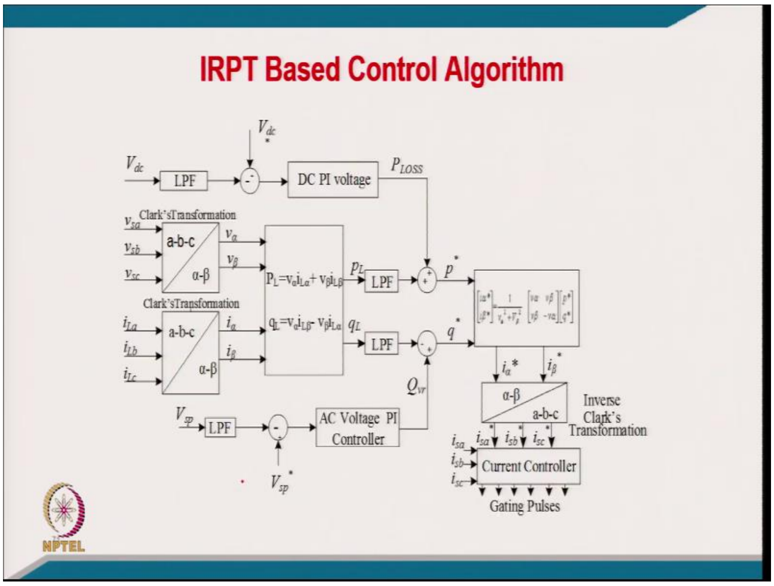

This is another control algorithm which is derived from the instantaneous reactive power theory or alpha-beta theory. The control block diagram and associated expressions are detailed in the following screenshots.

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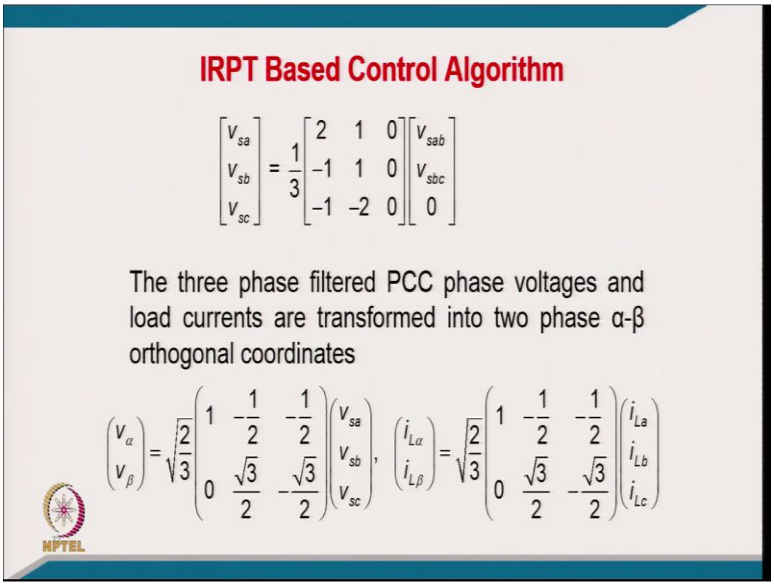

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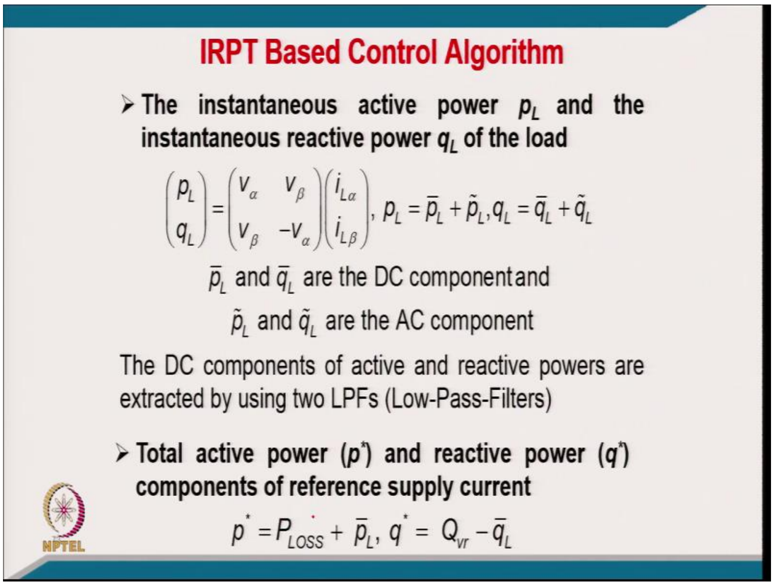

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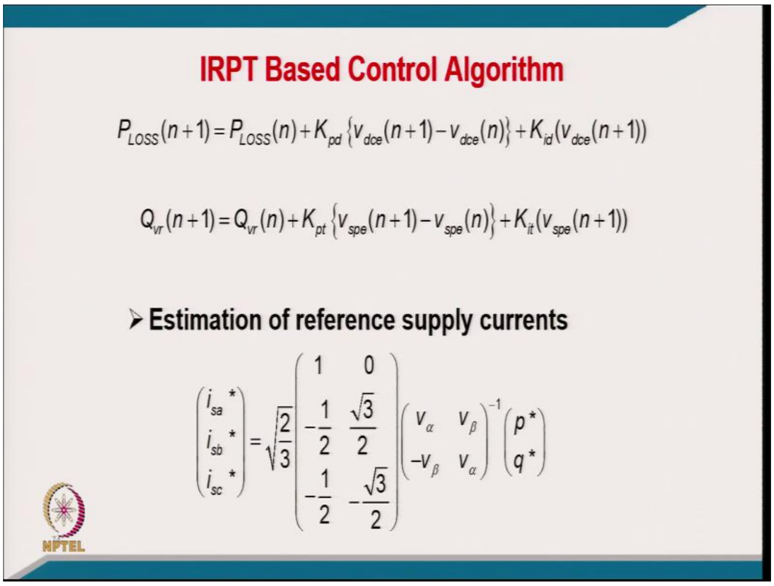

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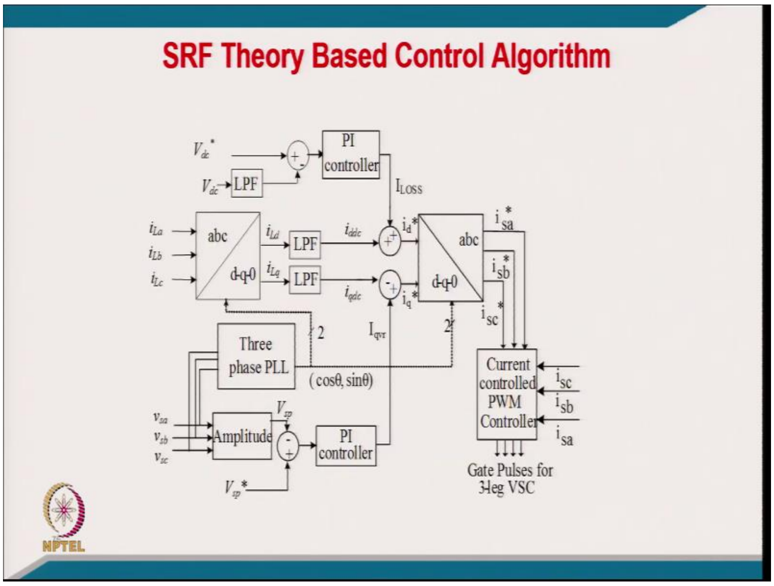

This is another control algorithm which is called synchronous reference frame theory. It is very extensively used. The block diagram and control expressions are derived as follows.

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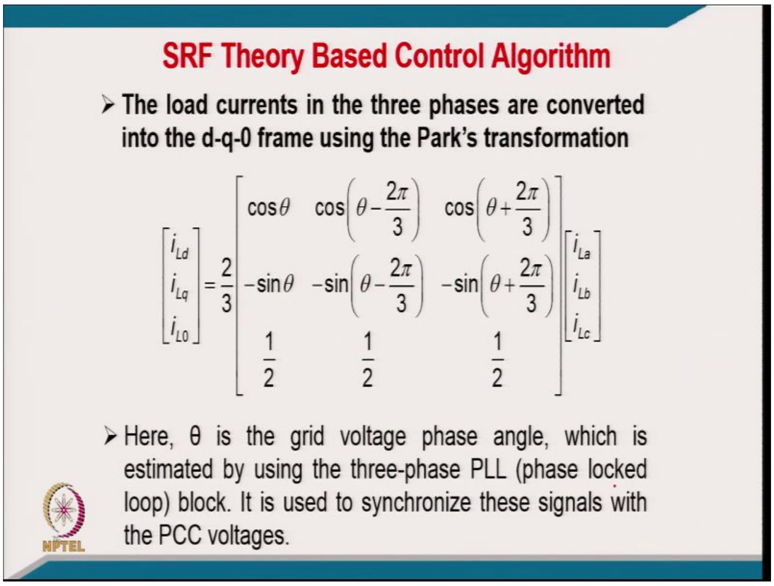

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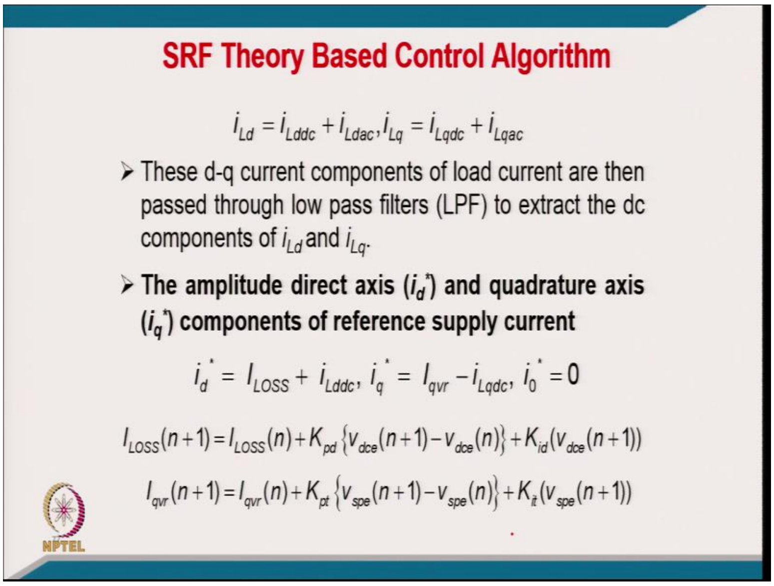

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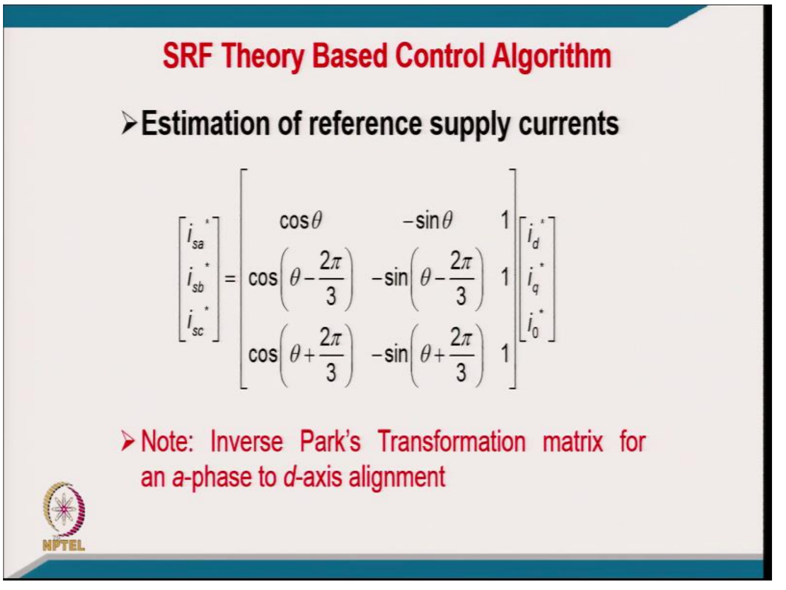

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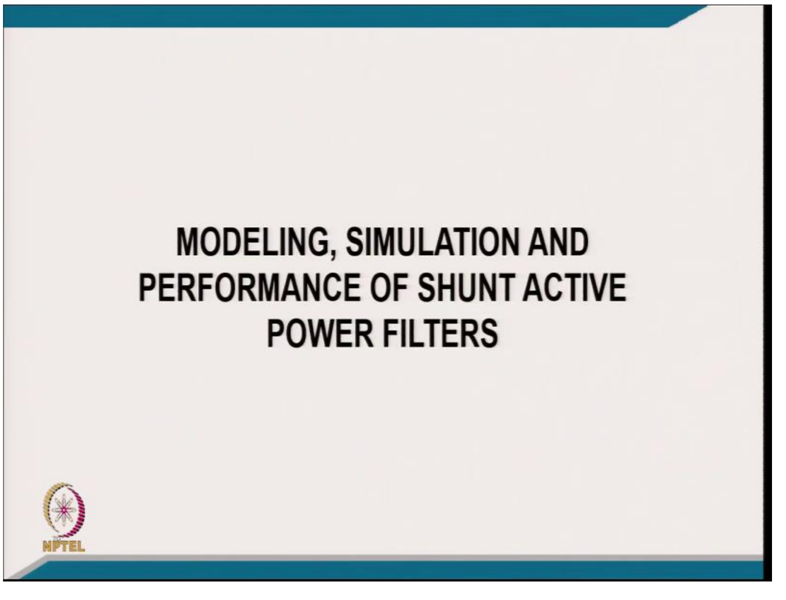

Based on the discussed control algorithms, few shunt active filter configurations are modelled and the simulated performances are described here. Please refer the screenshots.

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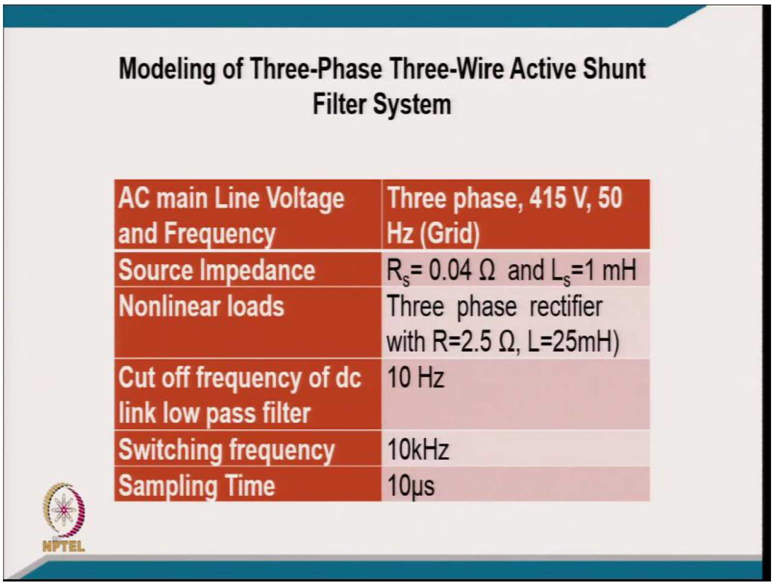

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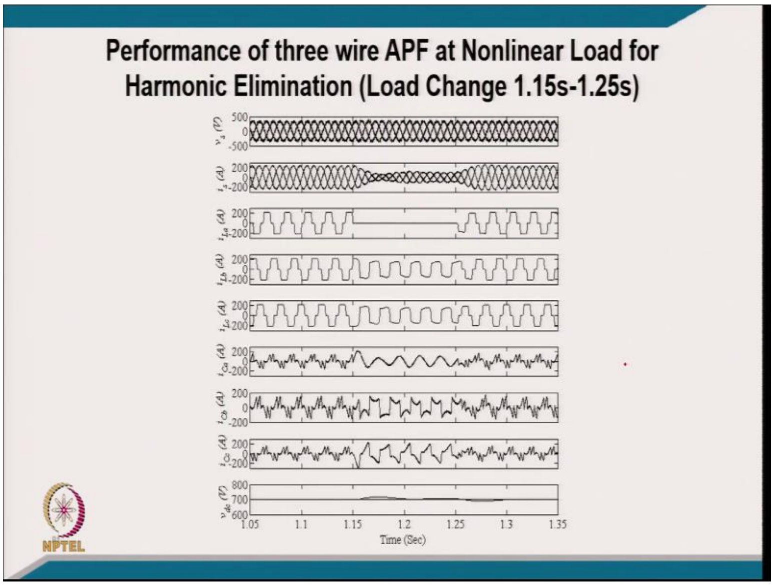

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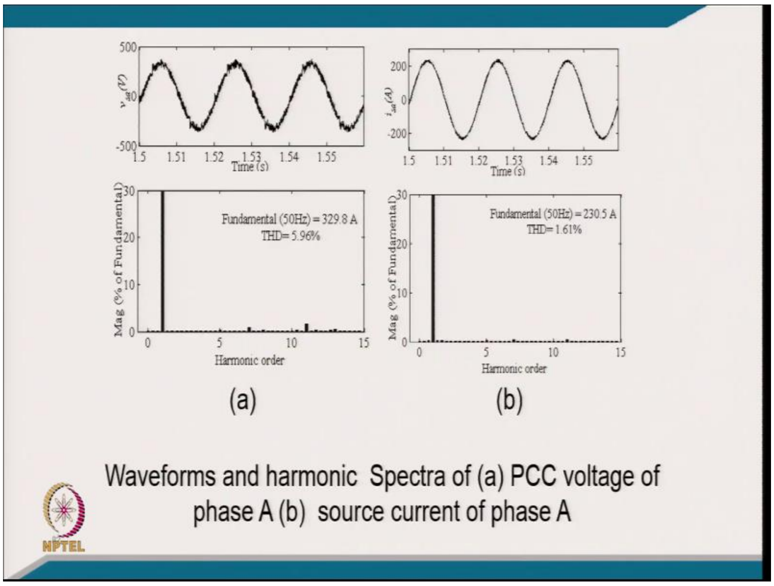

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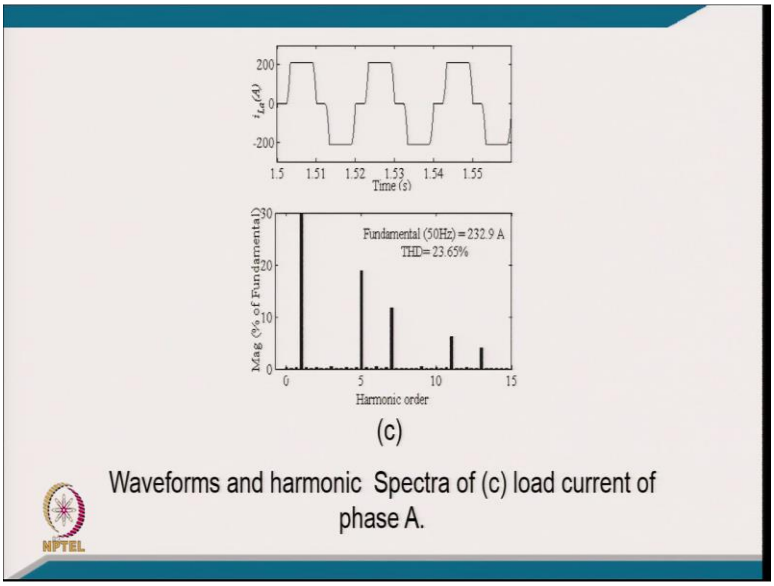

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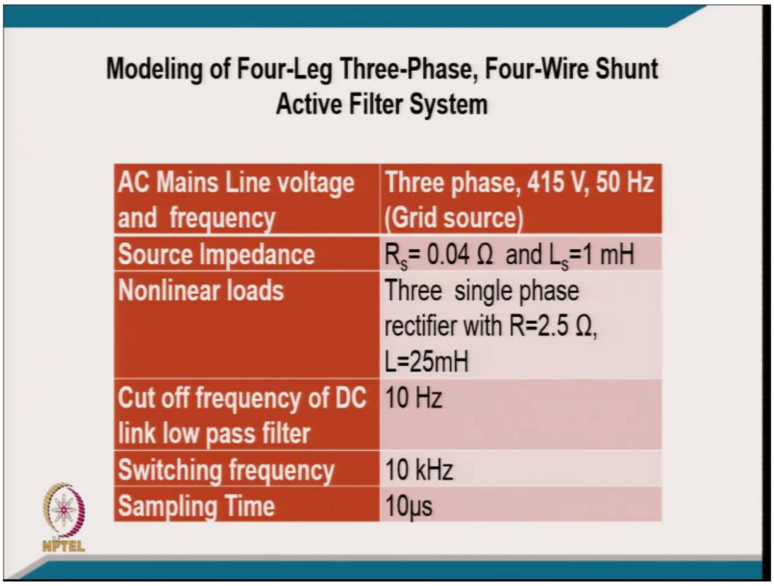

Modeling of Four-Leg Three-Phase, Four-Wire Shunt Active Filter System

AC Mains Line voltage and frequency	Three phase, 415 V, 50 Hz (Grid source)
Source Impedance	R_s= 0.04 Ω and L_s=1 mH
Nonlinear loads	Three single phase rectifier with R=2.5 Ω, L=25mH
Cut off frequency of DC link low pass filter	10 Hz
Switching frequency	10 kHz
Sampling Time	10μs

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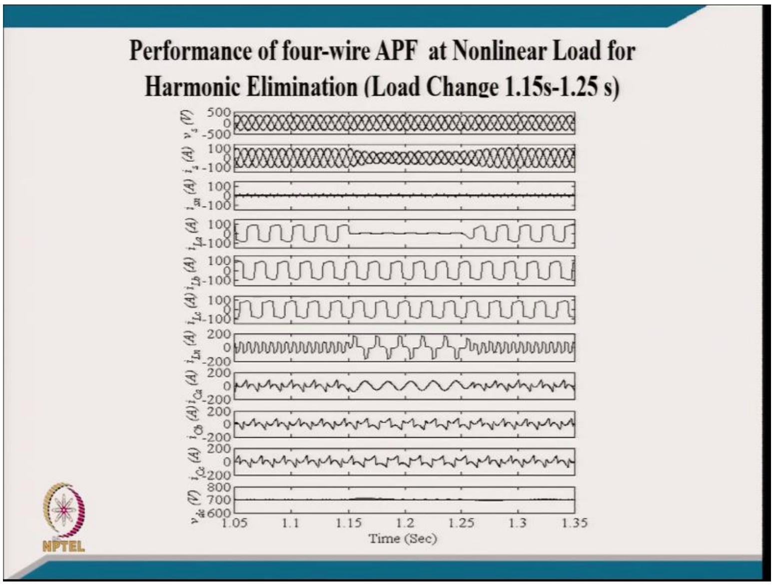

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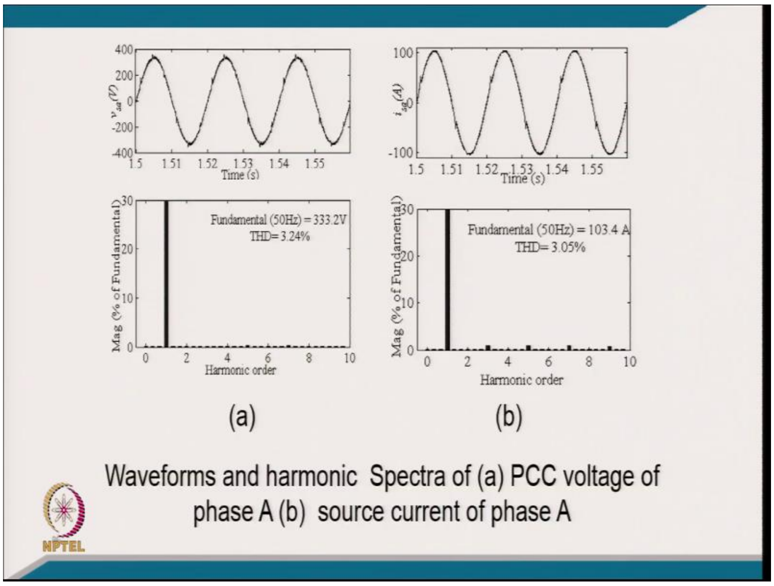

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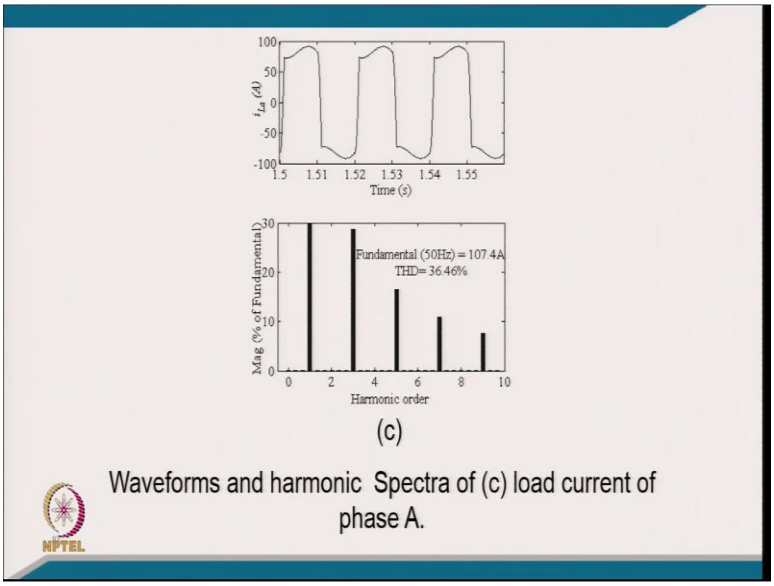

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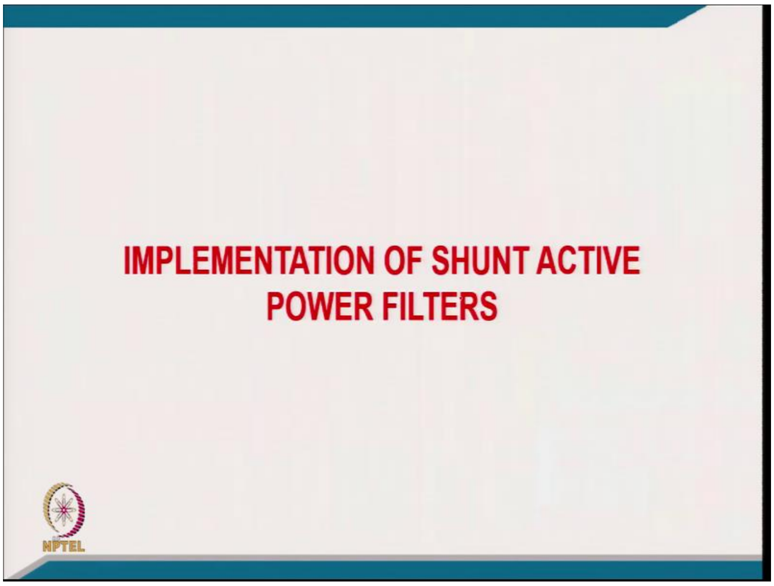

Now, experimental implementation of the above configurations are detailed.

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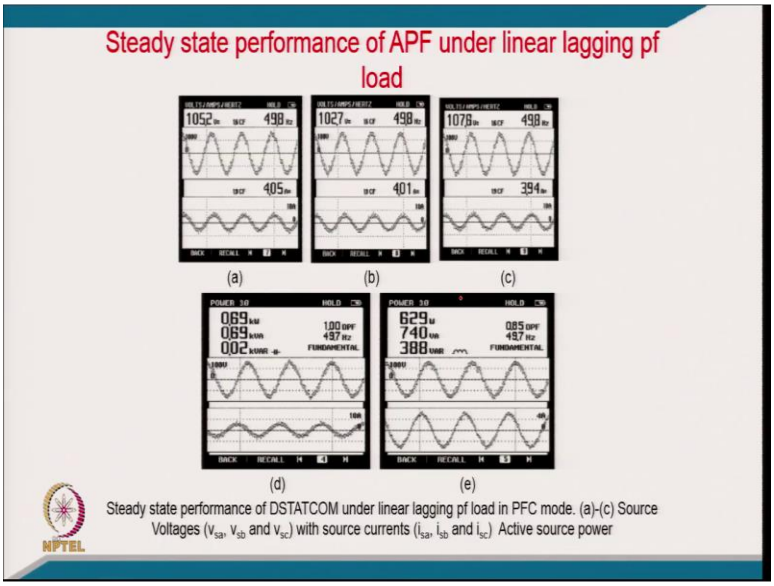

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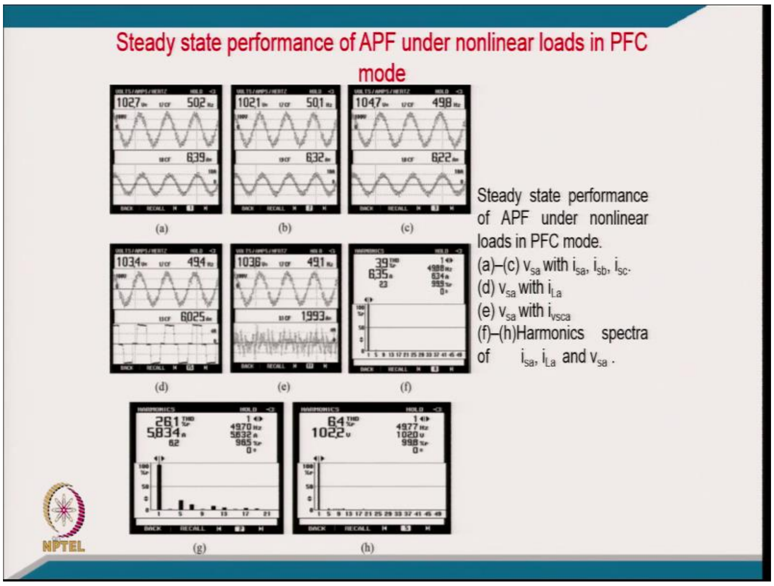

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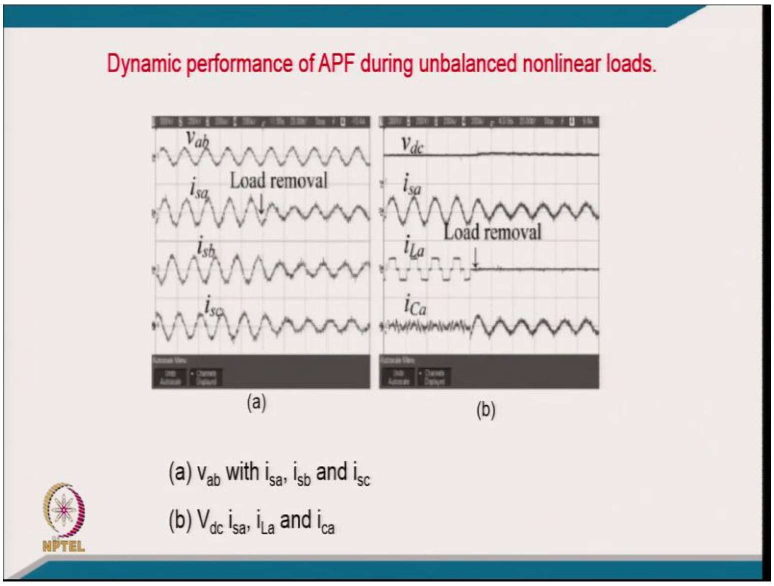

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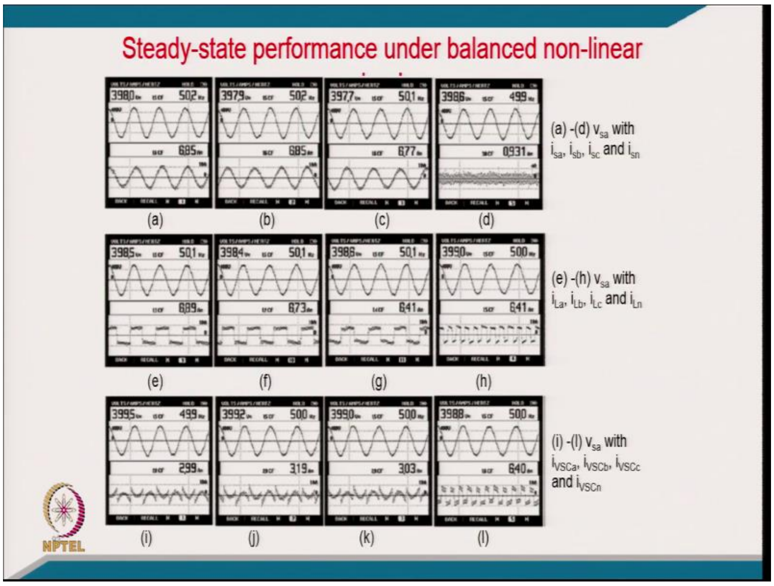

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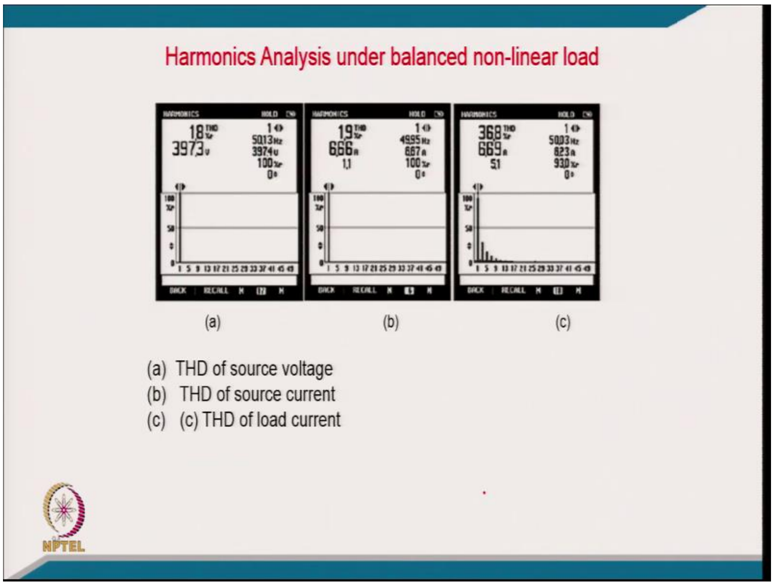

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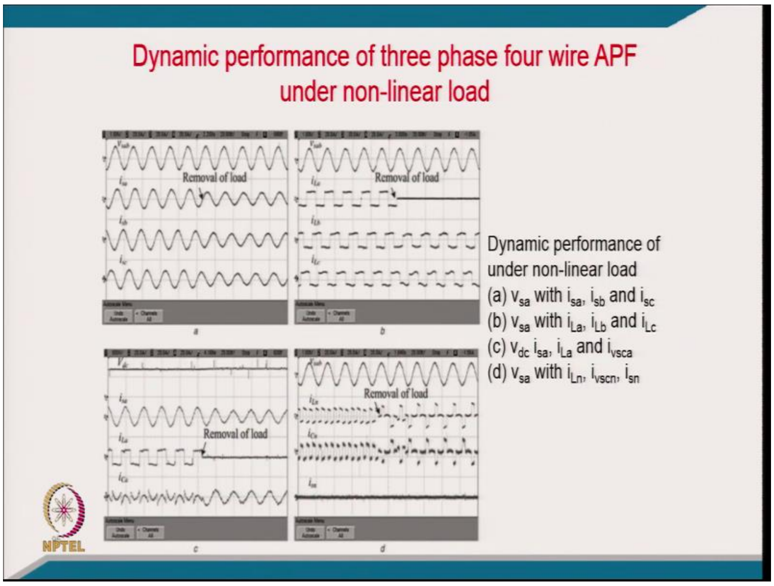

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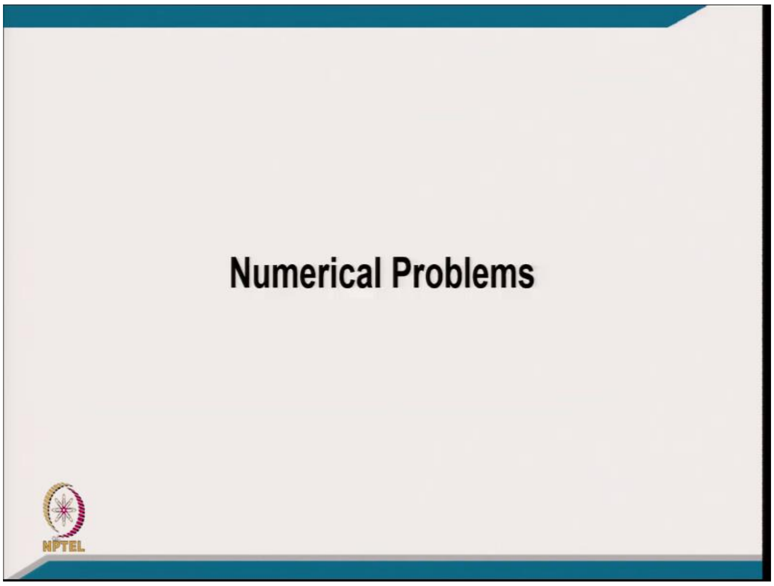

Now we will be talking about some of the numerical problems.

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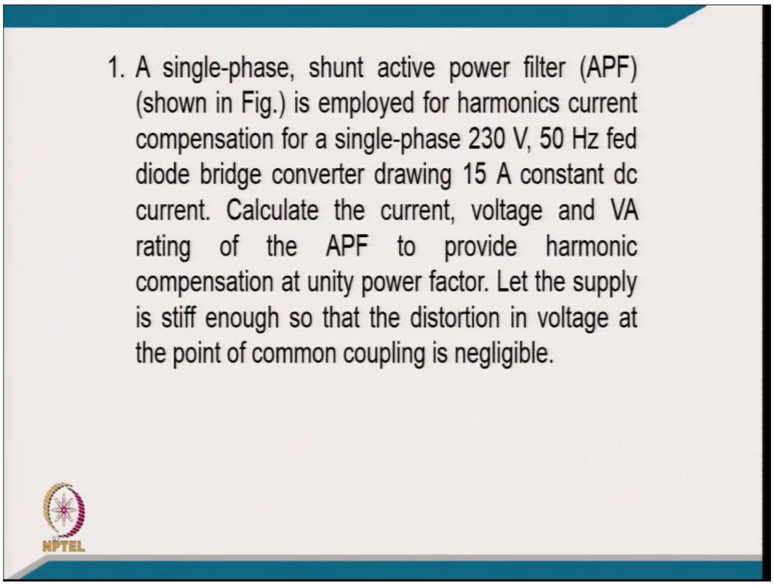

A single-phase, shunt active filter, I mean is employed for harmonic current compensation of a single phase 230 volt, 50 Hertz fed diode bridge converter drawing fifteen ampere constant dc current. Calculate the current voltage and VA rating of the shunt active power filter to provide a harmonic compensation at unity power factor. Let the supply is a stiff enough so that the distortion in voltage at the point of common coupling is negligible.

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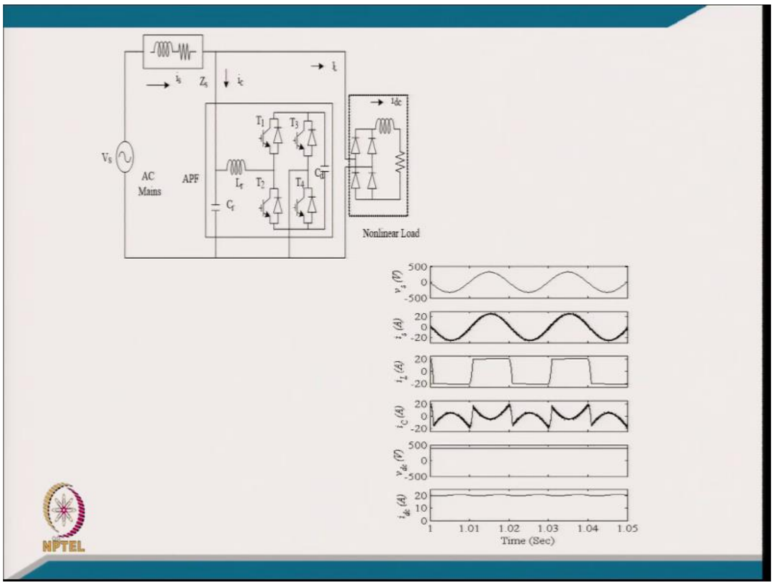

We have a non-linear load with diode rectifier with the RL load and constant current on DC side. The solution to the numerical is detailed in the following screenshots.

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Solution: Given that, V_s = 230 V, f=50 Hz, I_{dc} = 15A.

In single-phase diode bridge converter:

$I_s = I_{dc} = 15A$

$I_{s1} = (2\sqrt{2}/\pi)\, I_{dc} = 0.9\, I_{dc} = 13.5\ A$

Current rating of APF=current flowing through the filter

$= I_f = I_h = \sqrt{(Is^2 - I_{s1}^2)} = \sqrt{(15^2 - 13.5^2)} = 6.538A$

Voltage rating of the APF=voltage across the filter = V_f $= V_s = 230$ V

VA Rating of the APF=S = $V_f I_f$ = 230*6.538 = 1.503 kVA.

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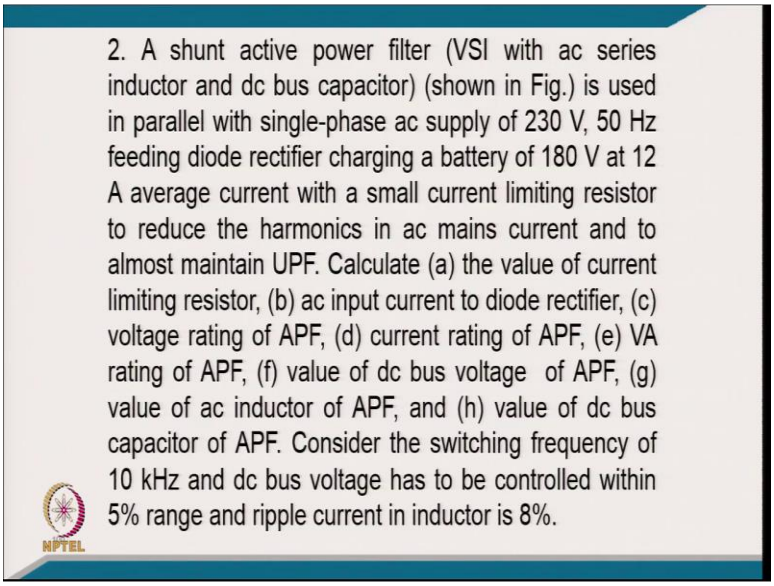

Coming to the typically second numerical problems; The shunt active power filter the voltage source inverter with the ac series inductor and dc capacitor shown in the figure is used in parallel with a single phase supply of 230 volt 50 Hertz feeding diode base rectifier charging a battery of 180 volt at 12 ampere average current with a small current limiting resistor to reduce the harmonics in ac mains current and to almost maintain unity power factor. Calculate the value of current limiting resistor the, ac input current to diode rectifier, the voltage rating of shunt active power filter, the current rating of active power filter, VA rating of active power filter, the value of dc bus voltage of active power filter, the value of ac inductor of active power filter and the value of dc bus capacitor of active power filter. Consider the switching frequency of 10 kilohertz and the dc bus voltage has to be controlled 5 percent and the ripple current inductor is to be 8 percent.

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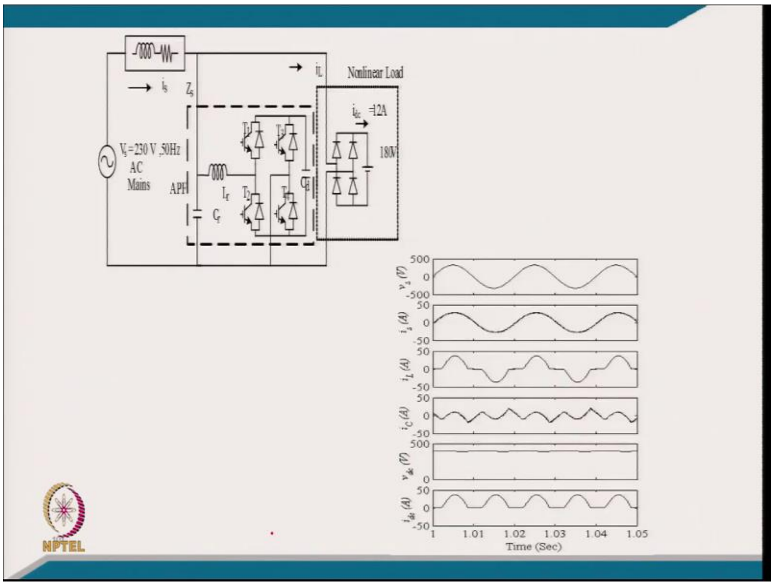

The solution to the numerical is detailed in the following screenshots.

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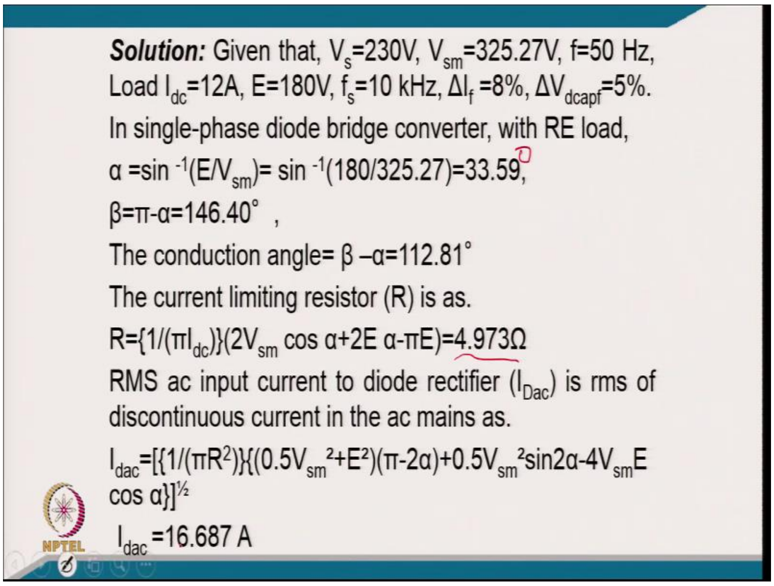

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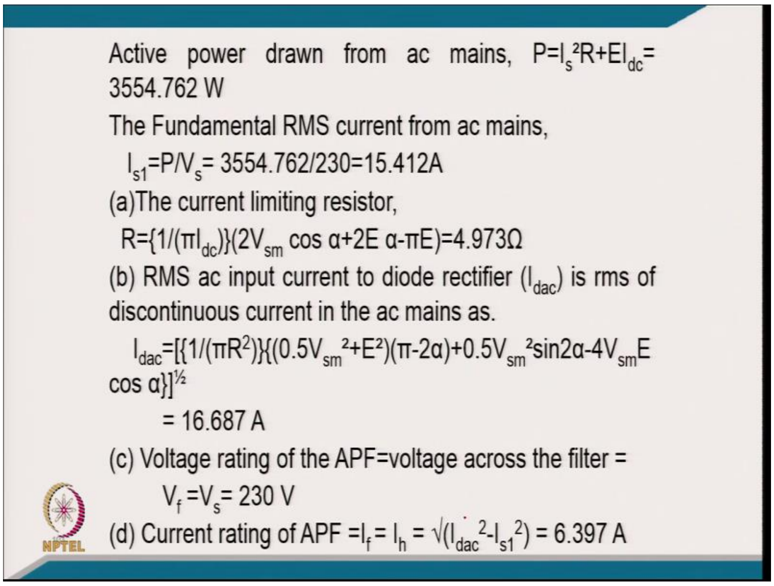

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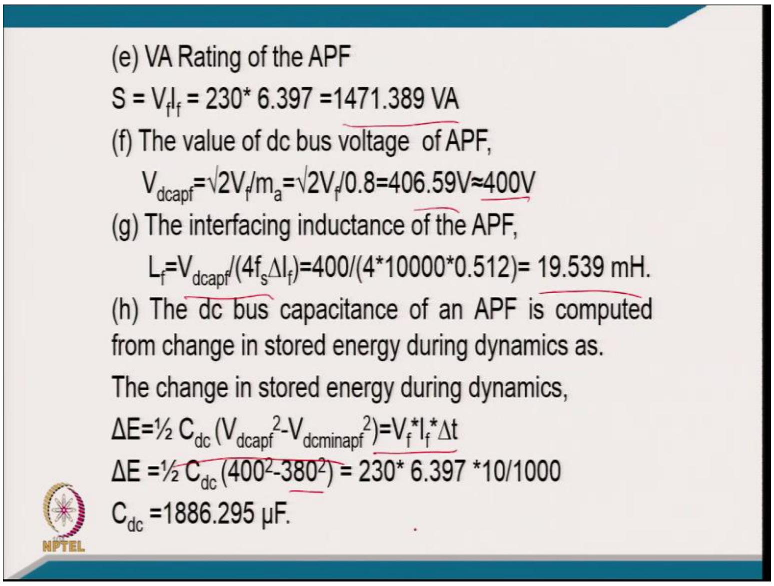

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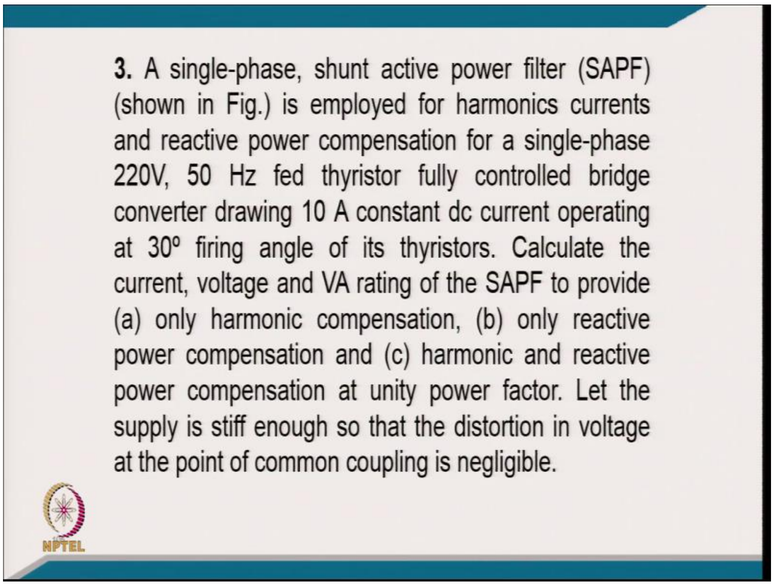

Coming to third numerical problem: A single phase shunt active power filter is employed for the harmonic currents and reactive power compensation, for a single phase 230 volt 50 Hertz fed thyristor fully control converter drawing a 10 ampere dc current operating at 30 degree fire angle of it is thyristor.

Calculate the current, voltage and VA rating of the shunt active power filter to provide; a, only harmonics compensation; b, only reactive power compensation; c, harmonics and reactive power compensation at the unity power factor. Let the supply is stiff enough so that the distortion in voltage at the point of common coupling is negligible.

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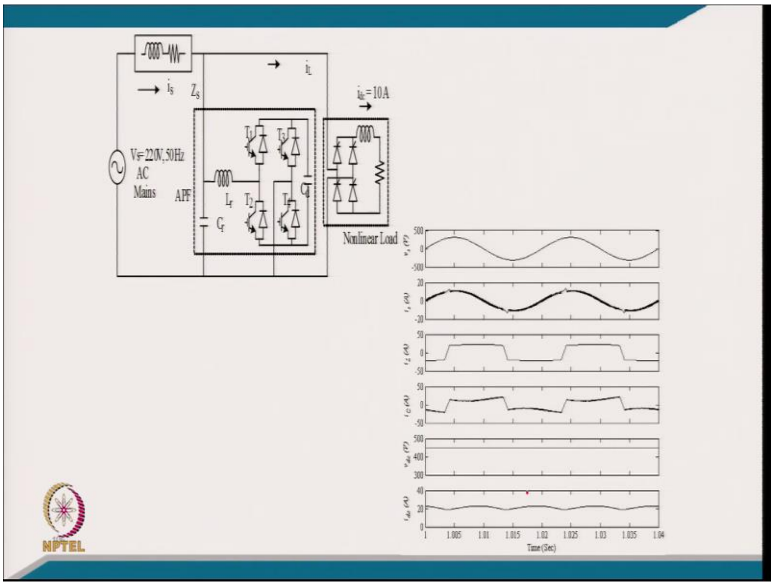

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The solution to the numerical is detailed in the following screenshots.

Solution: Given that, V_s = 220 V, f=50 Hz, I_{dc} = 10 A, $\alpha = 30^0$

In single-phase thyristor bridge converter:

$I_s = I_{dc}$ = 10 A and

$I_{s1} = 0.9\ I_{dc}$ = 9A

Hence total rms harmonic current,

$I_h = \sqrt{(I_s^2 - I_{s1}^2)} = \sqrt{(10^2 - 9^2)} = 4.359$ A

Active power component of supply current

$I_{s1a} = I_{s1} \cos\theta_1 = I_{s1} \cos\alpha = 9\cos30^0 = 7.794$ A

Total harmonics and reactive current ;

$I_f = \sqrt{(I_s^2 - I_{s1a}^2)} = \sqrt{(10^2 - 7.794^2)} = 6.265$ A

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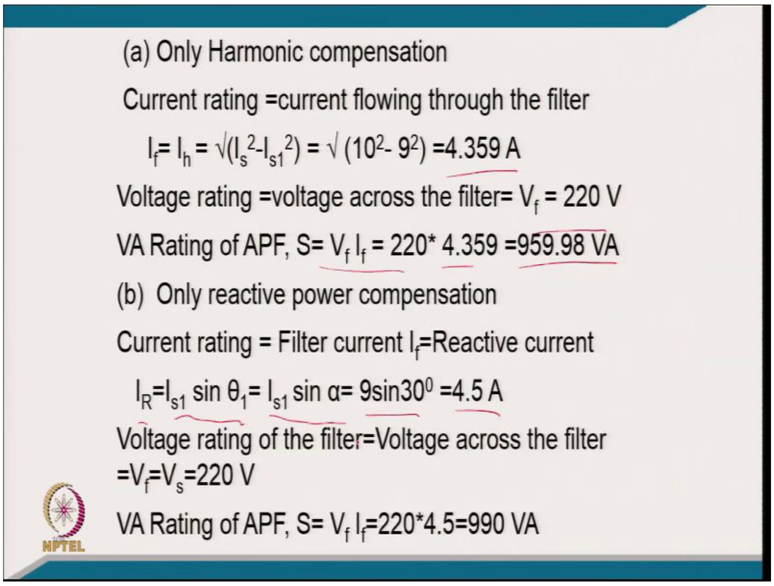

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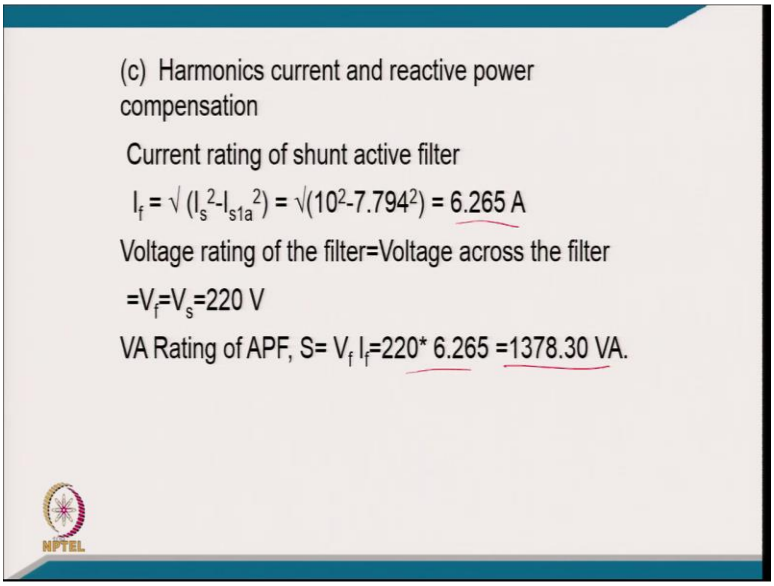

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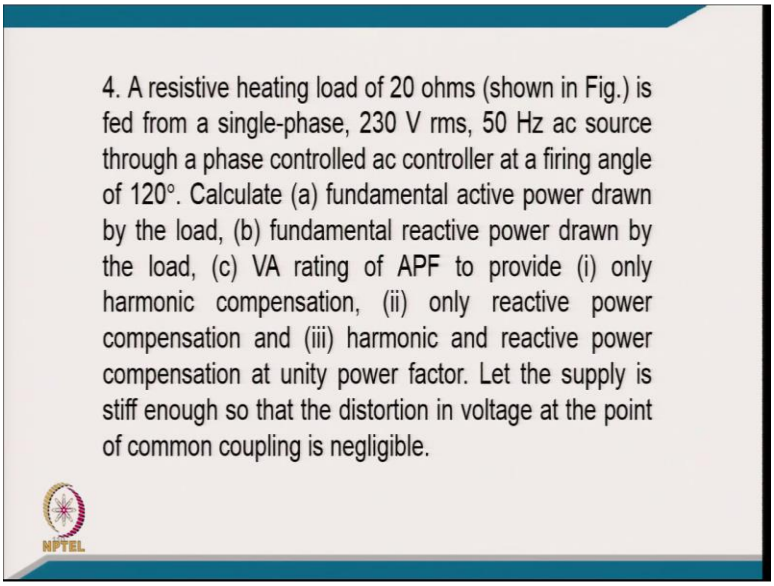

Now, coming to the fourth numerical problem: Resistive heating load of 20 ohm is fed from a single phase 230 volt rms, 50 Hertz ac source through a phase control ac controller at a firing angle of 120 degree.

Calculate the fundamental active power drawn by the load, fundamental reactive power drawn by the load, VA rating of active shunt filter to provide the only harmonic compensation; b, only reactive power compensation and third is a harmonics and reactive power compensation at unity power factor let the supply voltage is stiff enough so that the distortion in voltage at the point of common coupling negligible.

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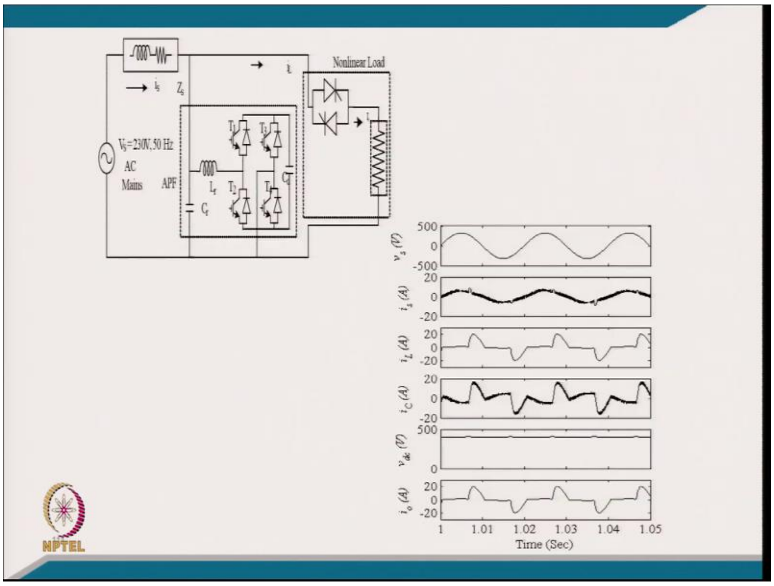

The solution to the numerical is detailed in the following screenshots.

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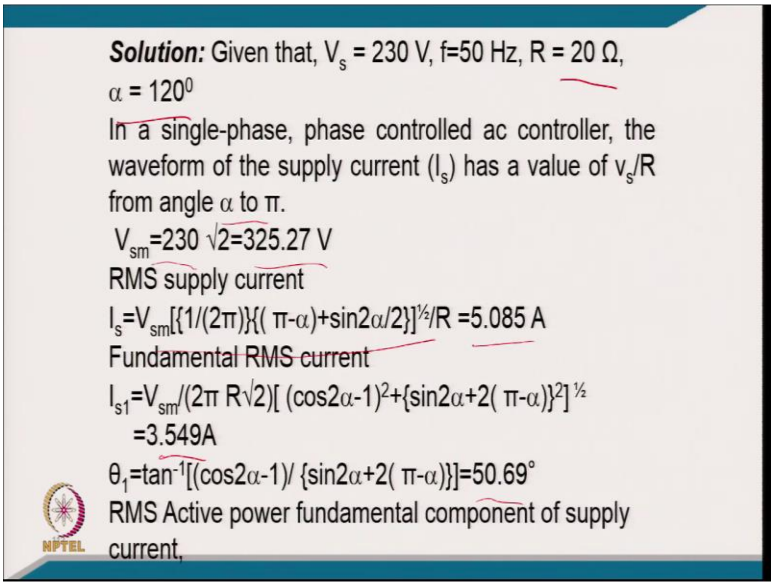

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$I_{s1a} = I_{s1}\cos\theta_1 = 2.248$ A

Hence total rms harmonic current,

$I_h = \sqrt{(I_s^2 - I_{s1}^2)} = \sqrt{(5.085^2 - 3.549^2)} = 3.642$ A

RMS reactive power fundamental component of supply current,

$I_{s1r} = I_{s1}\sin\theta_1 = I_{s1}\sqrt{(1 - \cos\theta_1^2)} = 2.746$ A

Total harmonics and reactive current = I_f

$= \sqrt{(I_s^2 - I_{s1a}^2)} = \sqrt{(5.085^2 - 2.248^2)} = 4.561$A

(a) Fundamental active power drawn by the load,

$P_1 = V_s I_{s1}\cos\theta_1 = 517.04$ W

(b) Fundamental reactive power drawn by the load,

$Q_1 = V_s I_{s1}\sin\theta_1 = 631.580$ VAR

(Refer Slide Time: 33:18)

(c) VA rating of APF to provide

(i) Only Harmonic compensation

Current rating =current flowing through the filter

$I_f = I_h = \sqrt{(I_s^2 - I_{s1}^2)} = \sqrt{(5.085^2 - 3.549^2)} = 3.642$ A

Voltage rating =voltage across the filter= $V_f = 230$ V

VA Rating of APF, $S = V_f I_f = 230 * 3.642 = 792.26$ VA

(ii) Only reactive power compensation

Current rating = Filter current I_f=Reactive current

$I_R = I_{s1}\sin\theta_1 = I_{s1}\sin\theta_1 = I_{s1}\sqrt{(1 - \cos\theta_1^2)} = 2.746$ A

Voltage rating of the filter=Voltage across the filter

$= V_f = V_s = 230$ V

VA Rating of APF, $S = V_f I_f = Q_1 = V_s I_{s1}\sin\theta_1$

$S = 631.580$ VAR

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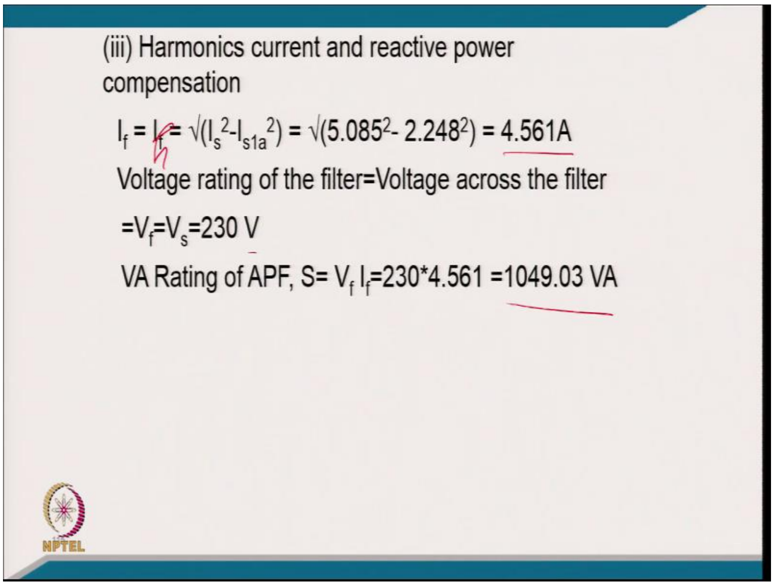

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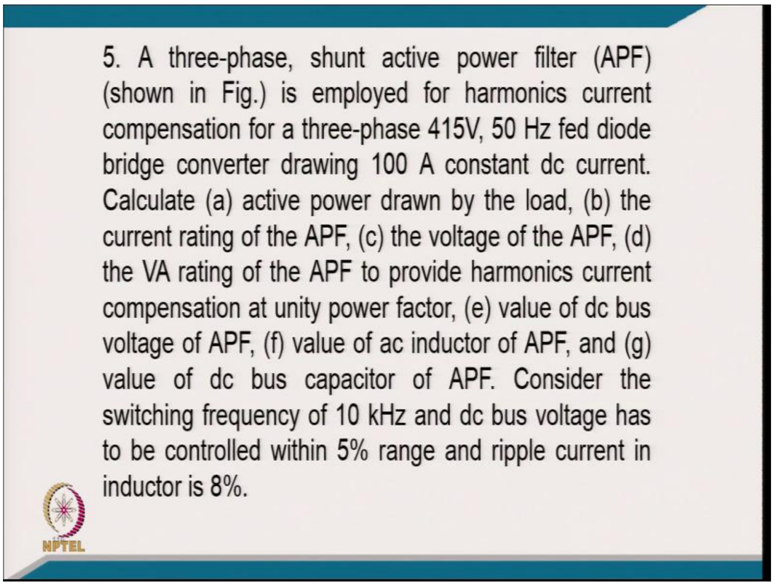

Coming to the 5th numerical problem: A three-phase, shunt active power filter is employed for harmonic current compensation for three-phase 415 volt 50 Hertz fed diode bridge converter drawing 100 ampere constant dc current.

Calculate active power drawn by the load, current rating of active filter, voltage rating of active filter, the VA rating of active filter to provide harmonic current compensation at unity power factor, value of dc bus capacitor, value of ac inductor the value of dc bus capacitor of APF and consider the switching frequency of 10 kilohertz and dc bus voltage to be controlled within 5 percent and the ripple current is 8 percent like.

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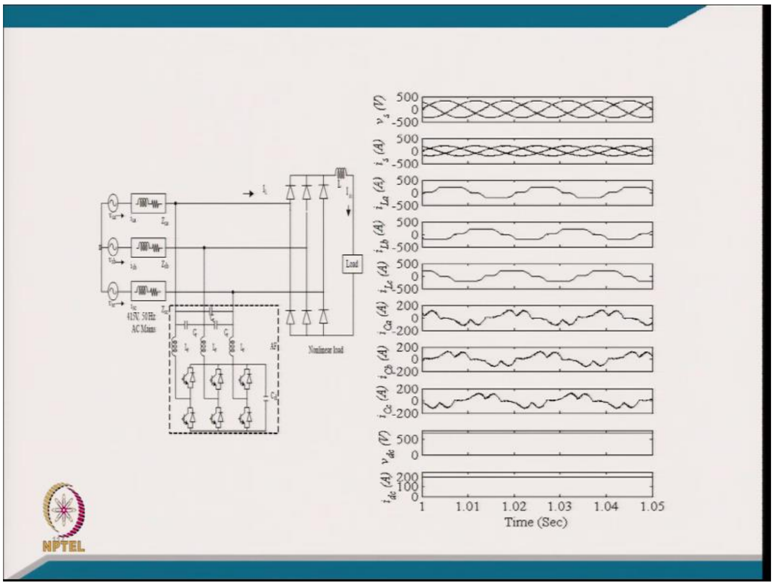


The solution to the numerical is detailed in the following screenshots.

(Refer Slide Time: 36:24)

Solution: Given that, $V_s=415/\sqrt{3}=239.6$ V, f=50 Hz, $I_{dc}=100A$

The rms of quasi-square wave load current,

$I_s=I_{dc}\sqrt{(2/3)}=81.65$ A

Moreover, the rms of fundamental component of quasi-square wave,

$I_{s1}=\{(\sqrt{6})/\pi\}\, I_{dc}=77.97A$

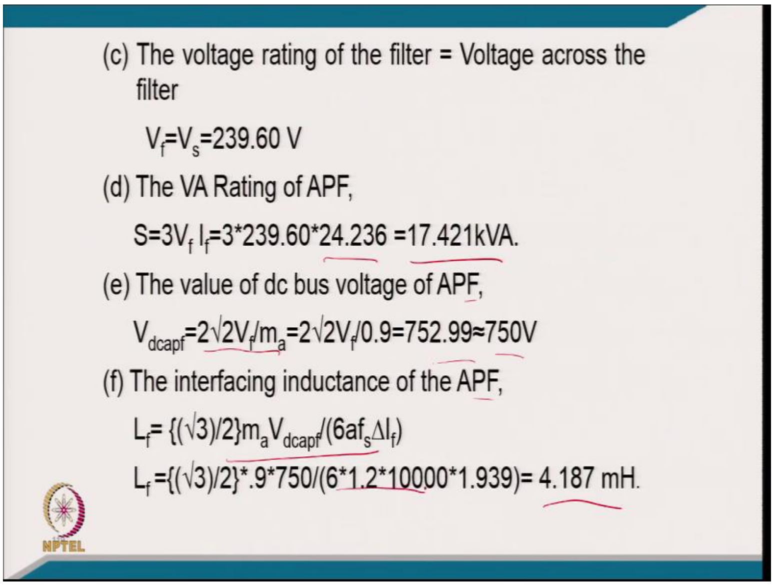
(a) The active power drawn by the load,

$P= 3V_sI_{s1}\cos\theta_1=56.045$ kW

(b) The current rating of APF=The total rms harmonic current,

$I_{APF}=I_f=I_h=\sqrt{(I_s^2-I_{s1}^2)}= 24.236$ A,

(Refer Slide Time: 37:19)



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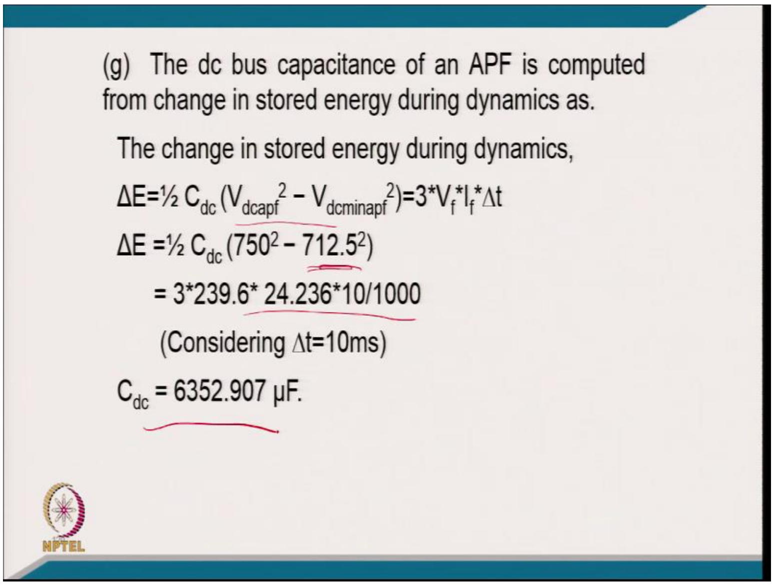

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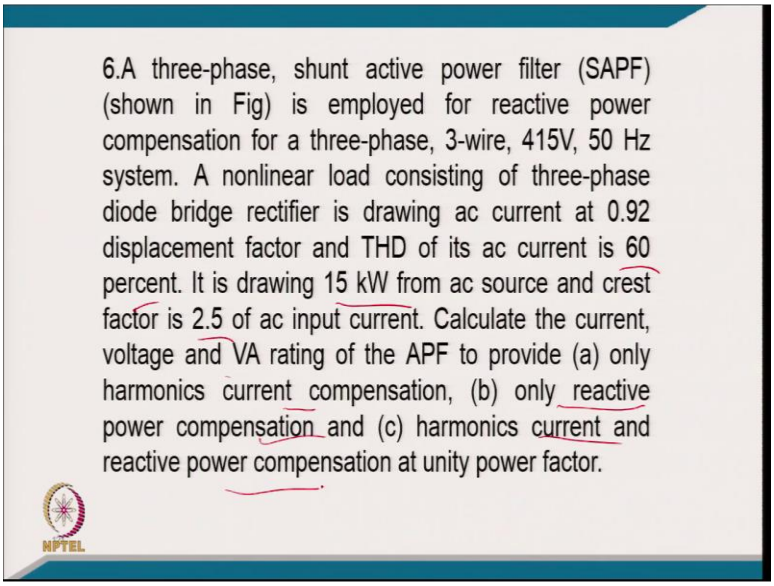
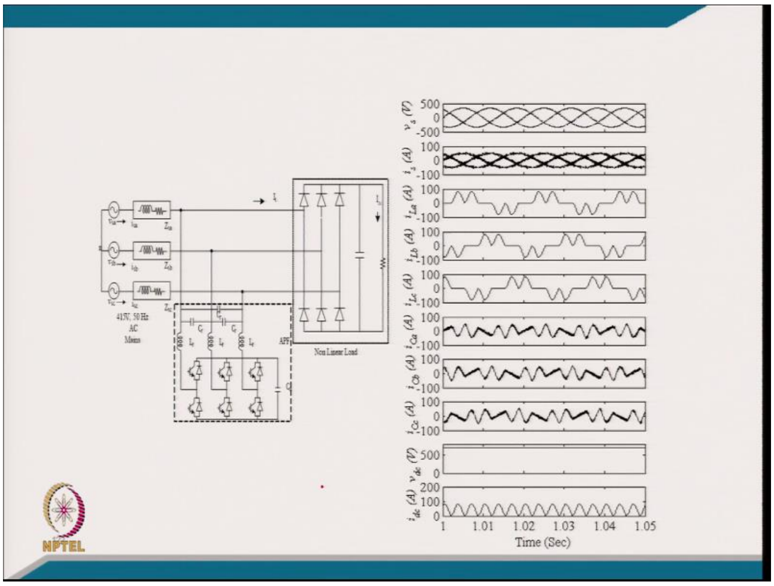


Coming to like another numerical problem, a three-phase shunt active power filter is employed for the reactive power compensation for a three-phase 3-wire 415 volt 50 Hertz system. A non-linear load consisting of three-phase diode rectifier sorry is drawing ac current at 0.92 displacement factor and THD of its ac current is 60 percent

It is drawing 15 kilowatt from ac source and crest factor is 2.5 of ac current calculate the current voltage and VA rating of active power filter to provide a only harmonics current compensation; b, only reactive power compensation; c, harmonic current and reactive power compensation.

(Refer Slide Time: 39:07)



The solution to the numerical is detailed in the following screenshots.

(Refer Slide Time: 39:50)

Solution: Given that, V_s=415/√3=239.6 V, f=50 Hz, THD of I_s=60%, DPF=0.92, CF of I_s=2.5, Active power, P=15 kW

In three-phase diode bridge converter, the fundamental active power component of supply current (I_{s1a}) is as.

Therefore, I_{s1a} =P/(3V_s)=20.868 A

The RMS fundamental supply current (I_{s1}) is as,

I_{s1}= I_{s1a}/DPF= 20.868 /0.92=22.683 A

Distortion factor is as DF=1/√(1+THD^2)=0.857

The power factor is as, PF=DF*DPF=0.789

Moreover, RMS supply current is as,

I_s=P/(3V_s*PF)=26.452A

(Refer Slide Time: 41:01)

VA rating of APF to provide

(a) Only Harmonic compensation

Current rating =current flowing through the filter

$I_f = I_h = \sqrt{(I_s^2 - I_{s1}^2)} = \sqrt{(26.452^2 - 22.683^2)} = 13.608A$

Voltage rating = voltage across the filter

$= V_f = 239.60\ V$

VA Rating of APF,

$S = 3V_f\, I_f = 3 * 239.6 * 13.608 = 9.782\ kVA$

(b) Only reactive power compensation

Current rating = Filter current I_f=Reactive current

$I_R = I_{s1} \sin\theta_1 = I_{s1}\sqrt{(1-DPF^2)} = 8.89A$

(Refer Slide Time: 41:57)

Voltage rating of the filter=Voltage across the filter

$= V_f = V_s = 239.60\ V$

VA Rating of APF,

$S = 3V_f\, I_f = 3V_s I_{s1} \sin\theta_1 = 6.39\ kVA$

(c) Harmonics current and reactive power compensation

$I_f = \sqrt{(I_s^2 - I_{s1a}^2)} = \sqrt{(26.452^2 - 20.868^2)} = 16.255\ A$

Voltage rating of the filter=Voltage across the filter

$= V_f = V_s = 239.60\ V$

VA Rating of APF,

$S = 3V_f\, I_f = 11.684\ kVA.$

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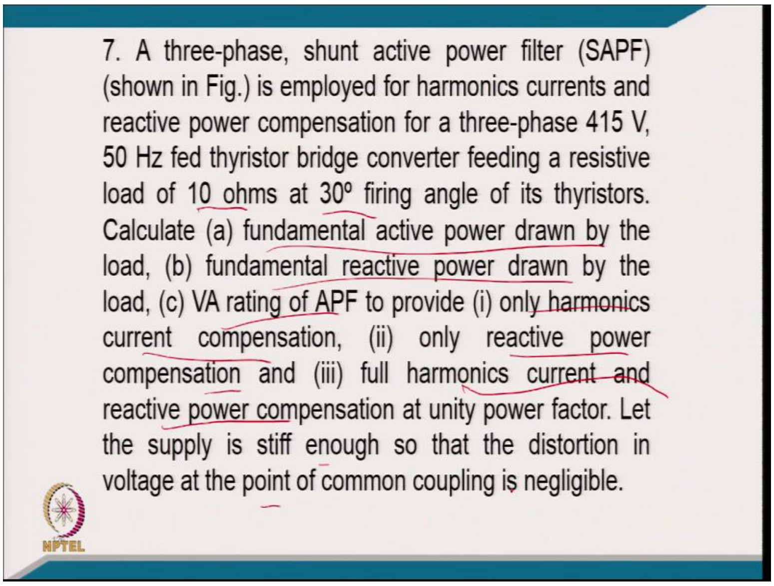

Coming to the numerical example 7: A three-phase shunt active power filter is used is employed for harmonic currents and reactive power compensation for a three-phase 415 volt, 50 Hertz fed thyristor bridge converter drawing a resistive load of 10 ampere at 30 degree fire angle of thyristor.

Calculate the fundamental active power drawn, fundamental reactive power drawn, VA rating of active filter to provide only harmonic current compensation, only reactive power compensation, and along with a harmonics current and reactive power compensation at unity power factor. Let the supply is a stiff enough so that the distortion in the voltage at the point of common coupling is negligible.

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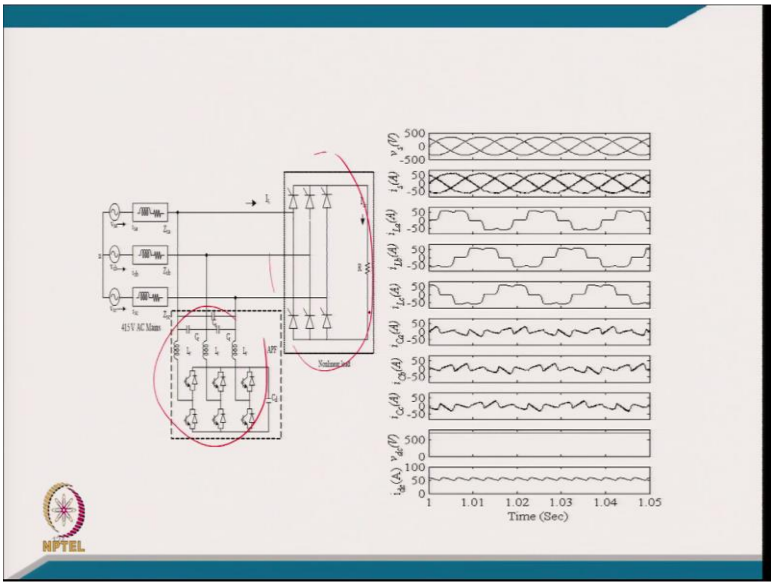

The solution to the numerical is detailed in the following screenshots.

(Refer Slide Time: 43:58)

Solution: Given that, supply rms voltage, $V_s = 415/\sqrt{3} = 239.6$ V, frequency of supply f=50 Hz, R=10Ω, $\alpha = 30^0$.

In three-phase thyristor bridge converter, the waveform of the supply current (I_s) is decided by load resistance and firing angle as.

Therefore, $I_s = \{V_s/(R)\}[\{(2\pi+3\sqrt{3}\cos 2\alpha)\}/\pi\}^{½} = 40.286$ A

RMS of fundamental component of load current,

$I_{s1} = \{(V_s/(2\pi R)\}\{(3\sqrt{3}\sin 2\alpha)^2+(2\pi+3\sqrt{3}\cos 2\alpha)^2\}^{½}$

$I_{s1} = 37.966$A

Hence total rms harmonic current,

$I_h = \sqrt{(I_s^2 - I_{s1}^2)} = \sqrt{(40.28^2 - 37.98^2)} = 13.472$ A

The fundamental active power drawn by the load,

$P = 3\{V_s^2/(2\pi R)\}[\{(2\pi+3\sqrt{3}\cos 2\alpha)\} = 24.34387$ kW

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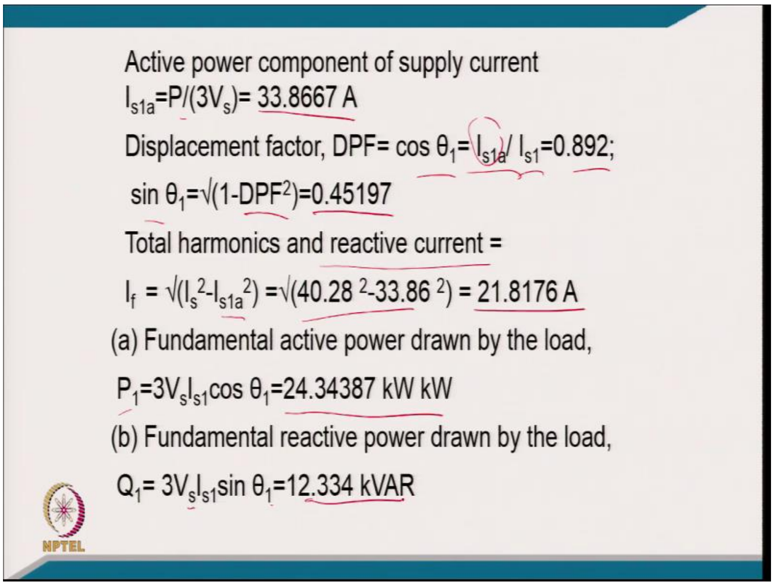

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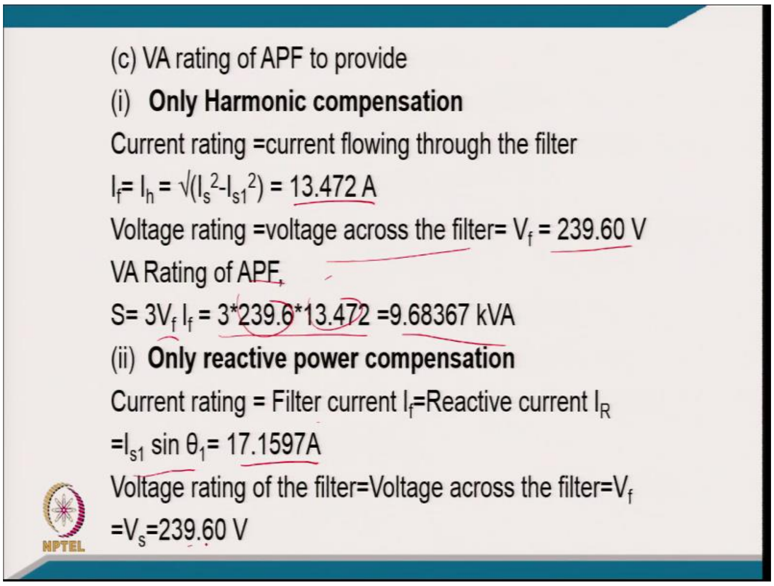

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