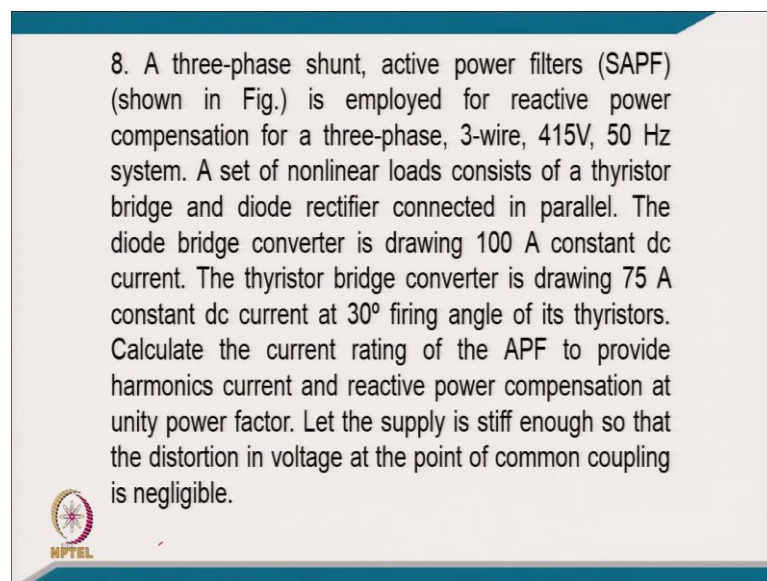


**Power Quality**  
**Prof. Bhim Singh**  
**Department of Electrical Engineering**  
**Indian Institute of Technology, Delhi**


**Lecture - 22**  
**Shunt Active Power Filters (contd.)**

Welcome to the course on Power Quality, [FL]-we are discussing the examples on Shunt Active Power Filter [FL].

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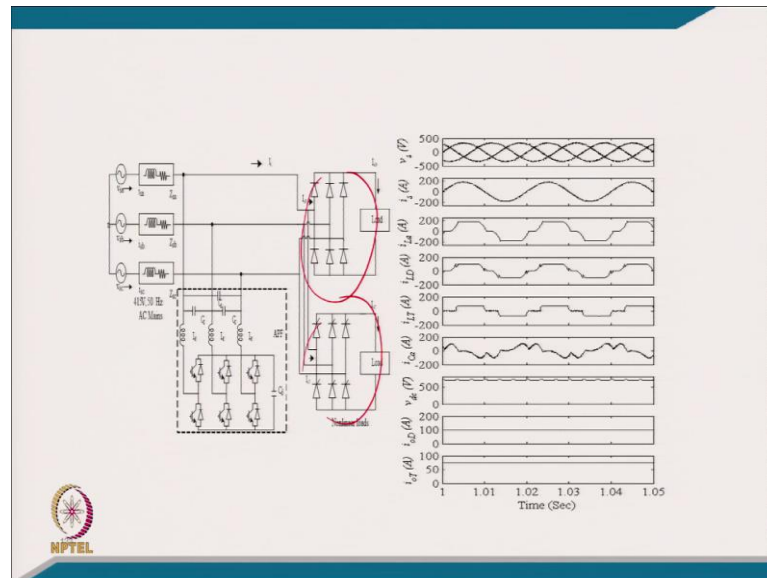
8. A three-phase shunt, active power filters (SAPF) (shown in Fig.) is employed for reactive power compensation for a three-phase, 3-wire, 415V, 50 Hz system. A set of nonlinear loads consists of a thyristor bridge and diode rectifier connected in parallel. The diode bridge converter is drawing 100 A constant dc current. The thyristor bridge converter is drawing 75 A constant dc current at 30° firing angle of its thyristors. Calculate the current rating of the APF to provide harmonics current and reactive power compensation at unity power factor. Let the supply is stiff enough so that the distortion in voltage at the point of common coupling is negligible.



This is the 8th example, a three phase shunt, active power filter is employed with a reactive power compensation for three phase, 3 wire, 415 Volt, 50 Hertz system. A set of non-linear load consist of thyristor bridge and diode rectifier connected in parallel. And the diode bridge converter is drawing 100 Ampere constant dc current.

Thyristor bridge converter is drawing 75 Ampere constant dc current at 30 degree firing angle of its thyristor. Calculate the current rating of the active power filter to provide harmonic current and reactive power compensation at unity power factor. Let the supply is 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: 01:36)

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

The diode bridge converter is drawing 100 A constant dc current. The thyristor-bridge AC-DC converter is drawing 75 A constant dc current at 30° firing angle of its thyristors.

In **three-phase diode bridge converter**, the rms of quasi-square wave load current,  $I_{sD} = I_{dcD} \sqrt{2/3} = 81.65$  A

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

$$I_{sD1} = \left\{ \frac{\sqrt{6}}{\pi} \right\} I_{dc} = 77.97$$
 A

Moreover, active component ac current of the diode converter is as,

$$I_{sD1a} = I_{sD1} = 77.97$$
 A.

(Refer Slide Time: 02:31)

**In three-phase thyristor bridge converter,**

$$I_{sT} = \sqrt{(2/3)} I_{dcT} = 0.81649 I_{dcT} = 61.24 \text{ A}$$

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


$$I_{sT1} = \{(\sqrt{6})/\pi\} I_{dcT} = 58.48 \text{ A}$$

Active power component of supply current

$$I_{sT1a} = I_{sT1} \cos \theta_1 = I_{sT1} \cos \alpha = 58.48 \cos 30^\circ = 50.64 \text{ A}$$

Therefore, total rms active power component of supply current of both loads is as.  $I_{s1a} = I_{sD1a} + I_{sT1a} = 128.61 \text{ A}$ .


Therefore, ideal supply current will be as.

$$i_s = I_{s1a} \sin \theta = 128.61 \sqrt{2} \sin \theta \text{ A.}$$


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Therefore, rms current of the shunt filter is computed with the half cycle integration as.

$$I_f = \left( \frac{1}{\pi} \right) \left\{ \int_0^{\pi/6} (128.61\sqrt{2}\sin\theta)^2 d\theta + \int_{\pi/6}^{\pi/6+\alpha} (128.61\sqrt{2}\sin\theta - 100)^2 d\theta + \int_{5\pi/6}^{\pi/6+\alpha} (128.61\sqrt{2}\sin\theta - 100 - 75)^2 d\theta + \int_{5\pi/6+\alpha}^{\pi/6+\alpha} (128.61\sqrt{2}\sin\theta - 75)^2 d\theta + \int_{5\pi/6}^{\pi} (128.61\sqrt{2}\sin\theta)^2 d\theta \right\}$$

$$I_f = 37.24 \text{ A}$$



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Voltage rating of the filter=Voltage across the filter=  
 $V_f = V_s = 239.6 \text{ V.}$   
VA Rating of APF,  
 $S = 3V_f I_f = 3 \times 239.6 \times 37.24 = 26771.25 \text{ VA.}$



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9. A three-phase, SAPF is employed for harmonics current compensation for a three-phase 415V, 50 Hz fed 12-pulse diode bridge converter drawing 400 A constant dc current. It consists of an ideal transformer with single primary star connected winding and two secondary windings connected in star and delta with same line voltages and unity turns ratios to provide  $30^\circ$  phase shift between two sets of three-phase output voltages. Two 6-pulse diode bridges are connected in series to provide 12-pulse ac-dc converter. Calculate the active power drawn by the load, the current, voltage and VA rating of the APF to provide harmonics current compensation at unity power factor.

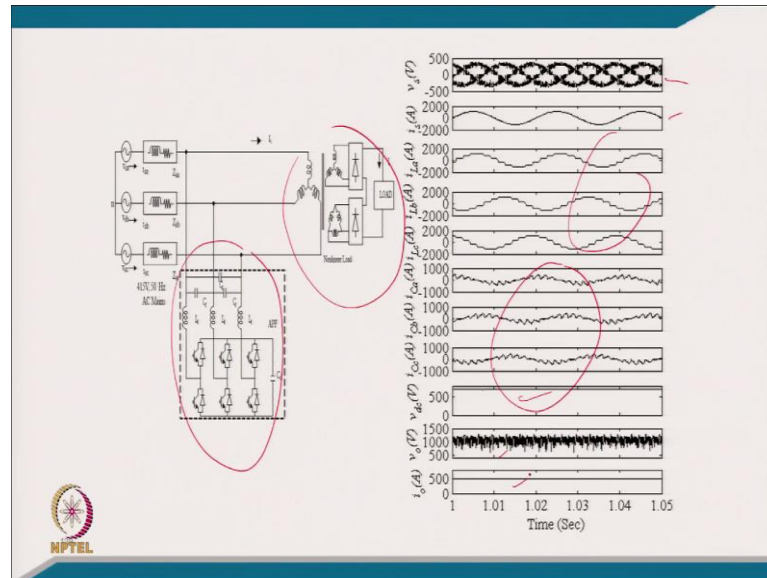


Coming to another example, example number 9, a three phase shunt active power filter is employed to for current harmonic current compensation of with three phase 415 Volt, 50 Hertz fed 12 pulse diode bridge converter drawing 400 Ampere dc current. It consist of an ideal transformer with single primary star connected winding and two secondary winding conducted in star and delta with the same phase voltage.

And unity turns ratios to provide 30 degree phase shift between two sets of three phase output voltage. And two 6 pulse diode bridges are connected in series to provide 12 pulse

ac dc converter. Calculate the active power drawn by the load, current, voltage and VA rating of the active power filter to provide harmonic current compensation at unity power factor.

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

(Refer Slide Time: 06:04)

**Solution:** Given that,  $V_s = 415/\sqrt{3} = 239.6$  V,  $f = 50$  Hz,  
 $I_{dc} = 400$  A.

In three-phase 12-pulse diode bridge converter, the waveform of the input ac current ( $I_s$ ) is a stepped waveforms as (i) first step of  $\pi/6$  angle (from  $0^\circ$  to  $\pi/6$ ) and input current magnitude of  $(I_{dc}/\sqrt{3})$ , (ii) second step of  $\pi/6$  angle (from  $\pi/6$  to  $\pi/3$ ) and input current magnitude of  $\{I_{dc}(1+1/\sqrt{3})\}$ , (iii) third step of  $\pi/6$  angle (from  $\pi/3$  to  $\pi/2$ ) and input current magnitude of  $\{I_{dc}(1+2/\sqrt{3})\}$  and it has all four symmetric segments of such steps.

Therefore, RMS of 12-pulse converter input current,

$$I_s = I_{dc} \sqrt{[(1/3) + (1+1/\sqrt{3})^2 + (1+2/\sqrt{3})^2]} = 1.57735 I_{dc} = 630.94 \text{ A}$$

(Refer Slide Time: 07:11)

The rms of fundamental component of 12-pulse converter input current,

$$I_{s1} = \left\{ \frac{2\sqrt{6}}{\pi} \right\} I_{dc} = 1.559393 I_{dc} = 623.757 \text{ A}$$

The active power drawn by the load,

$$P = 3V_s I_{s1} \cos\theta_1 = 448.358 \text{ kW}$$


Hence total rms harmonic current,

$$I_{APF} = I_f = I_h = \sqrt{I_s^2 - I_{s1}^2} = 94.934 \text{ A},$$

Voltage rating of the filter = Voltage across the filter =


$$V_f = V_s = 239.60 \text{ V}$$

VA Rating of APF,

$$S = 3V_f I_f = 3 * 239.60 * 94.934 = 68.239 \text{ kVA.}$$


(Refer Slide Time: 08:10)

10. A three-phase, shunt active power filter (SAPF) (shown in Fig.) is employed for harmonics currents and reactive power compensation for a three-phase 415 V, 50 Hz fed 12-pulse thyristor bridge converter drawing 400 A constant dc current at 30° firing angle of its thyristors. It consists of an ideal transformer with single primary star connected winding and two secondary windings connected in star and delta with same line voltages and unity turns ratios to provide 30° phase shift between two sets of three-phase output voltages. Two 6-pulse thyristors bridges are connected in series to provide 12-pulse ac-dc converter. Calculate (a) fundamental active power drawn by the load, (b) fundamental reactive power drawn by the load, (c) VA rating of APF to provide (i) only harmonics current compensation, (ii) only reactive power compensation and (iii) full harmonics current and reactive power compensation at unity power factor. Let the supply is stiff enough so that the distortion in voltage at the point of common coupling is negligible.



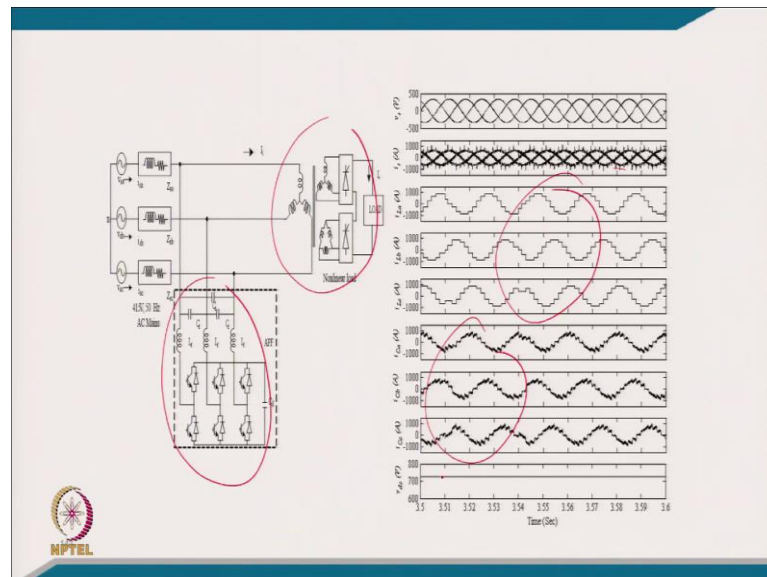
Now, coming to 10th example, a three phase shunt active power filter is employed for harmonic current and reactive power compensation for three phase 415 Volt, 50 Hertz, 12 pulse thyristor bridge converter drawing a 400 ampere constant dc current at 30 degree firing angle of its thyristor.

It consists of an ideal transformer with single primary star connected winding and two secondary winding connected in star and delta with the same line voltage and unity turns

ratios to provide 30 degree phase shift between the two sets of three phase output voltage.

And two 6 pulse thyristor bridges are connected in series to provide 12 pulse ac dc converter. Calculate the fundamental active power drawn by the load, fundamental reactive power drawn by the load, VA rating of active power filter to provide, only harmonic current compensation, only reactive power compensation, full harmonics current and reactive power compensation at unity power factor. Let the supply is stiff enough, so that the distortion in voltage at the point of common coupling is negligible.

(Refer Slide Time: 09:10)




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

(Refer Slide Time: 09:39)

**Solution:** Given that, supply rms voltage,  $V_s = 415/\sqrt{3} = 239.6$  V, frequency of supply  $f = 50$  Hz,  $I_{dc} = 400$  A,  $\alpha = 30^\circ$

In three-phase 12-pulse thyristor bridge converter, the waveform of the input ac current ( $I_s$ ) is a stepped waveforms as (i) first step of  $\pi/6$  angle {from  $\alpha$  to  $(\alpha + \pi/6)$ } and input current magnitude of  $(I_{dc}/\sqrt{3})$ , (ii) second step of  $\pi/6$  angle {from  $(\alpha + \pi/6)$  to  $(\alpha + \pi/3)$ } and input current magnitude of  $\{I_{dc}(1 + 1/\sqrt{3})\}$ , (iii) third step of  $\pi/6$  angle {from  $(\alpha + \pi/3)$  to  $(\alpha + \pi/2)$ } and input current magnitude of  $\{I_{dc}(1 + 2/\sqrt{3})\}$  and it has all four symmetric segments of such steps.

Therefore, rms of 12-pulse converter input current,  
 $I_s = I_{dc} [(1/3) + (1 + 1/\sqrt{3})^2 + (1 + 2/\sqrt{3})^2]^{1/2} = 1.57735 I_{dc} = 630.94$  A



(Refer Slide Time: 10:32)

Moreover, the rms of 12-pulse converter fundamental ac current,  $I_{s1} = \{(2\sqrt{6})/\pi\} I_{dc} = 1.559393 I_{dc} = 623.757$  A


Hence total rms harmonic current,  
 $I_h = \sqrt{(I_s^2 - I_{s1}^2)} = \sqrt{(630.94^2 - 623.757^2)} = 94.934$  A

Active power component of supply current  
 $I_{s1a} = I_{s1} \cos \theta_1 = I_{s1} \cos \alpha = 623.757 \cos 30^\circ = 540.19$  A

Total harmonics and reactive current  $I_f = \sqrt{(I_s^2 - I_{s1a}^2)}$   
 $= \sqrt{(630.94^2 - 540.19^2)} = 326.01$  A

(a) Fundamental active power drawn by the load,  
 $P_1 = 3V_s I_{s1} \cos \theta_1 = 3V_s I_{s1} \cos \alpha = 388.289$  kW

(b) Fundamental reactive power drawn by the load,  
 $Q_1 = 3V_s I_{s1} \sin \theta_1 = 224.172$  kVAR





(Refer Slide Time: 11:42)

(c) VA rating of APF to provide

**(i) Only Harmonic compensation**

Current rating = current flowing through the filter

$$I_f = I_h = \sqrt{(I_s^2 - I_{s1}^2)} = \sqrt{(630.94^2 - 623.757^2)} = 94.934 \text{ A}$$


Voltage rating = voltage across the filter =  $V_f = 239.60 \text{ V}$

VA Rating of APF,

$$S = 3V_f I_f = 3 \times 239.6 \times 94.934 = 68.2386 \text{ kVA}$$

**(ii) Only reactive power compensation**

Current rating = Filter current

$$I_f = \text{Reactive current } I_R = I_{s1} \sin \theta_1$$
$$= I_{s1} \sin \alpha = 623.757 \sin 30^\circ = 311.87 \text{ A}$$


(Refer Slide Time: 12:38)

Voltage rating of the filter = Voltage across the filter =  $V_f = V_s = 239.60 \text{ V}$

VA Rating of APF,  $S = 3V_f I_f = 3V_s I_{s1} \sin \theta_1 = 224.172 \text{ kVA}$


**(iii) Harmonics current and reactive power compensation**

$$I_f = \sqrt{(I_s^2 - I_{s1a}^2)} = \sqrt{(630.94^2 - 540.19^2)} = 326.01 \text{ A}$$

Voltage rating of the filter = Voltage across the filter


$$V_f = V_s = 239.60 \text{ V}$$

VA Rating of APF,

$$S = 3V_f I_f = 234.336 \text{ kVA.}$$


(Refer Slide Time: 13:32)

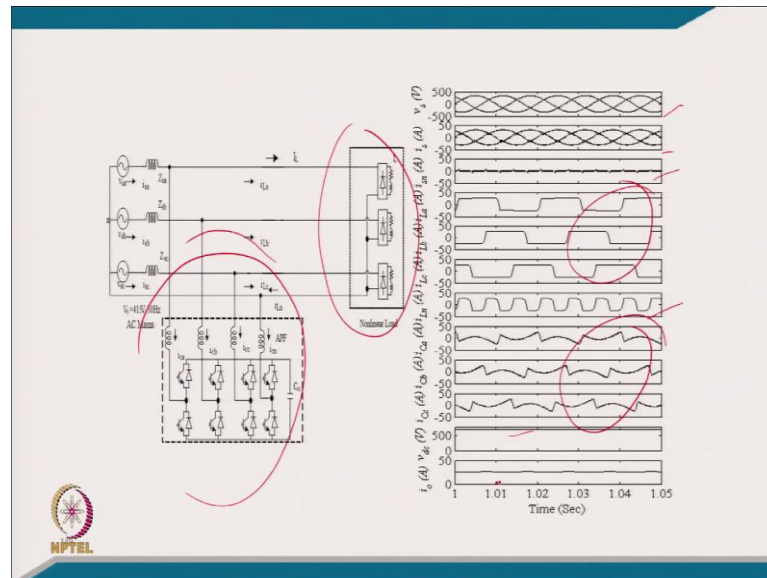
11. A three-phase, with a line voltage of 415 V, 50 Hz, 4-wire distribution system, three single-phase loads (connected between phases and neutral) having diode bridge converter drawing equal constant 25A dc current (shown in Fig.). A four leg VSI with dc bus capacitor is used as APF. Calculate (a) load neutral current, (b) APF phase current, (c) APF neutral current, (d) kVA rating of the APF to provide harmonics current compensation at unity power factor. Let the supply is stiff enough so that the distortion in voltage at the point of common coupling is negligible.



Coming to numerical number are 11, a three phase with a line voltage of 415 Volt, 50 Hertz, 4 wire distribution system, three single phase loads connected between phase and neutral having a diode bridge converter drawing a equal constant 25 Ampere dc current.

A four leg VSI with the dc bus capacitor is used as an active power filter. Calculate a load neutral current; b active power filter phase current; then the c active power filter neutral current; d k VA rating of the active power filter to provide harmonic current compensation at unity power factor. Let the supply is stiff enough, so that the distortion in voltage at the point of common coupling is negligible.

(Refer Slide Time: 14:16)



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

(Refer Slide Time: 14:47)

**Solution:** Given that, supply voltage,  $V_s = 239.6$  V, frequency of supply  $f=50$  Hz, DC link current,  $I_{dc} = 25$  A.

In single-phase diode bridge converter, the waveform of the supply current ( $I_s$ ) is a square wave with the amplitude of dc link current ( $I_{dc}$ ). Moreover, the rms of fundamental component of square wave is  $(2\sqrt{2}/\pi) = 0.9$  times the amplitude of it.

Therefore,  $I_s = I_{dc} = 25$  A  
 and  $I_{s1} = (2\sqrt{2}/\pi) I_{dc} = 0.9 I_{dc} = 22.5$  A

Current rating of APF=current flowing through the filter  
 $= I_f = I_h = \sqrt{(I_s^2 - I_{s1}^2)} = \sqrt{(25^2 - 22.5^2)} = 10.897$  A

Voltage rating of the APF=voltage across the filter=  
 $V_f = V_s = 239.6$  V


(Refer Slide Time: 15:47)

(a) Load neutral current  $I_{Ln} = 25 \text{ A}$   
(since it will also be square wave as 3 times the fundamental frequency)

(b) Phase current rating of APF  
 $I_f = I_h = \sqrt{(I_s^2 - I_{s1}^2)} = \sqrt{(25^2 - 22.5^2)} = 10.897 \text{ A}$


(c) APF neutral current  $I_{fn} = -I_{Ln} = 25 \text{ A}$   
(since it has to cancel total load neutral current)

(d) VA rating of the APF,  
 $S = 3V_{df} + V_{dfn} = 13.822 \text{ kVA}$   
(since  $V_f = V_s = 239.6 \text{ V}$ ).



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12. A three-phase 4-wire distribution system with line voltage of 415 V, 50 Hz, feeding three single-phase loads (connected between phases and neutral terminal) having a set of diode bridge rectifiers drawing ac current at 0.92 displacement factor and THD of its ac current is 60 percent. It is drawing 2000 W from ac source and crest factor is 2.5 of AC input current. A four-leg VSI with dc bus capacitors is used to realize as four-wire shunt APF. Calculate the current, voltage and VA rating of the APF to provide (a) harmonics current compensation, (b) reactive power compensation and (c) harmonics current and reactive power compensation at unity power factor.

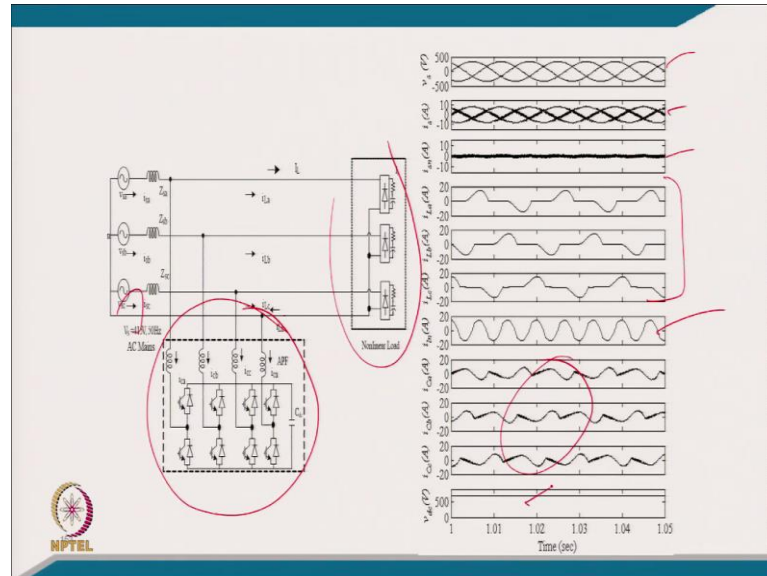


Coming to the 12th numerical problem, a three phase 4 wire distribution system with line voltage of 415 Volt, 50 Hertz, feeding the three single phase loads connected between phase and neutral having a set of diode bridge rectifier drawing ac current at 0.92 displacement factor and THD of the ac current is 60 percent.

It is drawing 2000 Watt from the ac source and crest factor is 2.5 ac of input current. A four leg voltage source in inverter with the dc bus capacitor is used to realize the four wire shunt active filter. Calculate the current voltage and VA rating of the active power

filter to provide; harmonic current compensation, reactive power compensation, harmonic current and reactive power compensation at unity power factor.

(Refer Slide Time: 17:11)



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

(Refer Slide Time: 17:48)

**Solution:** Given that, a three-phase, line voltage of 415 V, 50 Hz, 4-wire distribution system:  $V_s = 415/\sqrt{3} = 239.6$  V,  $f = 50$  Hz, THD of  $I_s = 60\%$ ,  $DPF = 0.92$ ,  $CF$  of  $I_s = 2.5$ ,  $P = 2000$ W on each phase there is a single-phase diode rectifier load connected between phases and neutral.

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

Therefore,  $I_{s1a} = P/(V_s) = 8.347$  A

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


$I_{s1} = I_{s1a}/DPF = 8.347/0.92 = 9.073$  A

Distortion factor is as  $DF = 1/\sqrt{(1+THD^2)} = 0.857$

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


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Moreover, RMS supply current is as,  
 $I_s = P / (V_s \cdot PF) = 10.580 \text{ A}$   
APF neutral current  $I_{fn} = -I_{Ln} = \sqrt{3} \cdot I_s = 18.325 \text{ A}$   
(since it has to cancel total load neutral current)  
VA rating of APF to provide  
**(a) Only Harmonic compensation**  
Current rating = current flowing through the filter  
 $I_f = I_h = \sqrt{(I_s^2 - I_{s1}^2)} = \sqrt{(10.580^2 - 9.073^2)} = 5.441 \text{ A}$   
Voltage rating = voltage across the filter  $V_f = 239.60 \text{ V}$   
VA Rating of APF,  
 $S = 3V_f I_f + V_f I_{fn} = 3 \cdot 239.6 \cdot 5.441 + 239.6 \cdot 18.325$   
 $S = 8.302 \text{ kVA}$



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**(b) Only reactive power compensation**  
Current rating = Filter current  $I_f =$  Reactive current  
 $I_R = I_{s1} \sin \theta_1 = I_{s1} \sqrt{(1 - DPF^2)} = 3.556 \text{ A}$   
Voltage rating of the filter = Voltage across the filter  
 $V_f = V_s = 239.60 \text{ V}$   
VA Rating of APF,  
 $S = 3V_f I_f + V_f I_{fn} = 3 \cdot 239.6 \cdot 3.556 + 239.6 \cdot 18.325$   
 $S = 6.946 \text{ kVA}$



(Refer Slide Time: 20:10)


**(c) Harmonics current and reactive power compensation**

$$I_f = \sqrt{(I_s^2 - I_{s1a}^2)} = \sqrt{(10.580^2 - 8.347^2)} = 6.501 \text{ A}$$

Voltage rating of the filter = Voltage across the filter


$$V_f = V_s = 239.60 \text{ V}$$

VA Rating of APF,

$$S = 3V_f I_f + V_f I_{fn} = 3 \times 239.6 \times 6.501 + 239.6 \times 18.325$$
$$S = 9.064 \text{ kVA}$$


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13. A three-phase with line voltage of 415 V, 50 Hz, 4-wire distribution system, three single-phase loads (connected between phases and neutral) having a set of single-phase uncontrolled diode bridge converter, which has a RE load with  $R=2$  ohms, and  $E=264\text{V}$  (shown in Fig.). A three-leg VSI with mid-point dc bus capacitors for neutral connection is used to realize as four-wire shunt APF. Calculate (a) fundamental active power drawn by the load, (b) voltage, current and VA rating of APF to provide unity power factor. Let the supply is stiff enough so that the distortion in voltage at the point of common coupling is negligible.

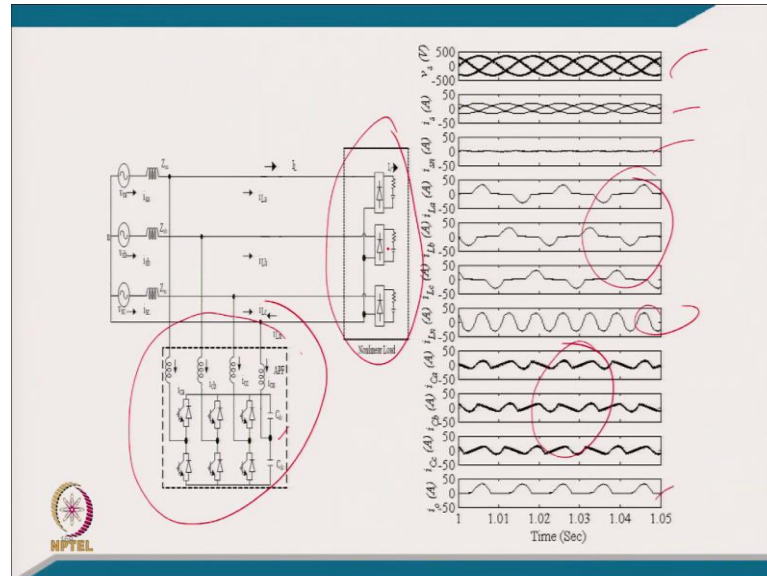


Now, coming to the numerical problem 13, a three phase with line voltage of 415 Volt, 50 Hertz, 4 wire distribution system, three single phases loads connected between the phases and neutral having a set of single phase uncontrolled bridge reactive wire, which have a RE load with resistance of 2 Ohm and the voltage of batteries 264 Volt.

A three leg VSI with the midpoint dc bus capacitor is used for neutral current compensation to realize as a four wire shunt active filter. Calculate a fundamental active power; b voltage, current and VA rating of active power filter to provide unity power

factor. Let the supply is stiff enough, so that the distortion in voltage at the point of common coupling is negligible like.

(Refer Slide Time: 21:19)



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

(Refer Slide Time: 21:51)

**Solution:** Given that, Supply phase voltage,  $V_s = 239.6V$ ,  
 $V_{sm} = 239.6 \times \sqrt{2} = 338.85V$ , Frequency of the supply  
 $f = 50 \text{ Hz}$ , Load  $R = 2 \Omega$ ,  $E = 264V$

In single-phase diode bridge converter, with RE load, the current will flow from angle ( $\alpha$ ) when ac voltage is equal to E and to the angle ( $\beta$ ) at which ac voltage reduces to E.

$$\alpha = \sin^{-1}(E/V_{sm}) = \sin^{-1}(264/338.87) = 51.179^\circ$$

$$\beta = \pi - \alpha = 128.82^\circ$$

The conduction angle =  $\beta - \alpha = 77.641^\circ$

RMS supply current ( $I_s$ ) is rms of discontinuous current in the ac mains as.

$$I_s = \left[ \frac{1}{\pi R^2} \left\{ (0.5V_{sm}^2 + E^2)(\pi - 2\alpha) + 0.5V_{sm}^2 \sin 2\alpha - 4V_{sm}E \cos \alpha \right\} \right]^{1/2} = 17.84 \text{ A}$$



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Average current ( $I_{dc}$ ) in the battery is as.

$$I_{dc} = \frac{1}{\pi R} (2V_{sm} \cos \alpha + 2E \alpha - \pi E) = 10.67 \text{ A}$$

Active power drawn from ac mains,

$$P = I_s^2 R + E I_{dc} = 3453.94 \text{ W}$$

Fundamental RMS current from ac mains,

$$I_{s1} = P/V_s = 14.415 \text{ A}$$


Current rating of APF = current flowing through the filter phase leg

$$= I_f = I_h = \sqrt{(I_s^2 - I_{s1}^2)} = 10.522 \text{ A}$$

APF neutral current  $I_{fn} = -I_{Ln} = \sqrt{3} I_s$


$$= \sqrt{3} \times 17.84 = 30.9 \text{ A}$$

(since it has to cancel total load neutral current)




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Voltage rating of the APF = voltage across the filter

$$V_f = V_s = 239.6 \text{ V}$$
$$S = 3V_f I_f + V_f I_{fn} = 3 \times 239.6 \times 10.552 + 239.6 \times 30.9$$
$$S = 14.998 \text{ kVA}$$


(Refer Slide Time: 23:59)

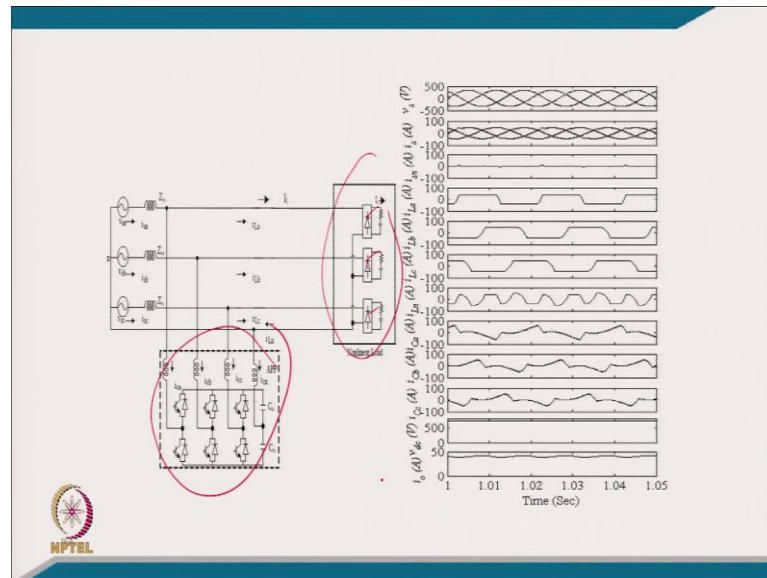
14. A three-phase with line voltage of 415 V, 50 Hz, 4-wire distribution system, three single-phase loads (connected between phases and neutral) having a single-phase thyristor bridge converter drawing equal 30 A constant dc current at  $45^\circ$  firing angle of its thyristors (shown in Fig.). A four leg VSI with dc bus capacitor is used as APF. Calculate the current, voltage and VA rating of the APF to provide (a) harmonics current compensation, and (b) harmonics current and reactive power compensation at unity power factor. Let the supply is stiff enough so that the distortion in voltage at the point of common coupling is negligible.



Coming to 14th numerical problem, a three phase line voltage of 415 Volt, 50 Hertz, 4 wire distribution system, three single phase loads connected between phases and neutral having a single phase thyristor bridge converter with the equal current of 30 Ampere constant dc current at a 45 degree angle of the thyristor.

And four leg VSI with the dc bus capacitor is used as active power filter. Calculate the current, voltage and VA rating of active power filter to provide; a harmonic current compensation, harmonics current and reactive power compensation and unity power factor. Let the supply is stiff enough, so that the distortion in the voltage at the point of common coupling is negligible.

(Refer Slide Time: 24:37)



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

(Refer Slide Time: 24:47)

**Solution:** Given that, Supply voltage,  $V_s = 239.6$  V, Frequency of the supply  $f=50$  Hz, DC link current,  $I_{dc} = 30$ A, Firing angle,  $\alpha = 45^\circ$

In single-phase thyristor bridge converter, the waveform of the supply current ( $I_s$ ) is a square wave with the amplitude of dc link current ( $I_{dc}$ ). Moreover, the rms of fundamental component of square wave is  $(2\sqrt{2}/\pi) = 0.9$  times the amplitude of it.

Therefore,  $I_s = I_{dc} = 30$  A and

$$I_{s1} = (2\sqrt{2}/\pi) I_{dc} = 0.9 I_{dc} = 27$$

RMS Fundamental active power component of load current,  $I_{s1a} = I_{s1} \cos\alpha = 19.092$ A

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Load neutral current  $I_{Ln} = 30$  A (since it will also be a square wave as 3 times the fundamental frequency)

APF fourth leg neutral current,  $I_{fn} = I_{Ln} = 30$  A (since it must be opposite to load neutral to cancel it)

VA rating of APF to provide

**(a) For harmonic compensation**


Current rating = current flowing through the filter

$$I_f = I_h = \sqrt{I_s^2 - I_{s1}^2} = \sqrt{30^2 - 27^2} = 13.077 \text{ A}$$

Voltage rating = voltage across the filter

$$V_f = 239.60 \text{ V}$$

VA Rating of APF,  $S = 3V_f I_f + V_f I_{fn} = 16.588 \text{ kVA}$



(Refer Slide Time: 26:10)


**(b) For harmonics current and reactive power compensation**

$$I_f = \sqrt{I_s^2 - I_{s1a}^2} = \sqrt{30^2 - 19.092^2} = 23.141 \text{ A}$$

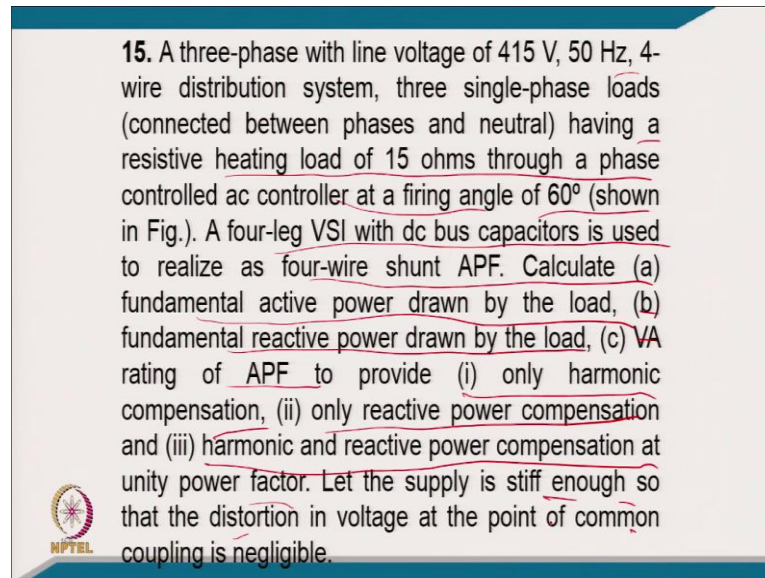
Voltage rating of the filter = Voltage across the filter

$$V_f = V_s = 239.60 \text{ V}$$


VA Rating of APF,

$$S = 3V_f I_f + V_f I_{fn} = 23.822 \text{ kVA}$$


(Refer Slide Time: 26:33)



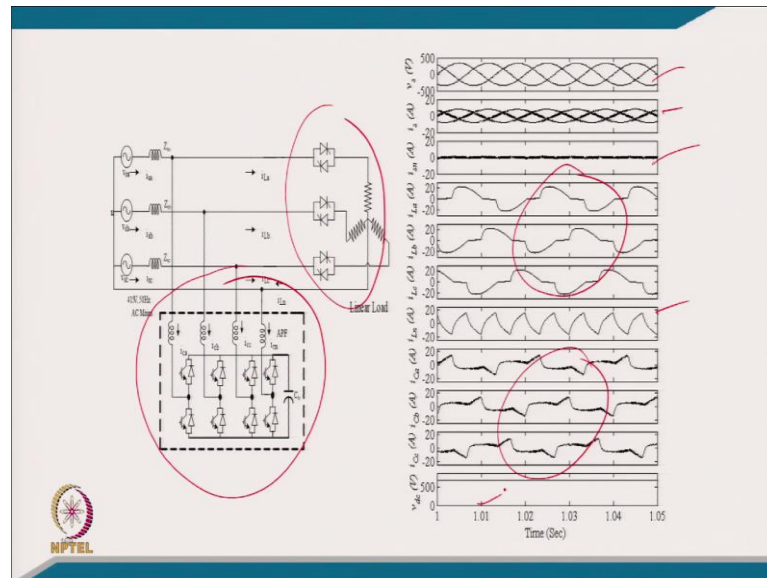
15. A three-phase with line voltage of 415 V, 50 Hz, 4-wire distribution system, three single-phase loads (connected between phases and neutral) having a resistive heating load of 15 ohms through a phase controlled ac controller at a firing angle of  $60^\circ$  (shown in Fig.). A four-leg VSI with dc bus capacitors is used to realize as four-wire shunt APF. Calculate (a) fundamental active power drawn by the load, (b) fundamental reactive power drawn by the load, (c) VA rating of APF to provide (i) only harmonic compensation, (ii) only reactive power compensation and (iii) harmonic and reactive power compensation at unity power factor. Let the supply is stiff enough so that the distortion in voltage at the point of common coupling is negligible.

 NPTEL

Coming to the numerical problem 15, a three phase with line voltage of 415 Volt, 50 Hertz, 4 wire distribution system, three single phase load connected between phase and neutral having a resistive heating element of 15 Ohm through a phase control ac controller with the firing angle of 60 degree. And a four leg VSI with the dc bus capacitor is used to realize as a four wire shunt active filter.

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

(Refer Slide Time: 27:22)



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

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**Solution:** Given that, supply rms voltage,  $V_s = 415/\sqrt{3} = 239.60$  V, Frequency of the supply  $f = 50$  Hz,  $R = 15 \Omega$ ,  $\alpha = 60^\circ$

In a single-phase, phase controlled ac controller, the waveform of the supply current ( $I_s$ ) has a value of  $V_s/R$  from angle  $\alpha$  to  $\pi$ .  $V_{sm} = 239.60\sqrt{2} = 338.8456$  V

RMS supply current

$$I_s = V_{sm} \left[ \frac{1}{2\pi} \int_{\alpha}^{\pi} (\pi - \alpha) + \sin 2\alpha / 2 \right]^{1/2} / R = 14.3267 \text{ A}$$


Fundamental RMS current

$$I_{s1} = V_{sm} / (2\pi R \sqrt{2}) \left[ (\cos 2\alpha - 1)^2 + \{\sin 2\alpha + 2(\pi - \alpha)\}^2 \right]^{1/2} = 13.4044 \text{ A}$$

$$\theta_1 = \tan^{-1} \left[ (\cos 2\alpha - 1) / \{\sin 2\alpha + 2(\pi - \alpha)\} \right] = -16.53^\circ$$


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RMS Active power fundamental component of supply current,  $I_{s1a} = I_{s1} \cos \theta_1 = 12.85 \text{ A}$   
Hence total rms harmonic current,  
 $I_h = \sqrt{(I_s^2 - I_{s1a}^2)} = \sqrt{(14.3267^2 - 13.4040^2)} = 5.0573 \text{ A}$   
RMS reactive power fundamental component of supply current,  
 $I_{s1r} = I_{s1} \sin \theta_1 = I_{s1} \sqrt{(1 - \cos^2 \theta_1)} = 3.814 \text{ A}$   
Total harmonics and reactive current  
 $I_f = \sqrt{(I_s^2 - I_{s1a}^2)} = \sqrt{(14.3267^2 - 12.85^2)} = 6.335 \text{ A}$   
(a) Fundamental active power drawn by the load,  
 $P_1 = 3V_s I_{s1} \cos \theta_1 = 9236.59 \text{ W}$   
(b) Fundamental reactive power drawn by the load,  
 $Q_1 = 3V_s I_{s1} \sin \theta_1 = 2741.35 \text{ VAR}$



(Refer Slide Time: 29:57)

(c) VA rating of APF to provide  
(i) **Only Harmonic compensation**  
Current rating = current flowing through the filter phase leg  
 $I_f = I_h = \sqrt{(I_s^2 - I_{s1a}^2)} = \sqrt{(14.3267^2 - 13.4044^2)} = 5.0573 \text{ A}$   
APF neutral current  $I_{fn} = -I_{Ln} = \sqrt{3} * I_s$   
 $= \sqrt{3} * 14.3267 = 24.815 \text{ A}$   
(since it has to cancel total load neutral current)  
Voltage rating = voltage across the filter =  $V_f = 239.60 \text{ V}$   
VA Rating of APF,  
 $S = 3V_f I_f + V_f I_{fn} = 3 * 239.6 * 5.0573 + 239.6 * 24.815$   
 $S = 9.581 \text{ kVA}$



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**(ii) Only reactive power compensation**

Reactive power  $Q=3P \sin \theta_1 / \cos \theta_1 = 2741.81 \text{ VAR}$

Current rating = Filter phase current  $I_f = \text{Reactive current}$

$I_R = I_{s1} \sin \theta_1 = I_{s1} \sin \theta_1 = I_{s1} \sqrt{1 - \cos^2 \theta_1} = 3.814 \text{ A}$


Voltage rating of the filter = Voltage across the filter

$V_f = V_s = 239.60 \text{ V}$

VA Rating of APF,

$S = 3V_f I_f + V_f I_{fn} = 3 \times 239.6 \times 3.814 + 239.6 \times 24.815$

$S = 8.687 \text{ kVA}$



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**(iii) Harmonics current and reactive power compensation**

$I_f = I_f = \sqrt{(I_s^2 - I_{s1a}^2)} = \sqrt{(14.3267^2 - 12.85^2)} = 6.334 \text{ A}$


Voltage rating of the filter = Voltage across the filter

$V_f = V_s = 239.60 \text{ V}$

VA Rating of APF,

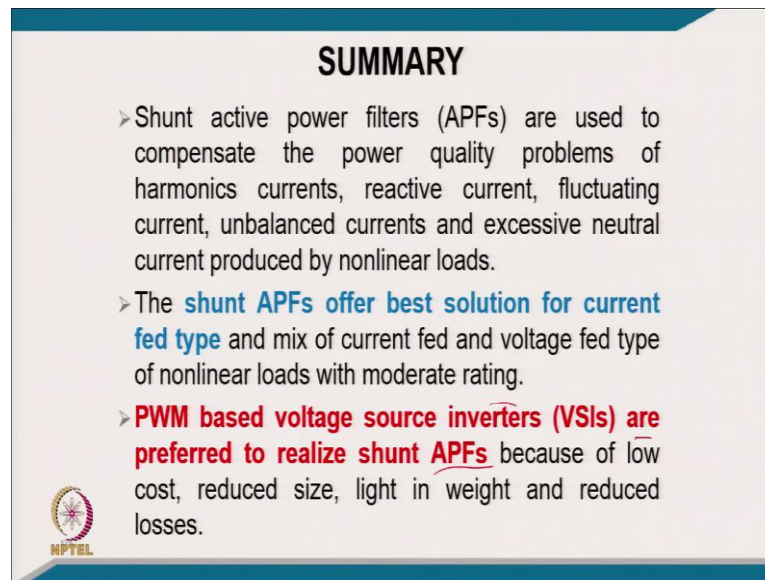
$S = 3V_f I_f + V_f I_{fn} = 3 \times 239.6 \times 6.334 + 239.6 \times 24.815$

$S = 10.499 \text{ kVA}$






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**SUMMARY**

- Shunt active power filters (APFs) are used to compensate the power quality problems of harmonics currents, reactive current, fluctuating current, unbalanced currents and excessive neutral current produced by nonlinear loads.
- The **shunt APFs offer best solution for current fed type** and mix of current fed and voltage fed type of nonlinear loads with moderate rating.
- **PWM based voltage source inverters (VSIs) are preferred to realize shunt APFs** because of low cost, reduced size, light in weight and reduced losses.



With this we would like to summarize the shunt active power filter. Shunt active power filter are used for to compensate the power quality problem of harmonic currents, reactive current, fluctuating current, unbalanced current and excessive neutral current produced by the non-linear load.


Shunt active filter offer the best solution for current fed type and mix type of load, current fed and voltage fed kind of non-linear load with moderate rating.

PWM based voltage source inverters are used preferred to realize the shunt active power filter, because of low cost, reduce size, light in weight and reduced losses.

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**SUMMARY**

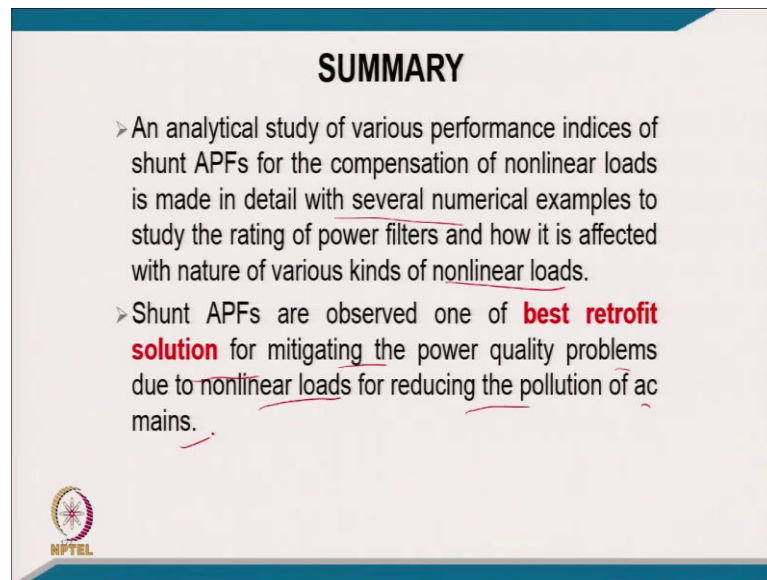
- A passive ripple filter is used at the PCC where shunt APF is connected to improve the voltage profile and to eliminate higher order harmonics, which shunt APF can not eliminate.
- This passive ripple filter does not have much losses even being sometimes damped type because energy associated with higher order harmonics is quite small.
- However, these higher order harmonics either produced by nonlinear loads or due to switching of shunt APF cause disturbance to communication systems and other electronics appliances.



A passive ripple filter is used at the point of common coupling, where the shunt active filter is connected to improve the voltage profile and to eliminate the higher order harmonics, which shunt active power filter cannot eliminate.


This passive shunt, a small passive ripple filter does not have much losses even being sometimes damp type because of energy associated with the higher order harmonics is a quite small. However, these higher order harmonics either produced by non-linear load or due to switching of shunt active power filter cause disturbance to communication system and other electronics appliances like.

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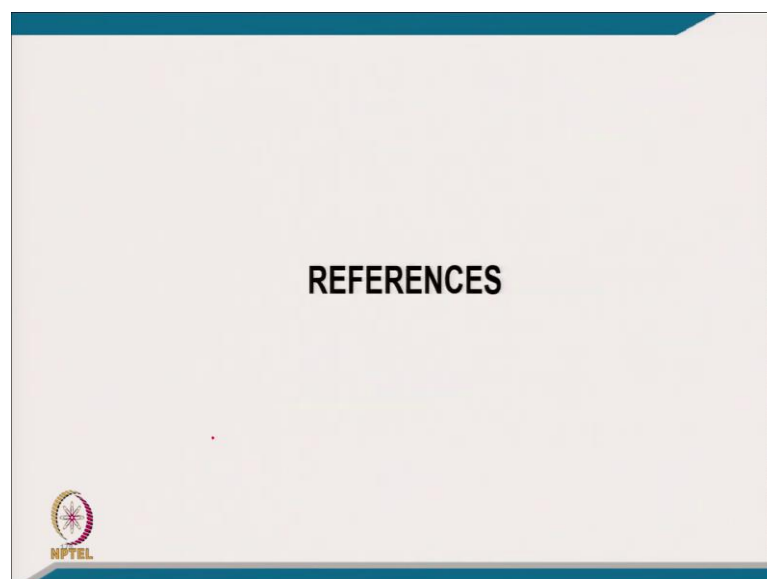
**SUMMARY**

- An analytical study of various performance indices of shunt APFs for the compensation of nonlinear loads is made in detail with several numerical examples to study the rating of power filters and how it is affected with nature of various kinds of nonlinear loads.
- Shunt APFs are observed one of **best retrofit solution** for mitigating the power quality problems due to nonlinear loads for reducing the pollution of ac mains.




An analytical study of various performance indices of shunt active power filter for compensation of non-linear load, it made it in detail with several numerical example to study the rating of power filter and how it is affected with the nature of the various kind of non-linear load. Shunt active power filter are observed one of the best retrofit solution for mitigating power quality problem due to non-linear load for reducing the pollution ac mains.


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