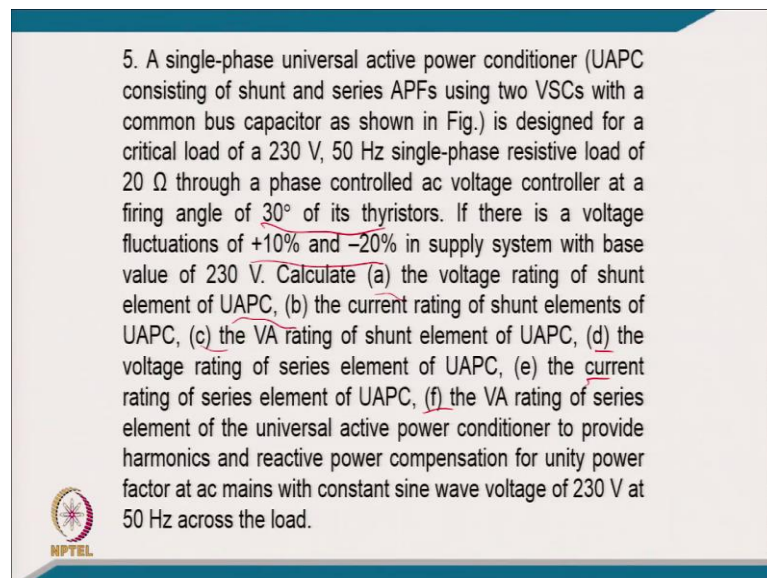


Power Quality
Prof. Bhim Singh
Department of Electrical Engineering
Indian Institute of Technology, Delhi


Lecture - 28
Hybrid Power Filters (contd.)

Welcome to the course on Power Quality. We are discussing the Hybrid Power Filters.

(Refer Slide Time: 00:27)



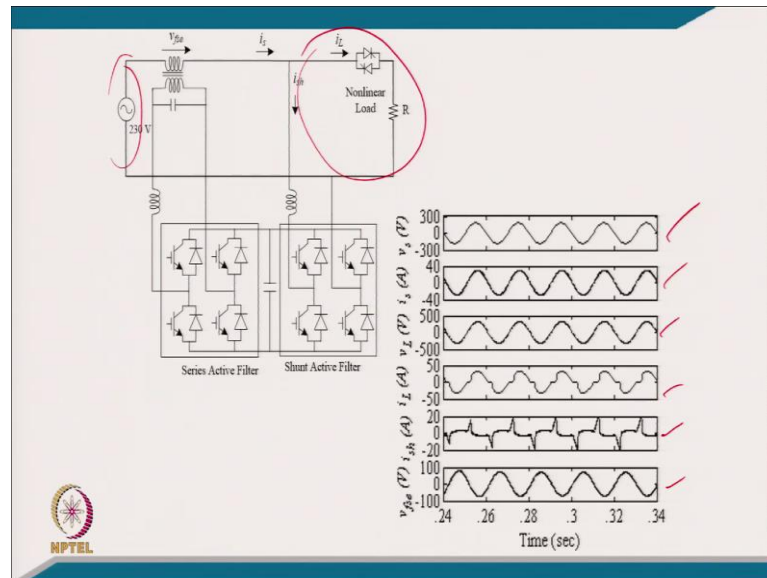
5. A single-phase universal active power conditioner (UAPC consisting of shunt and series APFs using two VSCs with a common bus capacitor as shown in Fig.) is designed for a critical load of a 230 V, 50 Hz single-phase resistive load of 20Ω through a phase controlled ac voltage controller at a firing angle of 30° of its thyristors. If there is a voltage fluctuations of +10% and -20% in supply system with base value of 230 V. Calculate (a) the voltage rating of shunt element of UAPC, (b) the current rating of shunt elements of UAPC, (c) the VA rating of shunt element of UAPC, (d) the voltage rating of series element of UAPC, (e) the current rating of series element of UAPC, (f) the VA rating of series element of the universal active power conditioner to provide harmonics and reactive power compensation for unity power factor at ac mains with constant sine wave voltage of 230 V at 50 Hz across the load.



Coming to the 5th numerical, A single phase universal active power conditioner consisting of shunt and series active power filters using two voltage source converter with common dc bus as shown in figure is design for critical load of 230 volt 50 hertz single phase the resistive load of 20 ohm, through a phase control ac voltage controller at fire angle of 30 degree of its thyristor.

And if there is any if there is a flow voltage fluctuations of plus 10 percent minus 20 percent in the supply voltage, this way with the base value of 230 volt calculate a the voltage rating of shunt element b current rating of shunt element, c VA rating of shunt element, d voltage rating of the series element, e current rating of series element, f VA rating of series element of the universal active power conditioner to provide harmonics and reactive power compensation for unity power factor at ac mains with constant sine wave voltage of 230 volt across the load.

(Refer Slide Time: 01:20)



The explanation of the numerical problem is described in the screenshots herein.

(Refer Slide Time: 02:15)

Solution: Given that, supply voltage, $V_s = 230$ V rms, frequency of supply, $f = 50$ Hz, a nonlinear load of a phase controlled ac voltage controller consisting of 230 V, 50 Hz, $R = 20 \Omega$, $\alpha = 30^\circ$ ($\pi/6$ rads). There is a voltage fluctuation of +10% and -20% in supply system with base value of 230 V. A single-phase universal active power conditioner (UAPC) is to provide unity power factor at the ac mains with constant sine wave voltage of 230 V at 50 Hz across the load. Let X be the pu voltage variation and V_s' be the PCC voltage under voltage variation.

In this system, load current harmonics and reactive power compensation are to be provided by the shunt active filter of UAPC. The voltage sag/swell compensation is provided by series filter of UAPC. However, while compensating for sag/swell, an active power is circulated between series and shunt active filters as explained earlier in chapter of UPQC. Under maximum voltage dip, the maximum rating for both the VSCs are realized. The various rating calculations are as follows,

(Refer Slide Time: 03:30)


The supply voltage under maximum voltage sag is as,
 $V_s' = V_s (1-X) = 230*(1-0.2) = 184 \text{ V.}$

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 α to π . The peak load voltage is as,
 $V_{sdc} = 230 \sqrt{2} = 325.27 \text{ V.}$

The load RMS current,
 $I_L = V_{sdc} \{1/(2\pi)\} \{(\pi-\alpha) + \sin 2\alpha/2\} / R = 11.333 \text{ A.}$

The fundamental RMS load current is as,
 $I_{L1} = V_{sdc} / (2\pi R \sqrt{2}) [(\cos 2\alpha - 1)^2 + \{\sin 2\alpha + 2(\pi - \alpha)\}^2]^{1/2} = 11.206 \text{ A.}$

The angle between fundamental voltage and current is as,
 $\theta_1 = \tan^{-1} \{(\cos 2\alpha - 1) / \{\sin 2\alpha + 2(\pi - \alpha)\}\} = 4.684^\circ.$



(Refer Slide Time: 04:23)


The RMS active power fundamental component of load current is as,
 $I_{L1a} = I_{L1} \cos \theta_1 = 11.206 * \cos (4.684) = 11.169 \text{ A.}$

The active power consumed by the load is as,
 $P_L = V_s * I_{L1a} = 230 * 11.169 = 2568.771 \text{ W.}$

The supply current under maximum voltage variation (-20% sag) is as,
 $I_s' = P_L / V_s' = 2568.771 / 184 \text{ A} = 13.961 \text{ A.}$

Total harmonics and reactive power component of load current is calculated as,
 $I_{Lr} = \sqrt{(I_L^2 - I_{L1a}^2)} = \sqrt{(11.333^2 - 11.169^2)} = 1.921 \text{ A.}$

(a) The voltage rating of shunt element of UAPC is equal to ac load voltage of $V_{sh} = 230 \text{ V}$, since it is connected across the load of 230 V sine waveform.




(Refer Slide Time: 05:19)

(b) The current rating of shunt element of UAPC is computed as,
The shunt element of UAPC is to provide load current harmonics and reactive power compensation, hence the required harmonics current and reactive power of the load it has to supply. Therefore, total harmonics and reactive power component of load current to be supplied by shunt active filter is as,

$$I_{shr} = I_{Lr} = 1.921 \text{ A.}$$

The supply fundamental voltage is lower as compared to the required load voltage. Hence, shunt APF absorbs active power and that active power is delivered back into the system via series APF. The active power component of shunt APF current is estimated as,

$$I_{sha} = I_s' - I_{L1a} = 13.961 - 11.169 = 2.792 \text{ A.}$$


(Refer Slide Time: 06:11)


The overall current rating of shunt active filter is estimated as,

$$I_{sh} = \sqrt{(I_{sha}^2 + I_{shr}^2)} = \sqrt{(2.792^2 + 1.921^2)} = 3.389 \text{ A.}$$

(c) The VA rating of VSC of shunt APF is estimated as,

$$S_{sh} = V_{sh} * I_{sh} = 230 * 3.389 \text{ VA} = 779.476 \text{ VA.}$$

(d) The voltage rating of series element of UAPC is computed as,
There is a voltage fluctuation of +10% and -20% in supply system with base value of 230 V. Therefore, the series APF must inject the difference of these maximum of these two voltages to regulate the voltage at the load terminal. The voltage rating of series APF under maximum sag condition is as,


$$V_{fse} = 230 * 0.20 = 46 \text{ V.}$$


(Refer Slide Time: 07:03)

(e) The current rating of series element of UAPC is same as supply current under voltage sag,


$$I_{se} = I_s = 13.961 \text{ A.}$$

(f) The VA rating of series element of UAPC is as,

$$S_{se} = V_{fse} * I_{se} = 46 * 13.961 \text{ VA} = 642.206 \text{ VA.}$$


(Refer Slide Time: 07:26)

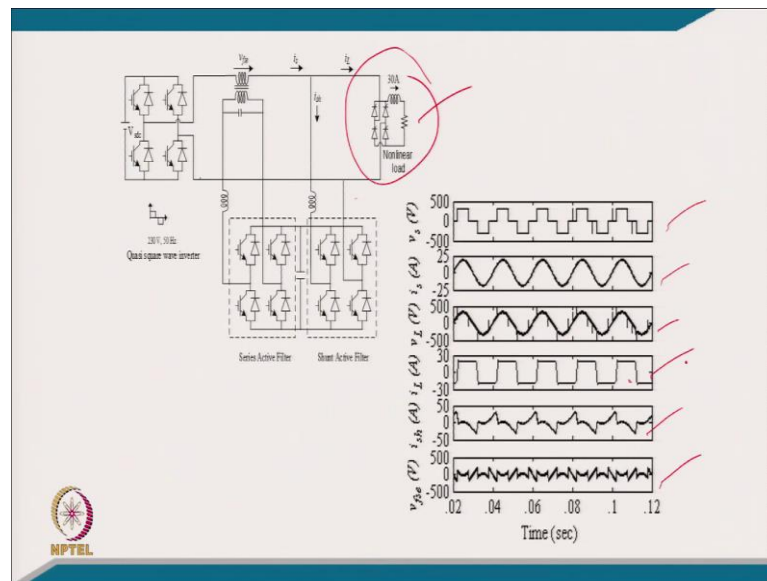
Q.6 A single-phase VSI with **quasi-square wave ac output of 230 V rms at 50 Hz** is feeding a critical load of 230 V, 50 Hz single-phase thyristor bridge with constant dc current of 30 A at 60° firing angle of its thyristors. A single-phase universal active power conditioner (UAPC consisting of shunt and series APFs using two VSCs with a common bus capacitor as shown in Fig.) is designed for this critical nonlinear load. Calculate (a) the voltage rating of shunt element of UAPC, (b) the current rating of shunt elements of UAPC, (c) the VA rating of shunt element of UAPC, (d) the voltage rating of series element of UAPC, (e) the current rating of series element of UAPC, (f) the VA rating of series element of UAPC to provide harmonics and reactive power compensation for unity power factor at ac mains by shunt element of UAPC and constant regulated sine wave voltage of a 230 V rms sine wave at 50 Hz across the load by series element of UAPC.



Coming to the 6th numerical problem a single phase voltage source inverter with a quasi square wave form ac output of 230 volt 50 hertz is feeding the critical load of 230 volt 50 hertz single phase thyristor bridge. With a constant dc current of 30 ampere, at the 60 degree fire angle of thyristor and single phase universal active power conditioner is design for this critical non-linear load calculate a the voltage rating of shunt element current rating of shunt element.

VA rating of shunt element and the voltage rating of series element and the current rating of series element and a VA rating of series element of universal active power conditioner to provide harmonics and reactive power compensation. For unity power factor at ac mains by shunt element of universal active power filter and constant regulated sine wave voltage of the 230 volt rms sine wave at 50 hertz across the load by series element of universal active power filter.

(Refer Slide Time: 08:20)



The explanation of the numerical problem is described in the screenshots herein.

(Refer Slide Time: 09:28)

Solution: Given that, supply voltage, $V_s = 230$ V rms quasi-square wave, frequency of supply, $f = 50$ Hz, a critical load of 230 V, 50 Hz single-phase thyristor bridge with constant dc current of 30 A at 60° ($\pi/6$ rad) firing angle of its thyristors.

In this system, load reactive power and harmonics current compensation are to be provided by the shunt active filter of UAPC. The voltage compensation is provided by series filter of UAPC. However, there is a difference in magnitude of fundamental voltage in the supply and load terminals, to compensate that an active power is circulated between series and shunt active filters as explained earlier in UPQC-P. The rating calculations for both the VSCs of UAPC are as follows. The load current is a square wave current with amplitude I_{dc} .

The ac load rms current is as,

$$I_L = 30 \text{ A.}$$

(Refer Slide Time: 10:32)

The fundamental component of load current is estimated as,
 $I_{L1} = 0.9 \cdot I_{dc}$.


The fundamental active power component of load current is,
 $I_{L1a} = I_{L1} \cos \alpha = 0.9 \cdot 30 \cdot \cos 60^\circ = 13.5 \text{ A}$.

The harmonics and reactive power component of load current is estimated as,
 $I_{Lr} = \sqrt{(I_L^2 - I_{L1a}^2)} = 26.791 \text{ A}$.

The amplitude of quasi-square wave is estimated as,
 $V_{sdc} = (230 / (\sqrt{2/3})) = 281.69 \text{ V}$.

The fundamental component of supply voltage is estimated as,
 $V_{s1} = (\sqrt{6/\pi}) \cdot V_{sdc} = 0.779 \cdot 281.69 = 219.634 \text{ V}$.

The active power consumed by the load is given by,
 $P_L = V_L \cdot I_{L1a} = 230 \cdot 13.5 = 3105 \text{ W}$.



(Refer Slide Time: 11:31)

The supply current is estimated as,
 $I_s = P_L / V_{s1} = 3105 / 219.63 = 14.137 \text{ A}$.


(a) The voltage rating of shunt element of UAPC is equal to ac load voltage of $V_{fsh} = 230 \text{ V}$, since it is connected across the load of 230V sine waveform.

(b) The current rating of shunt element of UAPC is computed as.

The shunt element of UAPC is to supply load current harmonics and reactive power compensation, hence the total harmonics and reactive power component of load current through shunt active filter is,

$$I_{shr} = \sqrt{(I_L^2 - I_{L1a}^2)} = \sqrt{(30^2 - 13.5^2)} = 26.791 \text{ A}$$

The supply fundamental voltage is lower as compared to the required load voltage. Hence, shunt APF absorbs active power and that active power is delivered back into the system via series APF.



(Refer Slide Time: 12:34)

The active power component of the shunt APF current is estimated as,

$$I_{sha} = I_s - I_{L1a} = (14.137 - 13.5) \text{ A} = 0.637 \text{ A}.$$

The net current rating of shunt APF is estimated as,


$$I_{sh} = \sqrt{(I_{sha})^2 + (I_{shr})^2} = \sqrt{(0.637)^2 + 26.791^2} = 26.799 \text{ A}.$$

(c) The VA rating of VSC of shunt APF is as,

$$S_{sh} = V_{fsh} * I_{sh} = 230 * 26.799 = 6163.674 \text{ VA}.$$

(d) The voltage rating of series element of UAPC is computed as.

The supply voltage is quasi-square wave of $V_s = 230 \text{ V rms}$ and the load voltage at load terminal must be sine wave of $V_L = 230 \text{ V}$. Therefore the series APF must inject the difference of these two voltages to provide the required voltage at the load end.



(Refer Slide Time: 13:30)


The voltage rating of series APF,

$$V_{sfe} = \frac{1}{\pi} \sqrt{\int_0^{\pi/6} (-230\sqrt{2}\sin\theta)^2 d\theta + \int_{\pi/6}^{5\pi/6} (281.69 - 230\sqrt{2}\sin\theta)^2 d\theta + \int_{5\pi/6}^{\pi} (-230\sqrt{2}\sin\theta)^2 d\theta} = 69.05 \text{ V}$$

(e) The current rating of series element of UAPC is same as supply current,


$$I_{se} = I_s = 14.137 \text{ A}.$$

(f) The VA rating of series element of UAPC is as,

$$S_{se} = V_{se} * I_{se} = 69.05 * 14.137 \text{ VA} = 976.176 \text{ VA}.$$


(Refer Slide Time: 14:16)

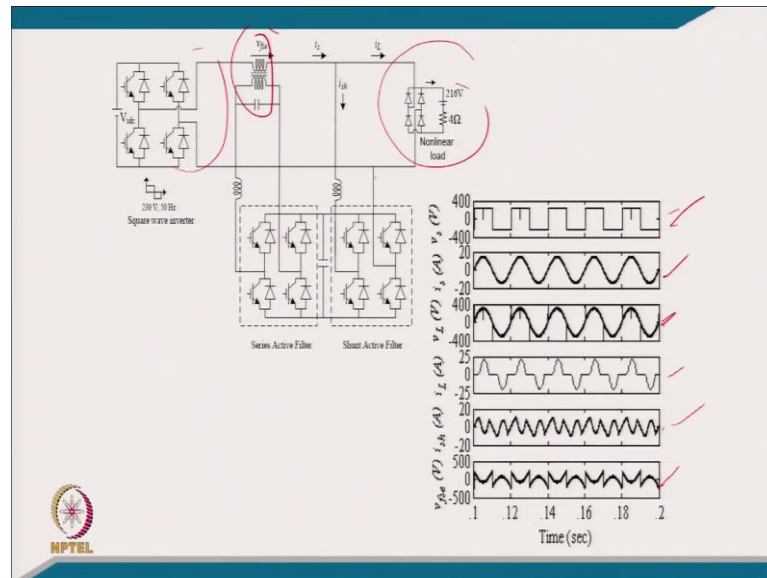
Q.7 A single-phase VSI with a **square wave ac output of 230 V rms at 50 Hz** is feeding a critical load at 220 V, 50 Hz single-phase and consisting of uncontrolled diode bridge converter, which has a RE (resistive with an emf) load with $R = 4 \Omega$, and $E = 216 \text{ V}$. A single-phase universal active power conditioner (UAPC consisting of shunt and series APFs using two VSCs with a common bus capacitor as shown in Fig.) is designed for this critical nonlinear load. Calculate (a) the voltage rating of shunt element of UAPC, (b) the current rating of shunt elements of UAPC, (c) the VA rating of shunt element of UAPC, (d) the voltage rating of series element of UAPC, (e) the current rating of series element of UAPC, (f) the VA rating of series element of UAPC to provide harmonics and reactive power compensation for unity power factor at ac mains by shunt element of UAPC and constant regulated sine wave voltage of a 220 V rms sine wave at 50 Hz across the load by series element of UAPC.



Coming to 7th numerical problem a single phase voltage source inverter with a square wave ac output of 230 volt at 50 hertz is feeding the critical load of 220 volt, 50 hertz a single phase. And consisting of un controlled diode bridge converter having a RE resistive and bend emf load with resistance equal to 4 ohm and E equal to 216 volt, a single phase universal active power conditioner consisting shunt and series active power filter using a 2 voltage source converter with common dc bus capacitor is use.

And which is design for critical non-linear load, calculate the a voltage rating of the shunt element of universal active power filter. b current rating of the shunt act element of universal active power conditioner, the c the VA rating of the shunt element of universal active power filter, d the voltage rating of series element of universal active power filter and e the current rating of series element of universal active power conditioner.

(Refer Slide Time: 15:34)



The explanation of the numerical problem is described in the screenshots herein.

(Refer Slide Time: 16:46)

Solution: : Given that, supply voltage, $V_s = 230$ V rms square wave, frequency of supply, $f = 50$ Hz a critical load at 220 V, 50 Hz single-phase and consisting of uncontrolled diode bridge converter, which has a RE (resistive with an emf) load with $R = 4 \Omega$, and $E = 216$ V.

In this system, load reactive power and harmonics current compensation are to be provided by the shunt active filter of UAPC. The voltage compensation is provided by the series filter of UAPC. However, there is a difference in magnitude of fundamental voltage in the supply and load terminals, to compensate that an active power is circulated between series and shunt active filters as explained earlier in UPQC-P. The rating calculations for both the VSCs of UAPC are as follows.

The amplitude of square wave is,

$V_{sdc} = 230$ V.

(Refer Slide Time: 17:45)

The fundamental component of supply voltage is estimated as,
 $V_{s1} = 0.9V_{sdc} = 0.9 \times 230 = 207$ V. However, the load terminal voltage is need to be regulated at, $V_L = 220$ V.


Under this reduced fundamental voltage, the rating calculations for both the conditioners are as follows,

In single-phase diode bridge converter with RE load, the current flows from angle (α) when ac voltage is equal to E and to the angle (β) at which ac voltage reduces to E .

The peak load voltage is,
 $V_{Lm} = 220 \times \sqrt{2} = 311.13$ V.

$\alpha = \sin^{-1}(E/V_{Lm}) = \sin^{-1}(216/311.13) = 43.96^\circ$,
 $\beta = \pi - \alpha = 136.03^\circ$,

The conduction angle = $\beta - \alpha = 92.06^\circ$.



(Refer Slide Time: 18:46)


The RMS load current (I_L) is rms of discontinuous current in the ac mains which is estimated as,
 $I_L = \left\{ \frac{1}{\pi R^2} \left[(0.5V_{Lm}^2 + E^2)(\pi - 2\alpha) + 0.5V_{Lm}^2 \sin 2\alpha - 4V_{Lm}E \cos \alpha \right] \right\}^{1/2}$
 $I_L = 12.32$ A.

An average current (I_{dc}) flowing into the battery is as,
 $I_{dc} = \frac{1}{\pi R} (2V_{Lm} \cos \alpha + 2E \alpha - \pi E) = 8.02$ A.

Active power drawn from the ac mains is as,
 $P_L = I_L^2 R + E I_{dc} = 12.32^2 \times 4 + 216 \times 8.02 = 2339.8$ W.

The active power component of fundamental load current from ac mains is,
 $I_{L1a} = P_L / V_L = 2339.8 / 220 = 10.63$ A.

The supply current is estimated as,
 $I_s = P_L / V_{s1} = 2339.8 / 207 = 11.30$ A.



(Refer Slide Time: 19:48)


The harmonics and reactive power component of load current is estimated as,

$$I_{Lr} = \sqrt{(I_L^2 - I_{L1a}^2)} = \sqrt{(12.32^2 - 10.36^2)} = 6.22 \text{ A.}$$

(a) The voltage rating of shunt element of UAPC is equal to ac load voltage of $V_{fsh} = 220 \text{ V}$, since it is connected across the load of 220 V sine waveform.

(b) The current rating of shunt element of UAPC is computed as,

The shunt element of UAPC supplies all current harmonics and reactive power component of load current hence harmonics and reactive power component of current from shunt active filter is as,

$$I_{shr} = \sqrt{(I_L^2 - I_{L1a}^2)} = \sqrt{(12.32^2 - 10.36^2)} = 6.22 \text{ A.}$$


(Refer Slide Time: 20:27)

The supply fundamental voltage is lower as compared to the required load voltage. Hence, shunt APF absorbs active power and that active power is delivered back into the system via series APF. The active power component of current from shunt APF is estimated as,

$$I_{sha} = I_s - I_{L1a} = (11.30 - 10.63) \text{ A} = 0.67 \text{ A.}$$

The net current rating of shunt APF is estimated as,


$$I_{sh} = \sqrt{(I_{sha}^2 + I_{shr}^2)} = \sqrt{(0.67^2 + 6.22^2)} = 6.25 \text{ A.}$$

(c) The VA rating of VSC of shunt APF,

$$S_{sh} = V_{fsh} * I_{sh} = 220 * 6.25 = 1434.4 \text{ VA.}$$

(d) The voltage rating of series element of UAPC is computed as.

The supply voltage is square wave of $V_s = 230 \text{ V rms}$ and the load voltage at load terminal must be sine wave of $V_L = 220 \text{ V}$. Therefore the series APF must inject the difference of these two voltages to provide the required voltage at the load end.



(Refer Slide Time: 21:26)


The voltage rating of series APF is estimated as,

$$V_{fse} = \sqrt{\frac{1}{\pi} \int_0^{\pi} (230 - 220 \cdot \sqrt{2} \sin \theta)^2 d\theta} = 100.93 \text{ V}$$

(e) The current through series element of UAPC is same as supply current hence current rating of series element is estimated as,


$$I_{se} = I_s = 11.30 \text{ A.}$$

(f) The VA rating of series element of UAPC is as,

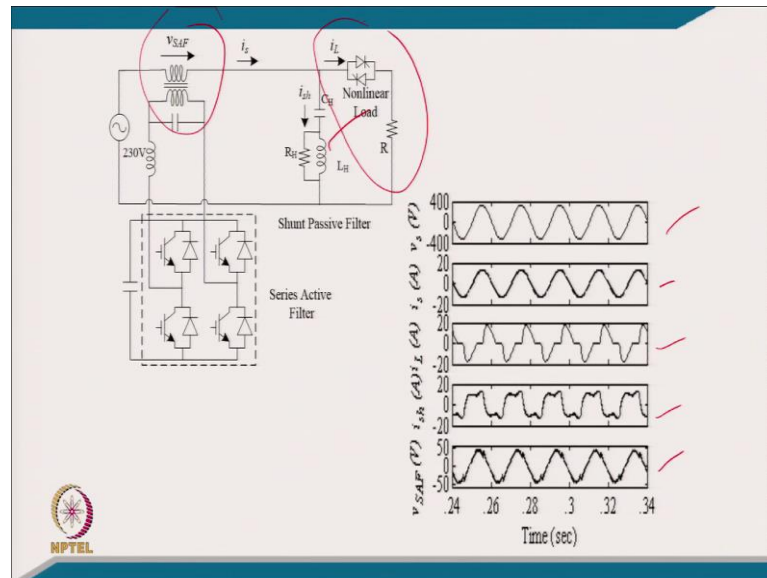
$$S_{se} = V_{fse} \cdot I_{se} = 100.93 \cdot 11.30 \text{ VA} = 1140.5 \text{ VA.}$$


(Refer Slide Time: 22:06)

Q8. A single-phase active hybrid filter (consisting of a one branch passive shunt filter as a high pass damped filter and series APF connected in series of ac mains using VSC with bus capacitor as shown in Fig.) is designed for a load of 230 V, 50 Hz thyristor ac voltage controller with a resistive load of 20.0Ω at 60° firing angle of its thyristors. Calculate the rating of both series APF and elements values of passive shunt filter used in a hybrid filter to provide harmonic compensation and reactive power compensation for unity power factor at ac mains.



(Refer Slide Time: 22:43)



The explanation of the numerical problem is described in the screenshots herein.

(Refer Slide Time: 24:05)

Solution: Given that, supply rms voltage, $V_s = 230$ V, frequency of the supply $f = 50$ Hz, $R = 20 \Omega$, $\alpha = 60^\circ$. A single-phase active hybrid filter (consisting of a shunt passive filter and series APF using VSC with dc bus capacitor) connected in series with ac mains is designed for this load compensation.

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 α to π . The peak load voltage is as,

$$V_{sdc} = 230\sqrt{2} = 325.27 \text{ V.}$$

An ac load rms current is as,

$$I_L = V_{sdc} \left[\frac{1}{2\pi} \int_{\pi-\alpha}^{\pi} (\pi-\alpha + \sin 2\alpha/2) \right]^{1/2} / R = 10.315 \text{ A.}$$

Fundamental RMS load current

$$I_{L1} = V_{sdc} / (2\pi R \sqrt{2}) \left[(\cos 2\alpha - 1)^2 + \{\sin 2\alpha + 2(\pi - \alpha)\}^2 \right]^{1/2} = 9.65 \text{ A.}$$

(Refer Slide Time: 24:58)

The displacement angle is as,
 $\theta_1 = \tan^{-1}[(\cos 2\alpha - 1) / (\sin 2\alpha + 2(\pi - \alpha))] = 16.528^\circ$.


The fundamental active power drawn by the load is as,
 $P_{L1} = V_s I_{L1} \cos \theta_1 = 2127.791 \text{ W}$.

The fundamental reactive power drawn by the load is as,
 $Q_{L1} = V_s I_{L1} \sin \theta_1 = 631.412 \text{ VAR}$.

The RMS load voltage is as,
 $V_L = V_{sdc} \sqrt{[1/(2\pi)](\pi - \alpha + \sin 2\alpha/2)} = 206.3 \text{ V}$.

The load Displacement factor is as,
 $\text{DPF} = \cos \theta_1 = \cos 16.528^\circ = 0.959$.

The load Distortion Factor is as,
 $\text{DF} = I_{L1}/I_L = 9.65/10.315 = 0.936$.



(Refer Slide Time: 25:56)


The load Power factor is as, $\text{PF} = \text{DPF} * \text{DF} = 0.897$.

The AC mains current after the compensation is as,
 $I_s = I_{L1} \cos \theta_1 = P_{L1} / V_s = 2127.791 / 230 = 9.251 \text{ A}$.

The shunt passive filter has to meet the reactive power requirement of the load for UPF at the ac mains, therefore, the capacitor of the passive shunt filter must be selected to provide this required reactive power.

There the value of the capacitor is as,
 $C = Q_1 / (V_s^2 \omega) = 631.412 / (230^2 * 314) = 37.993 \mu\text{F}$.

Since there is only one branch in the passive shunt filter, which must be tuned for lowest harmonic (3rd order harmonic in this case) present in the load current as a damped filter to take care all the harmonics currents, therefore, this value of the capacitor is the element of this passive filter.



(Refer Slide Time: 26:52)

$C_H = C = 37.993 \mu\text{F}$.

The value of an inductor for high pass damped harmonic filter (tuned at 3rd harmonic) is as,

$$L_H = 1 / (\omega_3^2 C_H) = 29.631 \text{ mH}.$$


The resistance in parallel of an inductor of a high pass damped harmonic tuned filter is as,

$$R_H = X_H / Q_H = 5 * 314 * 29.631 / (5 * 1000) = 5.585 \Omega. \text{ (Considering } Q_H = 5 \text{ for lower losses in it as it may be in the range of 0.5-5 depending upon the attenuation required.)}$$

All other harmonics load currents to flow in to high pass damped harmonic filter is as,

$$I_H = \sqrt{I_L^2 - I_{L1}^2} = \sqrt{10.315^2 - 9.65^2} = 3.644 \text{ A}.$$

All higher order harmonics voltage at the load end and across the passive filter is as,



(Refer Slide Time: 27:56)

All higher order harmonics voltage at the load end and across the passive filter is as,

$$V_H = I_H * R_H = 3.644 * 5.585 = 20.350 \text{ V}.$$

All harmonics voltages other than the fundamental voltage at the load end and across the passive filter is as,

$$V_{LH} = V_H = I_H * R_H = 20.350 \text{ V}.$$


The voltage rating of the passive shunt filter is as,

$$V_{PF} = \sqrt{V_s^2 + V_{LH}^2} = \sqrt{230^2 + 20.350^2} = 230.899 \text{ V}.$$

The current rating of the passive filter is as,

$$I_{PF} = \sqrt{I_L^2 - I_s^2} = \sqrt{10.315^2 - 9.251^2} = 4.563 \text{ A}.$$

The VA rating of the passive shunt filter is as,

$$S_{PF} = V_{PF} * I_{PF} = 230.899 * 4.563 = 1053.523 \text{ VA}.$$


(Refer Slide Time: 28:47)

The pu rating of the PF is as,

$$S_{PF_{pu}} = S_{PF}/S_L = 1053.523/(230*10.315) = 0.444$$

$S_{PF_{pu}} = 44.407\%$ of the load rating.


The series active filter must inject this all harmonics voltages to force all harmonics currents in to the passive filter. Therefore, the voltage rating of the series active filter is as,

$$V_{SAF} = V_{LH} = V_H = 20.350 \text{ V.}$$

The current rating of the series active filter is as,

$$I_{SAF} = I_s = \text{Fundamental active power component of load current,}$$
$$I_s = I_{L1} \cos \theta_1 = P_1/V_s = 2127.791/230 = 9.251 \text{ A.}$$

(Since, the series APF is connected in series with the ac mains before the passive shunt filter which is providing harmonics and reactive power compensation resulting in UPF at the ac mains).



(Refer Slide Time: 29:39)


The VA rating of the series APF is as,

$$S_{APF} = V_{SAF} * I_{SAF} = 20.350 * 9.251 = 188.258 \text{ VA.}$$

The pu rating of the series APF is as,


$$S_{APF_{pu}} = S_{APF}/S_L = 188.258 / (230*10.315) = 0.079$$

$S_{APF_{pu}} = 7.935\%$ of the load rating.



(Refer Slide Time: 30:10)

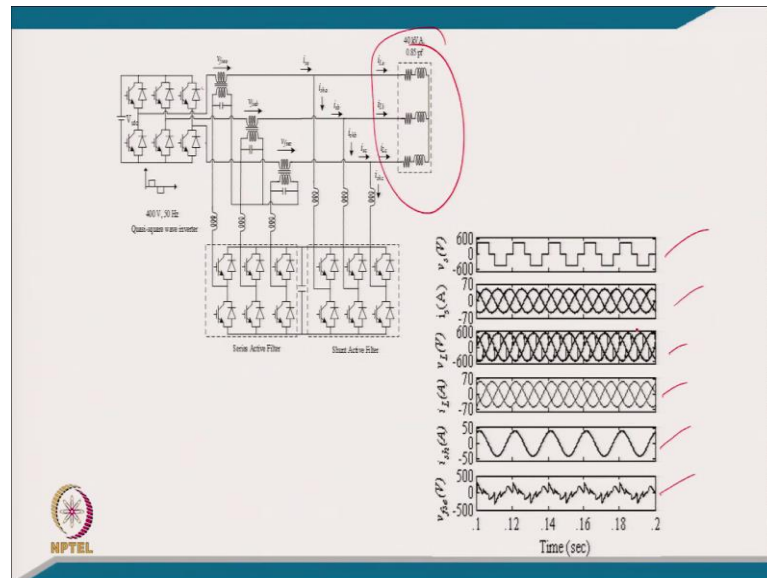
Q9. A three-phase VSI with **quasi-square wave ac output line voltage of 400 V rms at 50 Hz** is feeding a critical load of 415 V, 50 Hz, three-phase, 40 kVA at 0.85 lagging power factor. A three-phase universal active power conditioner (UAPC is consisting of series and shunt APFs using two VSCs with a common bus capacitor as shown in Fig.) is designed for this critical linear load. Calculate (a) the voltage rating of shunt element of UAPC, (b) the current rating of shunt elements of UAPC, (c) the VA rating of shunt element of UAPC, (d) the voltage rating of series element of UAPC, (e) the current rating of series element of UAPC, (f) the VA rating of series element of UAPC to provide harmonics and reactive power compensation for unity power factor at ac mains by shunt element of UAPC and constant regulated sine wave voltage of a 415 V rms at 50 Hz across the load by series element of UAPC.



Coming to the 9th numerical problem, a three phase voltage source inverter with quasi square wave ac output line voltage of 400 volt rms at 50 hertz is feeding a critical load of 415 volt 50 hertz three phase 40 k VA 0.85 lagging power factor load. A three phase universal active power conditioner I mean is design for this critical non-linear load calculate the a voltage rating of the shunt element, current rating of shunt element, VA rating of shunt element and the voltage rating of series element, current rating of series element.

And the VA rating of series element of universal active power conditioner to provide harmonics and reactive power compensation for unity power factor at ac main by shunt element of the universal active power conditioner. And constant regulated sine wave voltage of 415-volt rms at 50 hertz across the load by series element of universal active power conditioner.

(Refer Slide Time: 31:03)



The explanation of the numerical problem is described in the screenshots herein.

(Refer Slide Time: 31:59)

Solution: Given that, $V_{sl} = 400$ V rms of quasi-square wave line voltage, $f = 50$ Hz, a critical linear load of 40 kVA, 415 V, 50 Hz at 0.85 lagging pf.

The desired load phase voltage,

$$V_{Lp} = 415/\sqrt{3} = 239.6 \text{ V of sine wave.}$$

The magnitude of dc side voltage of supply side VSI is estimated as,

$$V_{sdc} = (V_{sl}/\sqrt{2/3}) = 400/0.8165 = 489.89 \text{ V.}$$

The load line current is as,

$$I_L = I_{L1} = 40000/(3 \times 239.6) = 55.648 \text{ A.}$$

The active power component of load line current is as,

$$I_{L1a} = (S_L \times \text{pf}) / (3 \times V_{Lp}) = 40000 \times 0.85 / (3 \times 239.6) = 47.301 \text{ A.}$$

The fundamental component of supply side line voltage is,

$$V_{sl1} = (\sqrt{6} \times V_{sdc} / \pi) = 0.779 \times 489.89 = 381.972 \text{ V.}$$

(Refer Slide Time: 33:04)

The fundamental component of supply phase voltage is as,

$$V_{sp1} = V_{sl1}/\sqrt{3} = 220.532 \text{ V.}$$

The supply current after the compensation is as,


$$I_s = \{S_L * pf / (3 * V_{sp1})\} = 51.391 \text{ A.}$$

The rating calculations for both the VSCs of UAPC are as follows.

(a) The voltage rating of shunt element of UAPC is equal to ac load phase voltage of $V_{sh} = 239.6 \text{ V}$, since it is connected across the load of 239.6 V sine waveform.

(b) The current rating of shunt element of UAPC is computed as,

The shunt element of UAPC compensates for the load reactive power, hence the required reactive power component shunt active filter current is estimated as


$$I_{shr} = \sqrt{(I_L^2 - I_{L1a}^2)} = \sqrt{(55.648^2 - 47.301^2)} = 29.315 \text{ A.}$$

(Refer Slide Time: 33:54)

The active power component of shunt APF current is estimated as,

$$I_{sha} = I_s - I_{L1a} = (51.391 - 47.301) \text{ A} = 4.09 \text{ A.}$$

The net current rating of shunt APF is estimated as,


$$I_{sh} = \sqrt{(I_{sha}^2 + I_{shr}^2)} = \sqrt{(4.09^2 + 29.315^2)} = 29.599 \text{ A.}$$

(c) The VA rating of VSC of shunt APF is as,

$$S_{sh} = 3 * V_{sh} * I_{sh} = 3 * 239.6 * 29.599 \text{ VA} = 21.276 \text{ kVA.}$$

(d) The supply of quasi-square line voltage results in stepped phase voltage.

The waveform of the phase voltage at the input of series active filter is a stepped waveforms as (i) first step of $\pi/3$ angle {from 0° to $(\pi/3)$ } and a magnitude of $(V_{sdc}/3)$, (ii) second step of $\pi/3$ angle {from $(\pi/3)$ to $(2\pi/3)$ } and a magnitude of $\{2V_{sdc}/3\}$, (iii) third step of $\pi/3$ angle {from $(2\pi/3)$ to (π) } and a magnitude of $\{V_{sdc}/3\}$ and it has both half cycles of symmetric segments of such steps.



(Refer Slide Time: 34:59)


The voltage rating of series APF, V_{fse} is computed by taking the difference of the supply phase voltage and required load sine phase voltage at the input of linear load as,

$$V_{fse} = \sqrt{\frac{1}{\pi} \int_0^{\pi/3} (239.6\sqrt{2}\sin\theta - 163.29)^2 d\theta + \frac{2\pi/3}{\pi/3} \int_{\pi/3}^{2\pi/3} (239.6\sqrt{2}\sin\theta - 326.59)^2 d\theta + \frac{\pi}{2\pi/3} \int_{2\pi/3}^{\pi} (239.6\sqrt{2}\sin\theta - 163.29)^2 d\theta} = 71.15 \text{ V}$$

(e) The current rating of series APF is as,


$$I_{se} = I_s = 51.391 \text{ A.}$$

(f) The VA rating of series connected APF is as,

$$S_{se} = 3 * V_{fse} * I_{se} = 3 * 71.15 * 51.391 \text{ VA} = 10.969 \text{ kVA.}$$


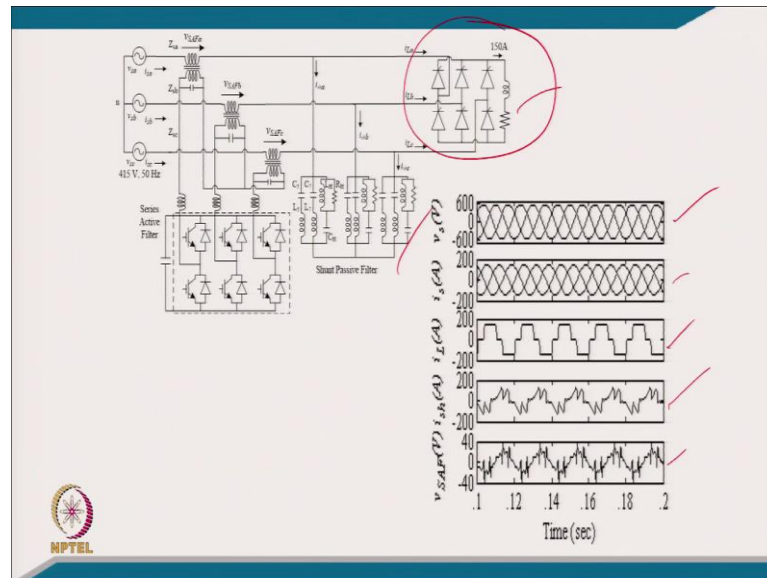
(Refer Slide Time: 35:43)

Q10. A three-phase active filter connected in series with ac mains and a three branch shunt passive filter (PF) (5th, 7th and high pass filter as shown in Fig.) is used for harmonics current and reactive power compensation in a three-phase 415 V, 50 Hz system to reduce the THD of supply current and to improve the displacement factor to unity. It has a load of three-phase thyristor bridge converter operating at 30° firing angle drawing constant 150 A dc current. Calculate (a) the designed value of passive filter components; (b) line current, (c) VA rating of series APF.



Coming to the 10th problem, a three phase active power filter connected in series with the ac mains and three phase and 3 branch passive shunt passive filter tune for 5th 7th and high pass is use for harmonics current and reactive power compensation in three phase 415 volt 50 hertz system to reduce the THD of supply current and to improve the displacement factory unity. It has a load of three phase thyristor bridge converter operating a 30-degree angle drawing a constant current of 150 ampere dc current, calculate the a desired value of passive filter element b line current c VA rating of series active filter.

(Refer Slide Time: 36:22)



The explanation of the numerical problem is described in the screenshots herein.

(Refer Slide Time: 37:48)

Solution: Given that, a three-phase ac line voltage of 415 V rms at 50 Hz is feeding a load of three-phase thyristor bridge converter operating at 30° firing angle drawing constant 150A dc current. A set of shunt connected ac tuned passive filters for this system is used to compensate the reactive power and 5th, 7th harmonics and high pass damped filter to compensate all higher order harmonics at the input ac mains.

In this system, load current harmonics and reactive power compensation are to be provided by the shunt passive filter and a series active filter is used to force all harmonics currents through this shunt passive filter.

In three-phase thyristor bridge converter, the waveform of the load current (I_L) is a quasi-square wave with the amplitude of dc link current (I_{dc}).

Therefore, $I_L = \sqrt{2/3} I_{dc} = 0.81649 \cdot 150 = 122.47 \text{ A}$.

(Refer Slide Time: 38:40)

Moreover, rms of fundamental component of quasi-square wave load current is as,

$$I_{L1} = \left\{ \frac{\sqrt{6}}{\pi} \right\} I_{dc} = 0.779 \times 150 = 117.01 \text{ A.}$$

An active power component of supply current is as,

$$I_{L1a} = I_{L1} \cos \theta_1 = I_{L1} \cos \alpha = 117.01 \cos 30^\circ = 101.33 \text{ A.}$$


The fundamental active power of the load,

$$P_L = 3 \times V_L \times I_{L1a} = 3 \times 239.6 \times 101.33 = 72.836 \text{ kW.}$$

The fundamental reactive power of the load,

$$Q_L = 3 \times V_L \times I_{L1} \sin \alpha = 3 \times 239.6 \times 117.01 \times 0.5 = 42.053 \text{ kVAR.}$$

The passive shunt filter has nine branches (three for each phase and nine for all three-phases). The total reactive power of 42.053 kVAR (required by thyristor rectifier) is to provide by all nine branches of the passive shunt filter.



(Refer Slide Time: 39:35)

Considering that all branches of the passive filter has equal capacitors, therefore, the value of this capacitor is as,

$$C = Q / (9V_s^2\omega) = 42053 / (9 \times 239.6^2 \times 314) = 259.21 \mu\text{F.}$$

Therefore, $C_5 = C_7 = C_H = C = 259.21 \mu\text{F.}$

Therefore, the value of an inductor for 5th harmonic tuned filter is as,


$$L_5 = 1 / (\omega_5^2 C_5) = 1.565 \text{ mH.}$$

The resistance of the inductor of 5th harmonic tuned filter is as,

$$R_5 = X_5 / Q_5 = 2.547 / 20 = 0.123 \Omega.$$

(Considering $Q_5 = 20$ as it may be in the range of 10-100 depending upon the design of the inductor.)

The value of an inductor of 7th harmonic tuned filter is as,

$$L_7 = 1 / (\omega_7^2 C_7) = 0.798 \text{ mH.}$$



(Refer Slide Time: 40:19)

The resistance of the inductor of 7th harmonic tuned filter is as,
 $R_7 = X_7/Q_7 = 1.7655/20 = 0.088 \Omega$. (Considering $Q_5 = 20$ as it may be in the range of 10-100 depending upon the design of the inductor.)

The value of an inductor for high pass damped harmonic filter (tuned at 11th harmonic) is as,
 $L_H = 1/(\omega_{11}^2 C_H) = 0.32337 \text{ mH}$.

The resistance in parallel of an inductor of a high pass damped harmonic tuned filter is as,
 $R_H = X_H/Q_H = 1.1169/2 = 0.558 \Omega$. (Considering $Q_H = 2$ as it may be in the range of 0.5-5 depending upon the attenuation required.)

A three-phase thyristor rectifier with quasi-square ac mains current has the fundamental rms current as,
 $I_{1TS} = I_{L1} = 117.01 \text{ A}$.



(Refer Slide Time: 41:14)


The 5th harmonic load current to flow in to 5th harmonic tuned filter is as,
 $I_5 = I_{1TS}/5 = 117.01/5 = 23.402 \text{ A}$.

The 5th harmonic voltage at the load end and across the passive filter is as,
 $V_5 = I_5 * R_5 = 23.402 * 0.122862 = 2.875 \text{ V}$.

The 7th harmonic load current to flow in to 7th harmonic tuned filter is as,
 $I_7 = I_{1TS}/7 = 117.01/7 = 16.72 \text{ A}$.

The 7th harmonic voltage at the load end and across the passive filter is as,
 $V_7 = I_7 * R_7 = 16.72 * 0.088275 = 1.48 \text{ V}$.

All other harmonics load currents to flow in to high pass damped harmonic filter is as,



(Refer Slide Time: 41:50)

$$I_H = \sqrt{[I_s^2 - I_{1TS}^2 - I_5^2 - I_7^2]} = \sqrt{[122.47^2 - 117.01^2 - 23.402^2 - 16.72^2]}$$
$$I_H = 21.92 \text{ A.}$$


All higher order harmonics voltage at the load end and across the passive filter is as,

$$V_H = I_H * R_H = 21.92 * 0.55845 = 12.24 \text{ V.}$$

All harmonics voltages other than the fundamental voltage at the load end and across the passive filter is as,

$$V_{LH} = \sqrt{(V_5^2 + V_7^2 + V_H^2)} = 12.66 \text{ V.}$$

The series active filter must inject this all harmonics voltages to force all harmonics currents in to the passive filter. Therefore, the voltage rating of the series active filter is as,

$$V_{SAF} = V_{LH} = \sqrt{(V_5^2 + V_7^2 + V_H^2)} = 12.66 \text{ V.}$$


(Refer Slide Time: 42:35)

(b) The line current after the compensation is at UPF as,

$$I_{L1a} = I_{L1} \cos \theta_1 = I_{L1} \cos \alpha = 117.01 \cos 30^\circ = 101.33 \text{ A.}$$


(c) The current rating of the series active filter is as,

$$I_{SAF} = I_{L1a} = 101.33 \text{ A. (Since, the series APF is connected in series with AC mains).}$$

(d) The VA rating of the series APF is as,


$$S_{APF} = 3 * V_{SAF} * I_{SAF} = 3 * 12.66 * 101.33 = 3848.5 = 3.8485 \text{ kVA.}$$

The pu rating of the series APF is as,

$$S_{pu} = S_{APF} / S_L = 3848.5 / (3 * 239.6 * 122.47) = 0.0437 = 4.37 \% \text{ of the load rating.}$$


(Refer Slide Time: 43:07)

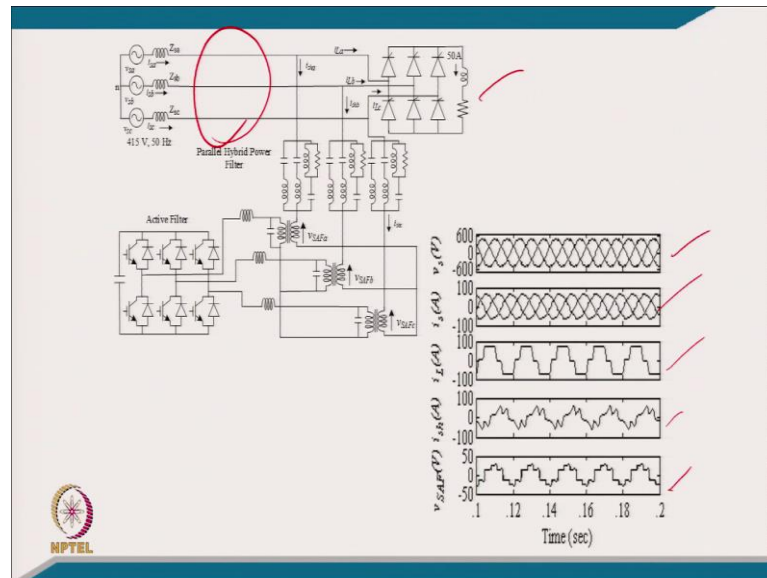
Q11. A three-phase, series active filter connected in series with a three branch shunt passive filter (PF) (5th, 7th and high pass filter as shown in Fig.) is used for harmonics current and reactive power compensation in a three-phase 415 V, 50 Hz system to reduce the THD of supply current and to improve the displacement factor to unity. It has a load of a three-phase thyristor bridge converter operating at 30° firing angle drawing constant 50 A dc current. Calculate (a) the designed value of passive filter components, (b) line current, (c) VA rating of APF, (d) ac inductor value of APF, and (e) its dc bus voltage and (f) the dc bus capacitor value of APF. Consider the switching frequency of 10 kHz and dc bus voltage has to be controlled within 5% range and ripple current in inductor is 10%. The turn's ratio of the injection transformer is 1:10.



Coming to the problem number 11. A three phase series active power filter connected in series with a three branch shunt passive filter 5th 7th and high pass filter is used for harmonic current and reactive power compensation in three phase 415 volt 50 hertz system to reduce the THD of supply current and to improve the displacement factor to unity it has a load of the three phase thyristor bridge converter operating at fire 30 degree fire angle drawing a current of constant current of 50 ampere.

Calculate a, the design value of the passive shunt filter component, b line current, c VA rating of series active filter, d ac inductor value of active power filter and e the dc link voltage of series active filter and the f the dc bus capacitor value of APF consider the switching frequency of 10 kilo hertz and dc link voltage have to be controlled within 5 percent of the range and ripple current of in the inductor 10 percent and turns ratio of injection transformer is 1 to 10.

(Refer Slide Time: 44:01)



The explanation of the numerical problem is described in the screenshots herein.

(Refer Slide Time: 45:11)

Solution: Given that, a three-phase ac line voltage of 415 V rms at 50 Hz is feeding a load of three-phase thyristor bridge converter operating at 30° firing angle drawing constant 50 A dc current. A three-phase, series active filter connected in series with a three branch shunt passive filter (PF) (5th, 7th and high pass filter) is used for harmonics current and reactive power compensation in a three-phase 415 V, 50 Hz system to reduce the THD of supply current and to improve the displacement factor to unity. Consider the switching frequency of 10 kHz and dc bus voltage has to be controlled within 5% range and ripple current in inductor is 10%. The turn's ratio of the injection transformer is 1:10.

In this system, load current harmonics and reactive power compensation are to be provided by the shunt passive filter and a series filter is used to such all harmonics currents through this shunt passive filter.

(Refer Slide Time: 46:06)

In three-phase thyristor bridge converter, the waveform of the load current (I_L) is a quasi-square wave with the amplitude of dc link current (I_{dc}).

Therefore, $I_L = \sqrt{(2/3)} I_{dc} = 0.816 \cdot 50 = 40.825 \text{ A}$.

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

$$I_{L1} = \{(\sqrt{6}/\pi)\} I_{dc} = 38.985 \text{ A}$$


Active power component of supply current,

$$I_{L1a} = I_{L1} \cos \theta_1 = I_{L1} \cos \alpha = 38.985 \cos 30^\circ = 33.762 \text{ A}$$

Total harmonics and reactive power component of load current,

$$I_f = \sqrt{(I_L^2 - I_{L1a}^2)} = \sqrt{(40.825^2 - 33.762^2)} = 22.953 \text{ A}$$

The fundamental reactive power of the load,

$$Q_L = 3 \cdot V_L \cdot I_{L1} \sin \alpha = 3 \cdot 239.6 \cdot 38.985 \cdot 0.5 = 14.011 \text{ kVAR}$$


(Refer Slide Time: 46:58)

The passive shunt filter has nine branches (three for each phase and nine for all three-phases). The total reactive power of 14.011 kVAR required for the thyristor converter, which a passive shunt filter has to provide by its all nine branches. Considering that all branches of the passive filter has equal capacitors, therefore, the value of this capacitor is as,

$$C = Q_L / (9V_L^2 \omega) = 14011.173 / (9 \cdot 239.6^2 \cdot 314) = 86.319 \mu\text{F}$$

So, $C_5 = C_7 = C_H = C = 86.319 \mu\text{F}$.


Therefore, the value of an inductor for 5th harmonic tuned filter is as,

$$L_5 = 1 / (\omega_5^2 C_5) = 4.695 \text{ mH}$$

The resistance of the inductor of 5th harmonic tuned filter is as,

$$R_5 = X_5 / Q_5 = 0.369 \Omega$$

(Considering $Q_5 = 20$ as it may be in the range of 10-100 depending upon the design of the inductor)




(Refer Slide Time: 47:50)

The value of an inductor of 7th harmonic tuned filter is as,
 $L_7 = 1/(\omega_7^2 C_7) = 2.395 \text{ mH}$.

The resistance of the inductor of 7th harmonic tuned filter is as,
 $R_7 = X_7/Q_7 = 0.263 \Omega$. (Considering $Q_5 = 20$ as it may be in the range of 10-100 depending upon the design of the inductor)

The value of an inductor for high pass damped harmonic filter (tuned at 11th harmonic) is as,
 $L_H = 1/(\omega_{11}^2 C_H) = 0.97 \text{ mH}$.

The resistance in parallel of an inductor of a high pass damped harmonic tuned filter is as,
 $R_H = X_H/Q_H = 3.35/2.5 = 1.341 \Omega$. (Considering $Q_H = 2.5$ as it may be in the range of 0.5-5 depending upon the attenuation required)



(Refer Slide Time: 48:22)


A three-phase thyristor rectifier with quasi-square ac input current has the fundamental rms current as,
 $I_{1TS} = I_{L1} = \{(\sqrt{6})/\pi\} I_{dc} = 38.985 \text{ A}$.

The 5th harmonic load current to flow in to 5th harmonic tuned filter is as,
 $I_5 = I_{1TS}/5 = 38.985/5 = 7.797 \text{ A}$.


The 5th harmonic voltage at the load end and across the passive filter is as,
 $V_5 = I_5 * R_5 = 7.797 * 0.369 = 2.877 \text{ V}$.

The 7th harmonic load current to flow in to 7th harmonic tuned filter is as,
 $I_7 = I_{1TS}/7 = 38.985/7 = 5.569 \text{ A}$.


The 7th harmonic voltage at the load end and across the passive filter is as,




(Refer Slide Time: 48:57)

$V_7 = I_7 \cdot R_7 = 5.569 \cdot 0.263 = 1.465 \text{ V.}$
 All other harmonics load currents to flow in to high pass damped harmonic filter is as,
 $I_H = \sqrt{I_L^2 - I_{1TS}^2 - I_5^2 - I_7^2} = \sqrt{40.825^2 - 38.985^2 - 7.797^2 - 5.569^2}$
 $I_H = 7.419 \text{ A.}$
 All higher order harmonics voltage at the load end and across the passive filter is as,
 $V_H = I_H \cdot R_H = 7.419 \cdot 1.341 = 9.949 \text{ V.}$
 All harmonics voltages other than the fundamental voltage at the load end and across the passive filter is as,
 $V_{LH} = \sqrt{V_5^2 + V_7^2 + V_H^2} = 10.46 \text{ V.}$
 The series active filter must inject this all harmonics voltages to force all harmonics currents in to the passive filter. Therefore, the voltage rating of the series active filter is as,

(Refer Slide Time: 49:43)

$V_{SAF} = V_{LH} = \sqrt{V_5^2 + V_7^2 + V_H^2} = 10.46 \text{ V.}$
 (b) The line current after the compensation is at UPF as,
 $I_{s1a} = I_{s1} \cos \theta_1 = I_{s1} \cos \alpha = 38.985 \cos 30^\circ = 33.762 \text{ A.}$
 (c) The current rating of the series active filter is as,
 $I_{SAF} = \sqrt{I_L^2 - I_{L1a}^2} = \sqrt{40.825^2 - 33.762^2} = 22.953 \text{ A.}$ (Since, the series APF is connected in series with the passive shunt filter).
 The VA rating of the series APF is as,
 $S_{APF} = 3 \cdot V_{SAF} \cdot I_{SAF} = 3 \cdot 10.46 \cdot 22.953 = 720.25 \text{ VA.}$
 The pu rating of the series APF is as,
 $S_{pu} = S_{APF} / S_L = 720.25 / (3 \cdot 239.6 \cdot 40.825) = 2.454 \% \text{ of the load rating.}$
 (d) The ac inductor value of series APF is as,
 $L_1 = N_2 / N_1 \{ (\sqrt{3}) / 2 \} m_a V_{dcapf} / (6 \omega f_s \Delta I_f)$

(Refer Slide Time: 50:34)


$$L_f = \frac{\{(\sqrt{3}/2) \cdot 8 \cdot 369.817\}}{(6 \cdot 1.2 \cdot 10000 \cdot 0.1 \cdot 22.953/10)}$$
$$L_f = 15.504 \text{ mH.}$$

(e) The VSC side of an ac injected voltage is as,

$$V_{inj} = V_{SAF} \cdot N_2/N_1 = 10.46 \cdot 10 = 104.6 \text{ V.}$$

The dc bus voltage to VSC to inject this phase rms voltage is as,

$$V_{dcapf} = 2\sqrt{2} \cdot V_{inj}/m_a = 2\sqrt{2} \cdot 104.6/0.8 = 369.817 \text{ V.}$$

(f) The dc bus capacitance of an APF is computed from change in stored energy during dynamics as.


The change in stored energy during dynamics,

$$\Delta E = \frac{1}{2} C_{dc} (V_{dcapf}^2 - V_{dminapf}^2) = 3 \cdot V_{SAF} \cdot I_{SAF} \cdot \Delta t$$
$$\Delta E = \frac{1}{2} C_{dc} (369.817^2 - 351.326^2) = 3 \cdot 10.46 \cdot 22.953 \cdot 10/1000$$

(Considering $\Delta t = 10\text{ms}$) ($V_{dminapf} = (1-0.05) \cdot V_{dcapf}$)

$$C_{dc} = 1080.291 \text{ }\mu\text{F.}$$

(Refer Slide Time: 51:05)

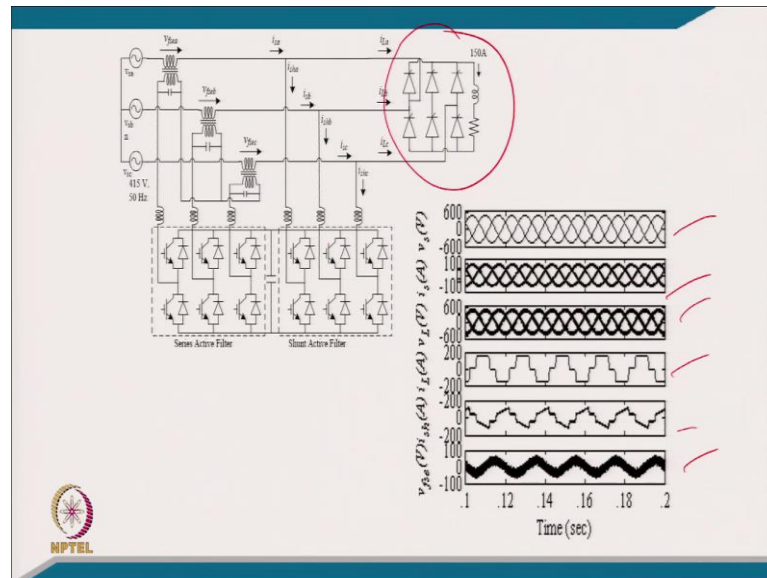


Q12. A three-phase universal active power conditioner (UAPC consisting of shunt and series APFs using two VSCs with a common bus capacitor as shown in Fig.) is designed for a load of 415 V, 50 Hz thyristor bridge with constant dc current of 150 A at 60° firing angle of its thyristors. If there is a voltage fluctuations of +10% and -20% in supply system with base value of 415 V. Calculate (a) the voltage rating of shunt element of UAPC, (b) the current rating of shunt elements of UAPC, (c) the VA rating of shunt element of UAPC, (d) the voltage rating of series element of UAPC, (e) the current rating of series element of UAPC, (f) the VA rating of series element of UAPC to provide harmonic and reactive power compensation for unity power factor at ac mains with constant regulated sine wave voltage of 415 V at 50 Hz across the load by the series active filter.

Coming to the 12th numerical problem a three phase universal active power conditioner consisting of shunt and series active filter using two voltage source converter with common dc bus capacitor is design for a load of 415 volt 50 hertz thyristor converter. Thyristor bridge with a constant dc current of 150 ampere, 60 degree fire angle of the thyristor. If there is any voltage fluctuation of 10 percent minus 20 percent in the supply system with the base value of 415 volt.

Calculate the voltage rating of the shunt active filter, current rating of shunt filter, VA rating of shunt filter, then the voltage rating of series active filter current rating of series filter and the VA rating of series filter to provide the harmonics and reactive power compensation for unity power factor at ac mains with the constant regulator sine wave voltage of 415 volt 50 hertz across the load by the series active filter.

(Refer Slide Time: 51:54)



The explanation of the numerical problem is described in the screenshots herein.

(Refer Slide Time: 52:47)

Solution: Given that, Supply rms voltage/phase is, $V_{sp} = 415/\sqrt{3} = 239.6$ V, frequency of the supply, $f = 50$ Hz, a nonlinear load of 415 V, 50 Hz thyristor bridge with constant dc current of 150 A at 60° firing angle of its thyristors. There is a voltage fluctuation of +10% and -20% in supply system with base value of 415 V.

Let X be the pu voltage variation and V_{sp}' be the PCC voltage under voltage variation.

The per phase load voltage is, $V_{Lp} = V_{Ll}/\sqrt{3} = 415/\sqrt{3} = 239.6$ V.

In this system, load current harmonics and reactive power compensation are to be provided by the shunt active filter of UAPC. The voltage sag/swell compensation is provided by series filter of UAPC. However, while compensating for sag/swell an active power is circulated between series and shunt active filters as explained earlier in UPQC-P. Under maximum voltage sag, the maximum rating for both the VSCs are realized. The various rating calculations are as follows,

(Refer Slide Time: 53:48)

The supply voltage under maximum voltage sag is as,

$$V_{sp}' = V_s (1-X) = 239.6 * (1-0.2) = 191.68 \text{ V.}$$

In three-phase thyristor bridge converter, the waveform of the load line current (I_L) is a quasi-square wave with the amplitude of dc link current (I_{dc}).

Therefore, $I_L = \sqrt{(2/3)} I_{dc} = 0.81649 * 150 = 122.47 \text{ A.}$


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

$$I_{L1} = \{(\sqrt{6})/\pi\} I_{dc} = 0.779 * 150 = 116.95 \text{ A.}$$

An active power component of supply current is as,

$$I_{L1a} = I_{L1} \cos \theta_1 = I_{L1} \cos \alpha = 116.95 * \cos 60^\circ = 58.48 \text{ A}$$

The active power rating of load is estimated as,

$$P_L = 3 * V_{Lp} * I_{L1a} = 3 * 239.6 * 58.48 = 42035.42 \text{ W.}$$


(Refer Slide Time: 54:37)

The supply current under voltage sag is estimated as

$$I_s' = P_L / (3V_{sp}') = 42035.42 / 191.68 = 73.1 \text{ A.}$$


Total harmonics and reactive power component of load current is estimated as,

$$I_{Lr} = \sqrt{(I_L^2 - I_{L1a}^2)} = \sqrt{(122.47^2 - 58.48^2)} = 107.61 \text{ A.}$$

(a) The voltage rating of shunt element of UAPC is equal to ac load phase voltage of $V_{sh} = 239.6 \text{ V/phase}$, since it is connected across the load of 239.6 V sine waveform. The line voltage rating for UAPC is $\sqrt{3} * 239.6 = 415 \text{ V.}$

(b) The current rating of shunt element of UAPC is computed as,

The shunt element of UAPC is to provide load current harmonics and reactive power compensation, hence the required harmonics current and reactive power of the load it has to supply. Therefore, total harmonics and reactive power component of current through shunt active filter is estimated as,



(Refer Slide Time: 55:31)

$$I_{shr} = \sqrt{I_L^2 - I_{L1a}^2} = \sqrt{122.47^2 - 58.48^2} = 107.51 \text{ A.}$$


The supply fundamental voltage is lower as compared to the required load voltage. Hence, shunt APF absorbs active power and that active power is delivered back into the system via series APF. The active power component of shunt active filter is estimated as,

$$I_{sha} = I_s - I_{L1a} = (73.1 - 58.48) \text{ A} = 14.62 \text{ A.}$$

The overall current rating of shunt active filter is estimated as,

$$I_{sh} = \sqrt{I_{sha}^2 + I_{shr}^2} = \sqrt{14.62^2 + 107.51^2} = 108.49 \text{ A.}$$

The VA rating of VSC of shunt APF is as,

$$S_{sh} = 3 * V_{sh} * I_{sh} = 3 * 239.6 * 108.49 \text{ VA} = 77989.45 \text{ VA.}$$


(Refer Slide Time: 56:15)

(c) The voltage rating of series element of UAPC is computed as,

There is a voltage fluctuation of +10% and -20% in supply system with base value of 239.60V. Therefore, the series APF must inject the difference of these maximum of these two voltages to provide the required voltage at the load end.


The voltage rating of series APF,

$$V_{fse} = 239.6 * 0.20 = 47.92 \text{ V.}$$

(e) The current rating of series element of UAPC is same as supply current under sag compensation,


$$I_{se} = I_s' = 73.1 \text{ A.}$$

(f) The VA rating of series element of UAPC is as,

$$S_{se} = 3 * V_{fse} * I_{se} = 3 * 47.92 * 73.1 \text{ VA} = 10508.85 \text{ VA.}$$


(Refer Slide Time: 57:00)

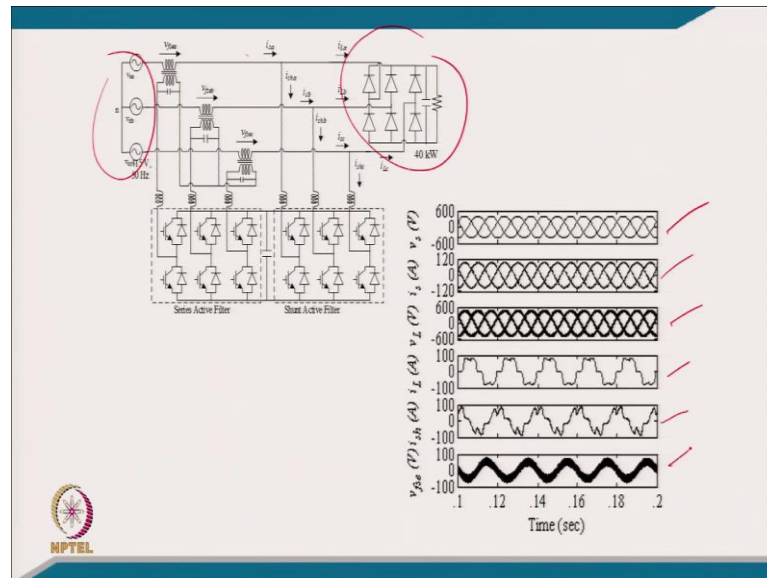
Q13. A three-phase universal active power conditioner (UAPC) is consisting of shunt and series APFs using two VSCs with a common bus capacitor as shown in Fig) is designed for feeding a critical load at 415 V, 50 Hz three-phase and consisting of a three-phase diode bridge rectifier is drawing ac current at 0.92 displacement factor and THD of its ac current is 65 percent. It is drawing 40 kW from ac source and crest factor is 2.5 of ac input current. If there is a voltage fluctuations of +10% and -20% in supply system with base value of 415 V. Calculate (a) the voltage rating of shunt element of UAPC, (b) the current rating of shunt elements of UAPC, (c) the VA rating of shunt element of UAPC, (d) the voltage rating of series element of UAPC, (e) the current rating of series element of UAPC, (f) the VA rating of series element of UAPC to provide harmonic and reactive power compensation for unity power factor at ac mains with constant regulated sine wave voltage of 415 V at 50 Hz across the load by series active filter.



Coming to 13th problem, a three phase universal active power conditioner consisting of shunt and series active filter using two voltage source converter, the common dc bus capacitor is design for feeding the critical load of 415 volt 50 hertz. Three phase and consisting of three phase diode rectifier is drawing ac current at 0.9 to displacement factor and THD of its current is 65 percent, it is drawing 40 kilowatt from the ac source and crest factor is 2.5 of ac mains current. If there is a voltage fluctuations of plus 10 percent and minus 20 percent in the supply system with base value of 415 volt.

Calculate a voltage rating of shunt element of universal active power filter b, current rating of the shunt element of universal active power filter c, the VA rating of shunt active filter and voltage rating of series active filter current rating of series active filter VA rating of series active filter to provide harmonics and reactive power compensation for unity power factor at ac main and constant regulated sine wave 415 voltage 50 hertz across the load by the series active filter.

(Refer Slide Time: 58:03)



The explanation of the numerical problem is described in the screenshots herein.


(Refer Slide Time: 58:42)

Solution: Given that, supply rms voltage, $V_{sp} = 415/\sqrt{3} = 239.6$ V, frequency of the supply $f = 50$ Hz feeding a critical load at 415 V, 50 Hz three-phase and consisting of a three-phase diode bridge rectifier is drawing ac current at 0.92 displacement factor and THD of its ac current is 65 percent. It is drawing 40 kW from ac source and crest factor is 2.5 of ac input current. There is a voltage fluctuation of +10% and -20% in supply system with base value of 415 V. The load phase voltage is to be regulated to nominal supply voltage hence,

$$V_{Lp} = V_{sp} = 239.6 \text{ V.}$$

Let X be the pu voltage variation and V_{sp}' be the PCC voltage under voltage variation.

In this system, load current harmonics and reactive power compensation are to be provided by the shunt active filter of UAPC. The voltage sag/swell compensation is provided by series filter of UAPC.



(Refer Slide Time: 59:38)

However, while compensating for sag/swell an active power is circulated between series and shunt active filters as explained in earlier chapter of UPQC. Under maximum voltage sag, the maximum rating for both the VSCs are realized. The various rating calculations are as follows,

The supply voltage under maximum voltage sag is as,

$$V_{sp}' = V_s * (1-X) = 239.6 * (1-0.2) = 191.68 \text{ V.}$$


The active power component of the load current is estimated as,

$$I_{L1a} = P_L / (3 * V_{Lp}) = 40000 / (3 * 239.6) = 55.648 \text{ A.}$$

The fundamental current of the load is as,

$$I_{L1} = I_{L1a} / \cos \theta_1 = 55.648 / 0.92 = 60.487 \text{ A.}$$

The load rms current is as,

$$I_L = I_{L1} \{ (1 + \text{THD}^2)^{1/2} \} = 60.487 * \sqrt{(1 + 0.65^2)} = 72.142 \text{ A.}$$


(Refer Slide Time: 60:25)

Total harmonics and reactive power component of current,

$$I_{Lr} = \sqrt{(I_L^2 - I_{L1a}^2)} = \sqrt{(72.142^2 - 55.648^2)} = 45.911 \text{ A.}$$


The supply current under voltage sag is estimated as

$$I_s' = P_L / (3 V_{sp}') = \{ 40000 / (3 * 191.68) \} = 69.56 \text{ A.}$$

(a) The voltage rating of shunt element of UAPC is equal to ac load phase voltage of $V_{sh} = 239.6 \text{ V}$, since it is connected across the load of 239.6 V sine waveform.

(b) The current rating of shunt element of UAPC is computed as,

The shunt element of UAPC is to provide load current harmonics and reactive power compensation, hence the required harmonics current and reactive power of the load it has to supply. Therefore, total harmonics and reactive power component of current through shunt active filter is estimated as,

$$I_{shr} = \sqrt{(I_{load}^2 - I_{L1a}^2)} = \sqrt{(72.142^2 - 55.648^2)} = 45.911 \text{ A.}$$


(Refer Slide Time: 61:14)

The supply fundamental voltage is lower as compared to the required load voltage. Hence, shunt APF absorbs active power and that active power is delivered back into the system via series APF. The active power component of shunt active filter is estimated as,

$$I_{sha} = I_s - I_{L1a} = (69.56 - 55.648) \text{ A} = 13.912 \text{ A}.$$


The overall current rating of shunt active filter is estimated as,

$$I_{sh} = \sqrt{I_{sha}^2 + I_{shr}^2} = \sqrt{13.912^2 + 45.911^2} = 47.973 \text{ A}.$$

(c) The VA rating of VSC of shunt APF is as,

$$S_{sh} = 3 * V_{sh} * I_{sh} = 3 * 239.6 * 47.973 = 34.483 \text{ kVA}.$$

(d) The voltage rating of series element of UAPC is computed as,



(Refer Slide Time: 61:53)

There is a voltage fluctuation of +10% and -20% in supply system with base value of 239.60 V. Therefore, the series APF must inject the difference of these maximum of these two voltages to provide the required voltage at the load end.


The voltage rating of series APF,

$$V_{fse} = 239.6 * 0.20 = 47.92 \text{ V}.$$

(e) The current rating of series element of UAPC is same as supply current under sag compensation,


$$I_{se} = I_s = 69.56 \text{ A}.$$

The VA rating of series element of UAPC is as,

$$S_{se} = 3 * V_{fse} * I_{se} = 3 * 47.92 * 69.56 = 10 \text{ kVA}.$$


(Refer Slide Time: 62:27)

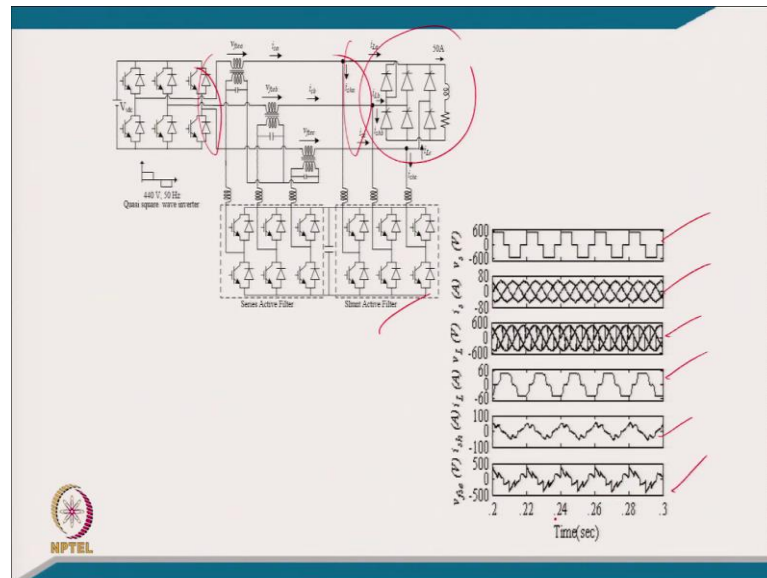
Q14. A three-phase VSI with quasi-square wave ac output line voltage of 440 V rms at 50 Hz is feeding a critical 415 V (line), 50 Hz three-phase thyristor bridge with constant dc current of 50 A at 30° firing angle of its thyristors. A three-phase universal active power conditioner (UAPC) is consisting of shunt and series APFs using two VSCs with a common bus capacitor as shown in Fig.) is designed for this critical nonlinear load. Calculate (a) the voltage rating of shunt element of UAPC, (b) the current rating of shunt elements of UAPC, (c) the VA rating of shunt element of UAPC, (d) the voltage rating of series element of UAPC, (e) the current rating of series element of UAPC, (f) the VA rating of series element of UAPC to provide harmonics and reactive power compensation for unity power factor at ac mains by shunt element of UAPC and constant regulated sine wave voltage of a 415 V rms at 50 Hz across the load by series element of UAPC.



Well coming to the 14th numerical problem a three phase VSI with quasi square ac line voltage of 440-volt rms and 50 hertz is feeding 415-volt line 50 hertz three phase thyristor bridge with the constant dc current of 50 ampere at 30 degree fire angle of its thyristor a three phase universal active power conditioner consisting of series and shunt active filter the 2 VSC with the common dc bus capacitor is design for this critical load.

Calculate the voltage rating of shunt active filter the current rating of shunt active filter VA rating of shunt active filter voltage rating of series active filter and current rating of series element and VA rating of series active filter to provide the harmonics and reactive power compensation for unity power factor ac mains by shunt element and constant regulated sine wave voltage of 415 volt 50 hertz across the load by series element of UA.

(Refer Slide Time: 63:16)



The explanation of the numerical problem is described in the screenshots herein.

(Refer Slide Time: 64:01)

Solution: Given that, a three-phase VSI with quasi-square wave ac output line voltage, $V_{sL} = 440$ V rms at 50 Hz is feeding a critical 415 V (line), 50 Hz three-phase thyristor bridge with constant dc current of 50 A at 30° firing angle of its thyristors.

In this system, load current harmonics and reactive power compensation is provided by shunt active filter of UAPC and voltage regulation and its harmonics compensation is to be provided by series conditioner of UAPC. However for voltage regulation an active power is circulated in between the series and shunt active filters of UAPC.

The supply is a quasi-square line voltage of 440 V rms, the amplitude of quasi-square waveform is estimated as,

$$V_{sdc} = V_{sL} \cdot \sqrt{3}/\sqrt{2} = 440 \cdot \sqrt{3}/\sqrt{2} = 538.89 \text{ V.}$$

Moreover, the rms of fundamental component of quasi-square supply voltage is,

$$V_{sL1} = \left\{ \frac{\sqrt{6}}{\pi} \right\} V_{sdc} = 420.17 \text{ V.}$$

(Refer Slide Time: 65:02)

The fundamental component of supply phase voltage is as,

$$V_{sp1} = V_{sL1}/\sqrt{3} = 242.58 \text{ V.}$$

However, the desired load phase voltage is, $V_{Lp} = 415/\sqrt{3} = 239.6 \text{ V}$ sine wave. This voltage is applied across a critical nonlinear load of 415 V (line), 50 Hz three-phase thyristor bridge with constant dc current of 50 A at 30° firing angle of its thyristors. In three-phase thyristor bridge converter, the waveform of the load current (I_L) is a quasi-square wave with the amplitude of dc link current (I_{dc}).

$$\text{Therefore, } I_L = \sqrt{(2/3)} I_{dc} = 0.81649 \cdot 50 = 40.82 \text{ A.}$$

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

$$I_{L1} = \{(\sqrt{6})/\pi\} I_{dc} = 0.779 \cdot 50 = 38.98 \text{ A.}$$

Active power component of supply current

$$I_{L1a} = I_{L1} \cos \theta_1 = I_{L1} \cos \alpha = 38.98 \cos 30^\circ = 33.76 \text{ A.}$$



(Refer Slide Time: 65:48)

Total harmonics and reactive power component of load current is estimated as,

$$I_{Lr} = \sqrt{(I_L^2 - I_{L1a}^2)} = \sqrt{(40.82^2 - 33.76^2)} = 22.95 \text{ A}$$

The active power consumed by the load is as,

$$P_L = 3 \cdot V_{Lp} \cdot I_{L1a} = 3 \cdot 239.6 \cdot 33.76 = 24266.69 \text{ W.}$$

The supply current is estimated as,

$$I_s = \{P_L / (3 \cdot V_{sp1})\} = \{24266.69 / (3 \cdot 242.58)\} = 33.34 \text{ A.}$$

(a) The voltage rating of shunt element of UAPC is equal to ac load voltage of $V_{sh} = 239.6 \text{ V}$, since it is connected across the load of 239.6 V sine waveform.

(b) The current rating of shunt element of UAPC is computed as,

The shunt active filter of UAPC facilitates harmonics and reactive power compensation. Therefore, total harmonics and reactive power component of current through shunt active filter is estimated as,



(Refer Slide Time: 66:40)

$$I_{shr} = \sqrt{(I_L^2 - I_{L1a}^2)} = \sqrt{(40.83^2 - 33.76^2)} = 22.94 \text{ A}$$

The supply fundamental voltage is higher as compared to the required load voltage. Hence, series APF absorbs active power and that active power is delivered back into the system via shunt APF. The active power component of shunt active filter is estimated as,

$$I_{sha} = I_s - I_{L1a} = (33.34 - 33.76) \text{ A} = -0.42 \text{ A}$$


The -ve sign for active power component denotes that the shunt active filter supplies active power (absorbed by series conditioner) into the system.

The overall current rating of shunt active filter is estimated as,

$$I_{sh} = \sqrt{(I_{sha}^2 + I_{shr}^2)} = \sqrt{(0.42^2 + 22.94^2)} = 22.94 \text{ A}$$

(c) The VA rating of VSC of shunt APF is as,

$$S_{sh} = 3 * V_{sh} * I_{sh} = 3 * 239.6 * 22.94 \text{ VA} = 16489.27 \text{ VA}$$




(Refer Slide Time: 67:36)

(c) The voltage rating of series APF, V_{fse} is computed as follows,

The supply of quasi-square line voltage results in stepped phase voltage. The series filter injects a voltage which is equal to difference between the supply voltage and voltage at load terminal.

The waveform of the phase voltage at the input of series active filter is a stepped waveforms as (i) first step of $\pi/3$ angle {from 0° to $(\pi/3)$ } and a magnitude of $(V_{sdc}/3)$, (ii) second step of $\pi/3$ angle {from $(\pi/3)$ to $(2\pi/3)$ } and a magnitude of $\{2V_{sdc}/3\}$, (iii) third step of $\pi/3$ angle {from $(2\pi/3)$ to (π) } and a magnitude of $\{V_{sdc}/3\}$ and it has both half cycles of symmetric segments of such steps.

The voltage rating of series APF, V_{fse} is computed by taking the difference of the supply phase voltage and required load sine phase voltage at the input of linear load as,




(Refer Slide Time: 68:20)

$$V_{fse} = \sqrt{\frac{(1/\pi) \int_0^{\pi/3} (179.63 - 239.6\sqrt{2}\sin\theta)^2 d\theta + \int_{\pi/3}^{2\pi/3} (359.26 - 239.6\sqrt{2}\sin\theta)^2 d\theta + \int_{2\pi/3}^{\pi} (179.63 - 239.6\sqrt{2}\sin\theta)^2 d\theta}}{3}} = 75.46 \text{ V}$$

(e) The current rating of series APF is as,


$$I_{se} = I_s = 33.34 \text{ A.}$$

(f) The VA rating of series connected APF is as,

$$S_{se} = 3 * V_{fse} * I_{se} = 3 * 75.46 * 33.34 \text{ VA} = 7549 \text{ VA.}$$


(Refer Slide Time: 68:53)

Q15 In a three-phase VSI with stepped wave ac line voltage output of 415 V rms at 50 Hz (quasi-square wave phase voltage), 4-wire distribution system, three single-phase loads (connected between phases and neutral) having a single-phase 230V, 50 Hz thyristor bridge converter drawing equal 20 A constant dc current at 45° firing angle of its thyristors. A three-phase universal active power conditioner (UAPC) is consisting of four leg VSC as shunt APF and three leg VSC as series APF using with common bus capacitor) is designed for this critical nonlinear load. Calculate (a) the voltage rating of shunt element of UAPC, (b) the current rating of shunt elements of UAPC, (c) the VA rating of shunt element of UAPC, (d) the voltage rating of series element of UAPC, (e) the current rating of series element of UAPC, (f) the VA rating of series element of UAPC to provide harmonics and reactive power compensation for unity power factor at ac mains and zero neutral current by shunt element of UAPC and constant regulated sine wave voltage of a 415 V (line) rms at 50 Hz across the load by series element of UAPC.



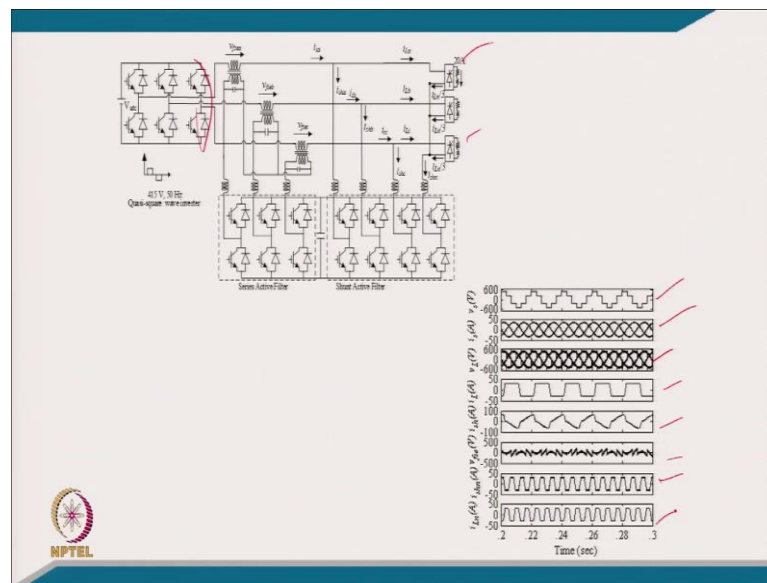
Coming to the 5th problem 15th problem in the three phase voltage source inverter with a stepped waveform of ac line voltage output of 415 volt 50 hertz quasi square wave. Four wire distribution system three single phase load connected between phase and neutral having a single phase 230 volt 50 hertz thyristor bridge converter drawing the 20 ampere, constant dc current at 45 degree fire angle of its thyristor.

A three phase universal active power conditioner consisting of 4 leg voltage source converter as a shunt active filter and 3 leg voltage source converter as series active filter

using common dc bus capacitor is design for this critical non-linear load. Calculate a voltage rating of shunt active element current rating of shunt active filter, VA rating of shunt active filter.

The voltage rating of series active filter current rating of series active filter VA rating of series active filter to provide harmonics and reactive power compensation for the unity power factor at ac mains and zero neutral current by shunt element and constant regulated sine wave voltage of the 415 volt at 50 hertz across the load by series element.

(Refer Slide Time: 69:53)



The explanation of the numerical problem is described in the screenshots herein.

(Refer Slide Time: 70:57)

Solution: Given that, a three-phase VSI with stepped wave ac line voltage output of 415 V rms at 50 Hz (quasi-square wave phase voltage) is feeding a single-phase 230V, 50 Hz thyristor bridge converter drawing equal 20 A constant dc current at 45° firing angle of its thyristors in each of three phases.

The supply is a stepped wave line voltage of 415 V rms, the amplitude of dc side voltage of supply side VSI is estimated as,

$$V_{sdc} = V_{sl} \cdot \sqrt{2} = 415 \cdot \sqrt{2} = 586.899 \text{ V.}$$


The fundamental component of supply side line voltage is,

$$V_{sl1} = (3 \cdot V_{sdc} / \sqrt{2\pi}) = 0.675 \cdot V_{sdc} = 396.296 \text{ V.}$$

The fundamental component of supply phase voltage is as,

$$V_{sp1} = V_{sl1} / \sqrt{3} = 228.801 \text{ V.}$$

In three-phase thyristor bridge converter,



(Refer Slide Time: 71:43)

The ac load line current is, $I_L = 20 \text{ A}$.

The fundamental active power component of load current is estimated as,

$$I_{L1a} = I_{L1} \cos \alpha = 0.9 I_{dc} \cos \alpha = 0.9 \cdot 20 \cdot \cos 45^\circ = 12.728 \text{ A.}$$

Total harmonics and reactive power component of load current is estimated as,

$$I_{Lr} = \sqrt{(I_L^2 - I_{L1a}^2)} = \sqrt{(20^2 - 12.728^2)} = 15.427 \text{ A.}$$


The active power consumed by the load is as,

$$P_L = 3 \cdot V_{lp} \cdot I_{L1a} = 3 \cdot 230 \cdot 12.728 = 8782.266 \text{ W.}$$

The supply current is estimated as,

$$I_s = \{P_L / (3 \cdot V_{sp1})\} = \{8782.266 / (3 \cdot 228.801)\} = 12.795 \text{ A.}$$

(a) The voltage rating of shunt element of UAPC is equal to ac load voltage of $V_{sh} = 230 \text{ V}$.



(Refer Slide Time: 72:31)

(b) The current rating of shunt element of UAPC is computed as,
The shunt active filter of UAPC facilitates harmonics and reactive power compensation. Therefore, total harmonics and reactive power component of current through shunt active filter is estimated as,

$$I_{shr} = \sqrt{I_L^2 - I_{L1a}^2} = \sqrt{20^2 - 12.728^2} = 15.427 \text{ A.}$$


The active power component of shunt active filter is estimated as,

$$I_{sha} = I_s - I_{L1a} = (12.795 - 12.728) \text{ A} = 0.067 \text{ A.}$$

The phase current rating of shunt active filter is estimated as,

$$I_{shp} = \sqrt{I_{sha}^2 + I_{shr}^2} = \sqrt{0.067^2 + 15.427^2} = 15.427 \text{ A.}$$


The rms current of fourth leg of shunt active filter is,

$$I_{shn} = I_{Ln} = 20 \text{ A.}$$


(Refer Slide Time: 73:10)

(c) The VA rating of VSC of shunt active filter is,
 $S_{sh} = 3 \cdot V_{sh} \cdot I_{shp} + V_{sh} \cdot I_{shn} = 3 \cdot 230 \cdot 15.427 + 230 \cdot 20 \text{ VA} = 15.245 \text{ kVA.}$

(d) The voltage rating of series APF, V_{ise} is computed as follows.
Three phase VSI will be operated in 120° conduction mode to get stepped wave ac line voltage. The supply stepped wave ac line voltage of $V_s = 415 \text{ V rms}$ (the stepped waveforms will be as (i) first step of $\pi/3$ angle {from 0° to $(\pi/3)$ } and a magnitude of (V_{sdc}) , (ii) second step of $\pi/3$ angle {from $(\pi/3)$ to $(2\pi/3)$ } and a magnitude of $(V_{sdc}/2)$, (iii) third step of $\pi/3$ angle {from $(2\pi/3)$ to (π) } and a magnitude of $(-V_{sdc}/2)$ and it has both half cycles of symmetric segments of such steps) will have an amplitude of $V_{sdc} = \sqrt{2} \cdot 415 = 586.89 \text{ V}$. Therefore, the supply stepped wave ac line voltage of amplitude $V_{sdc} = 586.89 \text{ V}$ results in quasi-square waveform of the phase voltage with the amplitude of

$$V_{sdc}/2 = 293.45 \text{ V.}$$


(Refer Slide Time: 74:02)


However, a phase shift may be considered for phase voltage to coincide with the sine waveform of the load phase voltage $V_L = 230 \text{ V}$.

The voltage rating of series conditioner is computed as,

$$V_{fse} = \sqrt{\left(\frac{1}{\pi}\right) \left[\int_0^{2\pi/3} (293.45 - 230\sqrt{2}\sin\theta)^2 d\theta + \int_{2\pi/3}^{\pi} (-230\sqrt{2}\sin\theta)^2 d\theta \right]} = 138.42 \text{ V}$$

(e) The current rating of series conditioner,
 $I_{se} = I_s = 12.795 \text{ A}$.


(f) The kVA rating of VSC of conditioner,
 $S = 3 * V_{fse} * I_{se} = 3 * 138.42 * 12.795 \text{ VA} = 5.313 \text{ kVA}$.



(Refer Slide Time: 74:42)

SUMMARY

- A comprehensive study of HFs is presented to provide a wide exposure on various issues of the HFs for power quality improvement.
- A classification of HFs into nine categories with many circuits in each category is expected to select an appropriate topology for a particular application.
- These hybrid filters are considered as a better alternative for power quality improvement due to reduced cost, simple design and control and high reliability compared to other options of power quality improvement.
- Some of the circuit configurations of HFs avoid the problems involved in passive and active filters, and therefore provide cost effective and better solution for harmonic elimination of nonlinear loads.



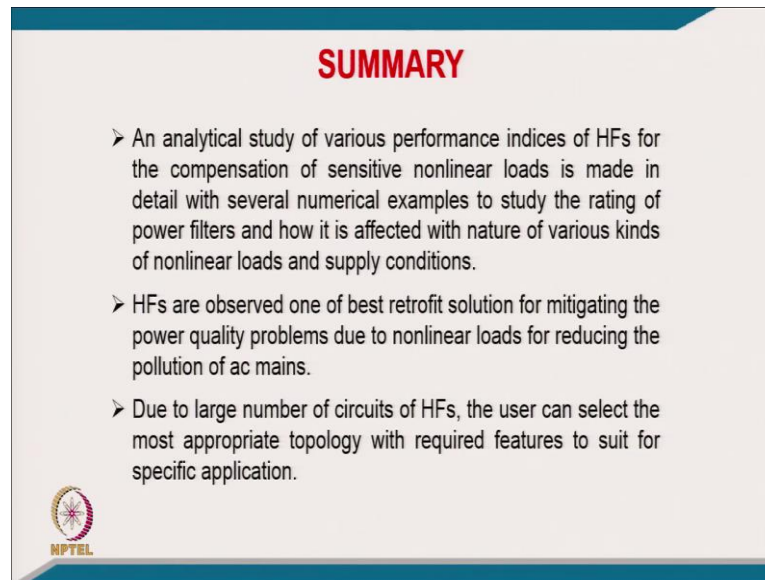
With this we conclude this hybrid filter, we will like to summarize here

A comprehensive study of hybrid filters is presented to provide the wide exposure on various issues of hybrid filter of for power quality improvement. A classification of hybrid filter into nine category with many circuits in each categories are expected to select an appropriate topology for the particular application.

These hybrid filter are considered as a better alternative for power quality improvement due to reduce cost simple design and control and high reliability compared to other


option of power quality improvement. Since the circuit configuration of hybrid filter avoid the problem of involved in passive and active filter and therefore, provide cost effective and better solution for harmonic elimination of the non-linear load.

(Refer Slide Time: 75:24)



SUMMARY

- An analytical study of various performance indices of HFs for the compensation of sensitive 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 and supply conditions.
- HFs are observed one of best retrofit solution for mitigating the power quality problems due to nonlinear loads for reducing the pollution of ac mains.
- Due to large number of circuits of HFs, the user can select the most appropriate topology with required features to suit for specific application.

 NPTEL

Any analytical study of various performance indices of hybrid filter for the compensation of sensitive non-linear load is made in the in detail with several numerical examples to study rating of power filters and how it is affected with the nature of various kind of non-linear load and supply condition.

Hybrid filter are observed one of the best retrofit solution for mitigating the power quality problem due to the non-linear load and for reducing the pollution in ac main. And due to large number of circuits of hybrid filter user can select most appropriate topology with required feature to suit specific application.

(Refer Slide Time: 75:56)




(Refer Slide Time: 75:58)



And of course, these are the references which we have referred.

(Refer Slide Time: 76:00)



[13] S. B. Mani, M. Hing, M. Aronov, D. Divan, S. Bhattacharya, and R. Lenz, "Design of an Active Series-Parallel Resonant Filter for ASD Loads at a Wastewater Treatment Plant," in *Proc. IEEE PQA Conference Record*, 1992, pp. 1-5.

[14] G. Boudart, M. Caprin, G. Giamani, and S. Tenconi, "Line Filter for high power inverter locomotive using active circuit for harmonic reduction," in *Proc. of 3rd IPEC'99*, pp. 267-271.

[15] Y. Mochizuki, Y. Hatanaka, M. Takada, T. Miyahata, and K. Hasekawa, "Static power conditioner using GTO converter for AC electric railway," in *Proc. IEEE Power Conversion Conference* 99, 1999, Yokohama, pp.611-616.

[16] F.Z. Peng, H. Akagi, and A. Nabae, "Compensation Characteristics of the Combined System of Shunt Passive, Series Active Filters," *IEEE Trans. on Industry Applications*, vol. 29, no. 1, pp.114-117, Jan. Feb. 1993.

[17] S. Bhattacharya, D.M. Divan, and B.B. Bassem, "Control, Reduction of Terminal Voltage Total Harmonic Distortion (THD) in a Hybrid Series Active, Parallel Passive Filter System," in *Proc. IEEE PESC'95*, 1995, pp. 779-786.

[18] N. Baldo, D. Saha, E. Perez, G. Stokich, D. Cappelloni, L. Maltoni, and A. Zaccari, "Hybrid Active Filter for Parallel Harmonic Compensation," in *Proc. EPF'93*, 1993, pp.113-118.

[19] J.N. Li, M. Pernet, K. Rens, and G. Vanopst, "Active Damping of Resonances in Power Systems," *IEEE Trans. on Power Delivery*, vol. 9, no.2, pp.1001-1008, Apr. 1994.

[20] L.S. Cramerici, "Combined Time-Domain, Frequency-Domain Approach to Hybrid Compensation in Unbalanced Nonlinear Systems," *European Trans. on Electrical Power Eng.*, vol. 4, no. 6, pp.477-484, Nov. Dec. 1994.

[21] K. Hasegawa, S. Saitoh and H. Ohtsu, "Statistical study on dynamical compensation of the static and dynamic performance of combined shunt passive and series active filters," in *Proc. Fifth International Conference on Power Electronics and Variable-Speed Drive* '94, 1994, pp. 147-151.

[22] M. A. Brannan and S. A. Mann, "Active power line conditioner with low cost surge protection and fast overload recovery," U. S. Patent 5,237,283, Feb. 15, 1994.

[23] C.D. Schaefer and S. A. Mann, "Multiple-reference frame controller for active filters and power line conditioners," U. S. Patent 5,338,553, May 3, 1994.

[24] M. A. Brannan, "Series-parallel active power line conditioner utilizing reduced state ratio transform for enhanced peak voltage regulation capability," United States Patent 5,319,534, June 7, 1994.

[25] M. A. Brannan, "Active power line conditioner having capability for rejection of common mode disturbances," U. S. Patent 5,319,535, June 7, 1994.

[26] M. A. Brannan, "Active power line conditioner utilizing harmonic frequency injection for improved peak voltage regulation," U. S. Patent 5,349,517, Sept. 20, 1994.

[27] M. A. Brannan and S. A. Mann, "Active power line conditioner with a derived load current fundamental signal for fast dynamic response," U. S. Patent 5,351,178, Sept. 27, 1994.

[28] M. A. Brannan and S. A. Mann, "Highly fault tolerant active power line conditioner," U. S. Patent 5,353,180, Sept. 27, 1994.

[29] M. A. Brannan, S. A. Mann, and G. Gyugyi, "Low cost active power line conditioner," U. S. Patent 5,331,181, Sept. 27, 1994.

[30] M. A. Brannan and S. A. Mann, "Multiple reference frame controller with synchronous transformation control," U. S. Patent 5,353,021, Oct. 11, 1994.

[31] M. Brannan, "Series-parallel active power line conditioner utilizing temporary link energy boosting for enhanced peak voltage regulation capability," U. S. Patent 5,350,290, Oct. 11, 1994.

[32] T.O. Itoh and T. Takai, "Total Compensation of Line Side Switching Harmonics in Converter Fed AC Locomotives," in *Proc. IEEE IAS Annual Meeting Record* '94, 1994, pp.813-820.

[33] M. Ranajng, N. Mohan, and A.A. Edris, "Hybrid-Active Filtering of Harmonic Currents in Power Systems," *IEEE Trans. on Power Delivery*, vol. 10, no. 4, pp.1994-2000, Oct. 1995.

[34] C.S. Chang, K.S. Lock, F. Wang and A.C. Liew, "Harmonic level control schemes and evaluation methods in power system," in *Proc. International Conference on Energy Management and Power Delivery, EMFPD'93*, 1993, vol.1, pp.140-143.

[35] G. Lohndorf and P. Dinkler, "Multiple Converter Performance, Active Filtering," *IEEE Trans. on Power Electronics*, vol. 10, no. 4, pp.272-278, May 1995.

[36] F. Kamran, and T.G. Habetler, "Combined Diode-Capacitor Control of a Series-Parallel Converter Combination Used as a Universal Power Filter," in *Proc. IEEE PESC'93*, 1993, pp.196-201.


[37] N.R. Raja, S.S. Venkatesh, R.A. Karghwaik, and V.V. Sastri, "An Active Power Quality Conditioner for Reactive Power, Harmonics Compensation," in *Proc. IEEE PESC'93*, 1993, pp.209-214.

[38] L. M. Moran, P. Wolkstein, J. Dixon, and R. Wallace, "A Series Active Power Filter Which Compensates Current Harmonics, Voltage Unbalance Simultaneously," in *Proc. IEEE PESC'90*, 1990, pp.20-23.

[39] F. Kamran, and T.G. Habetler, "A Novel On-Line UPS with Universal Filtering Capabilities," in *Proc. IEEE PESC'93*, 1993, pp.500-506.

[40] T. C. Lim, J.K. Park, T.G. Jang, S.H. Na, C.H. Cha and T.H. Chang, "Development of a simulator for comparative performance evaluation of hybrid active power filter using three-dimensional current control," in *Proc. IEEE International Conf on Power Electronics and Drive Systems*, 1991, pp. 427-432.

(Refer Slide Time: 76:01)



[1] S. A. Mann, and M.B. Brannan, "Active Power Line Conditioner with Fundamentally Negative Sequence Compensation," U. S. Patent 584,694, Jun. 1997.

[2] S. Bhattacharya, and D.M. Divan, "Hybrid Series Active-Parallel Passive Power Line Conditioner with Controlled Harmonic Injection," U. S. Patent 5,445,263, Nov. 1995.

[3] S. Bhattacharya, D.M. Divan and B. Banerjee, "Active filter solutions for utility interface," in *Proc. IEEE IAS'93*, 1993, pp. 53-63.

[4] S. Bhattacharya and D. Divan, "Design, Implementation of a Hybrid Series Active Filter System," in *Proc. IEEE PESC'93*, 1993, pp.189-193.

[5] M. Ranajng, N. Mohan and A.A. Edris, "Filtering of Harmonic Currents, Damping of Resonances in Power Systems With a Hybrid-Active Filter," in *Proc. IEEE APSC'93*, 1993, pp.807-812.

[6] H. Akagi, and H. Fajna, "A New Power Line Conditioner for Harmonic Compensation in Power Systems," *IEEE Trans. on Power Delivery*, vol. 10, no. 3, pp.1578-1579, July 1995.

[7] C.E. Lim, W.F. Su, S.L. Lu, C.L. Chen, and C.L. Huang, "Open-loop Strategy of Hybrid Harmonic Filter in Demand Side System," in *Proc. IEEE IAS Annual Meeting* '95, 1995, pp.1862-1866.

[8] S. Bhattacharya, and D. Divan, "Synchronous Frame Based Controller Implementation for a Hybrid Series Active Filter System," in *Proc. IEEE IAS Annual Meeting* '95, 1995, pp.2331-2340.

[9] J. Dixon, G. Venegas and L. Moran, "A Series Active Power Filter Based on a Sinusoidal Current Controlled Voltage Source Inverter," in *Proc. IEEE IECON'95*, 1995, pp.639-644.

[10] G. Kamath, N. Mohan, and D. Albertson, "Hardware Implementation of a Novel Reduced Rating Active Filter for 3-Phase, 4-Wire Loads," in *Proc. IEEE APSC'95*, 1995, pp.941-949.

[11] L.M. Tolbert, H.D. Holtz and P.S. Hsieh, "Evaluation of harmonic suppression devices," in *Proc. IEEE IAS Annual Meeting* '94, 1994, pp.2340-2347.

[12] G.H. Ross, I. Kang, W.G. Kim and J.S. Kim, "A Shunt Hybrid Active Filter with Two Passive Filters in Parallel," in *Proc. IEEE APSC'96*, 1996, pp.361-366.

[13] S. Bhattacharya and D. M. Divan, "Hybrid series active, Parallel Passive, Power line conditioner for Harmonic Injection between a supply and load," U. S. Patent 5,513,090, Apr. 30, 1996.

[14] N. Mohan and M. Ranajng, "Hybrid Filter for reducing distortion in power system," U. S. Patent 5,748,165, Aug. 28, 1996.

[15] A.V. Padi, J.E.R. Easden, W.H. Steyn, R. Speck, "A New Unified Approach to Power Quality Management," *IEEE Trans. on Power Electronics*, vol. 11, no. 5, pp. 691-697, Sept. 1996.

[16] F.B. Libano, D.S.L. Simoes and J. Uceda, "Frequency characteristics of hybrid filter systems," in *Proc. IEEE PESC'96*, 1996, pp.1142-1148.

[17] T. Kuroyaka, E. Satozaki and H. Satozaki, "A new method of alternating current harmonic compensation in parallel systems of hybrid filters," in *Proc. IEEE IAS'96*, vol. 2, 1996, pp. 196-201.

[18] R. Stencloek, G. Benjak and L. Franckovic, "Dynamic properties of hybrid filters in regenerative braking hybrid systems," in *Proc. IEEE IAS'96*, 1996, vol. 2, 1996, pp. 612-617.

[19] Y. Tashiki, S. Kawahito, N. Eguchi, and K. Hino, "Self-Compensated Static Diode Compensator for AC Furnaces," in *Proc. IEEE APSC'94*, 1994, pp. 891-897.

[20] N.R. Raja, S.S. Venkatesh and V.V. Sastri, "A decoupled series compensator for voltage regulation and harmonic compensation," in *Proc. IEEE PESC'96*, 1996, pp. 527-531.

[21] H. Akagi, "New Trends in Active Filters for Power Conditioning," *IEEE Transactions on Industry Applications*, vol. 32, no. 6, pp. 1312-1322, 1996.

[22] S. Muljadi and J. M. S. Kim, "Steady state Operating Characteristics of Unified Active Power Filters," in *Proc. IEEE APSC'97*, 1997, pp.199-206.

[23] J. Habetler, M. Anderson, and K. Hirasawa, "A shunt active power filter applied to high-voltage distribution lines," *IEEE Trans. on Power Delivery*, vol. 13, no. 1, pp. 266-272, Jan. 1997.

[24] A. Mantecon, "Low Frequency conducted disturbances compensation using a Hybrid Filter System," in *Proc. IEEE IAS'97*, vol. 2, 1997, pp. 403-410.

[25] N. Seguen, E.B. T. Elgizani, P. B. Sanchez and J.N. Perez, "Experimental Performance of Passive and Hybrid Filters Applied to AC/DC Converters Fed by a Weak AC System," in *Proc. IEEE IAS'97*, vol. 2, 1997, pp. 668-675.

[26] S. Bhattacharya, P. T. Cheng and D. M. Divan, "Hybrid Solutions for Improving Passive Filter Performance in High-Power Applications," *IEEE Trans. on Industry Applications*, vol. 33, no. 3, pp. 112-121, May/June 1997.


[27] A. A. B. Rashed, J. S. Anwar, M. S. Badi, and A. I. Elmaghrabi, "Searching for the better topology and control strategy in Hybrid Power Filters," in *Proc. EPF'97*, 1997, pp. 432-439.

[28] F. Libano, J. Coban and J. Uceda, "Simplified Control Strategy for Hybrid Active Filters," in *Proc. IEEE PESC'97*, vol. 2, 1997, pp. 1102-1108.

[29] S. Dikovskian and S. Stangorovitch, "Design of harmonic current detector and stability analysis of a hybrid parallel active filter," in *Proc. IEEE Power Conversion Conference - Singapore*, 1997, pp. 181-186.


[30] L. A. Pittino, J. A. Du Toit and J. H. R. Easden, "Evaluation of converter topologies and controllers for Power Quality Compensation under Unbalanced Conditions," in *Proc. IEEE PESC'99*, 1999, pp. 1121-1123.

(Refer Slide Time: 76:01)




- [1] Seung-Jooh Son, and Gyu-Hyung Cho, "A series-parallel compensated unintermittible power supply with imposed input current and uncontrolled output voltage," in *Proc. IEEE PESC '99*, 1999, pp. 297-303.
- [2] T. Maeha, T. Watanabe, A. Mechi, T. Shinto and K. Iida, "A hybrid single phase power active filter for high order harmonic compensation in converter fed high speed train," in *Proc. Power Conversion Conference - Nagasaki '97*, 1997, pp. 711-717.
- [3] H. Fujita and H. Akagi, "An Approach to Harmonic Current Free ac-dc Power Conversion for Large Industrial Loads: The Integration of a series active filter with a double series diode rectifier," *IEEE Transactions on Industry Applications*, vol. 33, no. 3, pp. 1233-1248, 1997.
- [4] W.F. Su, C. E. Lin and C. L. Huang, "Hybrid Filter application for Power Quality Improvement," *Electric Power Systems Research*, vol. 47, pp.165-171, Feb. 1998.
- [5] P.T. Cheng, S. Bhattacharya, D.M. Divan, "Power Line Harmonic Reduction by Hybrid Parallel Active Power Filter System with Square Wave Inverter and DC Bus Control," *U.S. Patent 5719390*, March 24, 1998.
- [6] M. Arredas, K. Hasmann and E.H. Watanabe, "An Universal Active Power Line Conditioner," *IEEE Transactions on Power Delivery*, vol. 13, no. 2, pp. 545-551, April 1998.
- [7] P.T. Cheng, S. Bhattacharya, D.M. Divan, "Hybrid Parallel Active Power Filter System with Dynamically Variable Inductance," *U.S. Patent 5737099*, May 26, 1998.
- [8] P.T. Cheng, S. Bhattacharya and D. M. Divan, "Control of Square Wave Inverter in High-Power Hybrid Active Filter Systems," *IEEE Trans. on Industry Applications*, vol. 34, no. 3, pp. 435-472, May/June 1998.
- [9] I. M. Stepan, K. R. Padaveera and V. Ramanamayanan, "Digital Simulation of a Hybrid Active Filter - An Active Filter in Series with Shunt Passive Filter," in *Proc. IEEE PES Meeting on Power Quality '98*, 1998, pp. 65-71.
- [10] G.H. Song and H. Cho, "New power active filter with simple low cost structure without used filter," in *Proc. IEEE PESC '98*, 1998, pp. 317-322.
- [11] D. Bauc, V. S. Rameshan and P. K.Martick, "Performance of Combined Power Filters in Harmonic Compensation of High-Power Cyclo-converter Drives," in *Proc. IEEE Power Electronics and Variable Speed Drive '90*, Conf. Publication no. 458, Sept 1990, pp. 674-679.
- [12] S.S. Venkata, N.R. Raju, R.A. Karghavaiah and V.V. Jayan, "Active Power Conditioner for Reactive and Harmonic Compensation having PWM and Stepped Wave Inverters," *U.S. Patent 5,791,138*, May 1998.
- [13] B.N. Singh, A. Chandra, K. Al-Haddad, and B. Singh, "Fuzzy control algorithm for universal active filter," in *Proc. IEEE Power Quality '98*, 1998, pp. 73-80.
- [14] S.J. Huang, J.C. Wu, and H.L. Jou, "Electric power-quality improvement using parallel active power conditioners," *IEE Proc. Generation, Transmission and Distribution*, vol. 145, no. 4, pp. 397-405, Sept 1998.
- [15] P.G. Barbosa, J.A. Santambrogio, and E.H. Watanabe, "Shunt-series active power filter for rectifiers AC and DC sides," *IEE Proceedings-Electric Power Applications*, vol. 145, no. 6, pp. 577-584, Nov 1998.
- [16] W.F. Su, C. E. Lin and C.L. Huang, "Hybrid filter application for power quality improvement," *Journal of Electric Power Systems Research*, vol. 47, pp. 165-171, Nov 1998.
- [17] Feng Zhang Peng, J.W. McKeever, and D.J. Adams, "A power line conditioner using cascade multilevel inverters for distribution systems," *IEEE Transactions on Industry Applications*, vol. 34, no. 6, pp.1293-1294, Nov Dec 1998.
- [18] G. Chen, M. H. T. Zhang and Q. Chuaning, "A hybrid solution to active power filter for the purpose of harmonic suppression and resonance damping," in *Proc. IEEE POWERTECH'98*, 1998, pp. 1542-1546.
- [19] Feng Zhang Peng, "Application issues of active power filters," *IEEE Industry Applications Magazine*, vol. 4, no. 5, pp.21-30, Sept Oct 1998.
- [20] F.Z. Peng and D.J. Adams, "Resonance sources and filtering approaches-series parallel, active-passive, and their combined power filters," in *Proc. IEEE IAS Annual Meeting '99*, 1999, pp. 448-452.
- [21] W. Korczak and B. Dolyn, "AC voltage hybrid filter," in *Proc. IEEE INTELEC '99*, 1999, p. 3-7.
- [22] J. Liu, J. Yang and Z. Wang, "A new approach for single-phase harmonic current detecting and its application in a hybrid active power filter," in *Proc. IEEE IECOV'99*, 1999, pp. 849-854.
- [23] S. J. Huang, J. C. Wu, "Design and Operation of Cascaded Active Power Filters for the reduction of harmonic distortions in power systems," *IEEE Proc. Gener. Transm. Distrib.*, vol. 146, no. 2, pp. 193-199, March 1999.
- [24] L.M. Tolbert, F.Z. Peng and G. Habetler, "An island of converter based universal power conditioner," in *Proc. IEEE PESC '99*, 1999, pp. 393-398.
- [25] V. Valouch, S. Dolezalova, "Evaluation of Performance Criteria of Hybrid Power Filters," in *Proc. IEEE PESC '99*, 1999, pp. 9.
- [26] D. D. Beater, A. D. Le Roux, T. H. du Toit, J. H. R. Emslin, "Evaluation of Power Ratings for Active Power Quality Compensators," in *Proc. IEEE PESC '99*, 1999.
- [27] D. Hanz, "Combined filtering system consisting of passive filter with capacitors in parallel with diodes and low-power active," *IEEE Proc. on Electric Power Applications*, vol. 146, no. 2, pp. 88-94, Apr 1999.
- [28] R. Li, A. B. Jahan, M. M. El-Khatib and F. V. P. Robinson, "Comparative study of parallel hybrid filters in resonance damping," in *Proc. IEEE International Conf on Electrical Power Engineering, Power Tech Budapest '99*, 1999, pp. 220.

(Refer Slide Time: 76:01)



- [109] X. Y. Tang, X. Xiangping and L. Lianping, "New approaches of low cost hybrid active filter," in *Proc. IEEE International Conference on Electric Power Engineering, Power Tech Budapest '99*, 1999, pp. 291-295.
- [110] B. N. Singh, S. Singh, A. Chandra and K. A. Haddad, "Digital implementation of a New type of Hybrid Filter With Simplified Control Strategy," in *Proc. IEEE APSC '99*, vol. 1, 1999, pp. 462-464.
- [111] A.M. Al-Zamel and D.A. Tawry, "A three-phase hybrid series-passive shunt active filter system," in *Proc. IEEE APSC '99*, 1999, pp. 873-881.
- [112] B. Dana, V. S. Rameshan and P. Maeha, "Minimization of Active Filter Rating in High Power Hybrid Filter Systems," in *Proc. IEEE Conf PESC'99*, vol. 2, July 1999, pp. 1043-1048.
- [113] B. N. Singh, S. Singh, A. Chandra and K. A. Haddad, "A New Control scheme of Series Hybrid Active Filter," in *Proc. IEEE PESC'99*, 1999, vol. 1, pp. 249-254.
- [114] S. Pak, J. H. Sung and K. Nam, "A New Parallel Hybrid Filter Configuration Minimizing Active Filter Size," in *Proc. IEEE PESC '99*, vol. 1, 1999, pp. 400-405.
- [115] E. Lavez and R. D'Amico, "Hybrid Active power filter with programmed impedance characteristics," *U.S. Patent 5,910,889*, June 8, 1999.
- [116] S.S. Shalabadi, I. Greshbach, and S. Stankovic, "A comparative study between two structures of hybrid active filter for harmonic compensation of a 18 thyristor cycloconverter fed induction motor drive," in *Proc. IEEE '99*, 1999.
- [117] R. Li, M.M. El-Khatib, A.T. Jones and F.V. Robinson, "Performance of Parallel Hybrid Filters in Damping Harmonic Resonance," in *Proc. IEEE '99*, 1999, pp. 10.
- [118] S. Hasmann, N. Vranas, M. Oliver, C. Hanz and T. Carabona, R., "Harmonic compensation in the AC mains by the use of current and voltage active filters controlled by a genetic algorithm," in *Proc. IEEE International Power Electronics Congress (IEPEC'00)*, 2000, pp. 47-50.
- [119] V. Valouch, "Compensation of Harmonic Voltage Source by Using Parallel and Series Active Filters," *Proc. IEEE PESC '00, Indira*, 2000, pp. 420-423.
- [120] H. Fujita, T. Yamazaki and H. Akagi, "A hybrid active filter for damping of harmonic resonance in industrial power systems," *IEEE Trans. on Power Electronics*, vol. 15, no. 2, pp. 212-222, March 2000.
- [121] J.H. Sung, S. Pak and K. Nam, "New hybrid parallel active filter configuration minimizing active filter size," *IEE Proc. on Electric Power Applications*, vol. 147, pp. 93-98, March 2000.
- [122] D. Bauc, V. S. Rameshan and P. K. Martick, "Hybrid filter control system with adaptive filters for selective elimination of harmonics and interharmonics," *IEE Electric Power Applications*, vol. 147, no. 3, pp. 293-300, May 2000.
- [123] S. Pak, S.B. Han, B.M. Jung, S.H. Cha and H.G. Jeong, "A current control scheme based on multiple synchronous reference frames for parallel hybrid active filter," in *Proc. Third International Conference on Power Electronics and Motion Control, PLEMC '00*, 2000, pp. 218-223.
- [124] B. Vranas, N. Sung and D. Zhu, "Study on the performance of the combined power filter with nonperiodical condition," in *Proc. Third International Conference Power Electronics and Motion Control PLEMC'00*, 2000, pp. 345-370.
- [125] C. Guozhu, Z. Lu and Q. Zhiming, "The design and implement of series hybrid active power filter for variable nonlinear loads," in *Proc. Third International Conference on Power Electronics and Motion Control, PLEMC'00*, 2000, pp. 1041-1044.
- [126] K. Karthik and J.E. Quincey, "Voltage compensation and harmonic suppression using series active and shunt passive filters," in *Proc. IEEE Canadian Conference on Electrical and Computer Engineering '00*, 2000, pp. 382-386.
- [127] D. Hanz, L. Miran, J. Dixon and J. Egusquiza, "A simple control scheme for hybrid active power filter," in *Proc. IEEE PESC'00*, 2000, pp. 991-996.
- [128] D. Bauc, V. S. Rameshan and P. K. Martick, "Selective compensation of cycloconverter harmonic and interharmonics by using a hybrid power filter system," in *Proc. IEEE PESC'00*, vol. 3, 2000, pp. 1137-1142.
- [129] H. Akagi, "Active and hybrid filters for power conditioning," in *Proc. IEEE AIEE '00*, vol. 1, 2000, pp. TU 26-TU 36.
- [130] M. Feng, P. Feng and J. Jiao, "The design of a hybrid power filter based on variable structure control," in *Proc. of the 3rd World Congress on Intelligent Control and Automation '00*, 2000, pp. 2982-2986.
- [131] S. Senita and P.J. Wafar, "Hybrid active filter for harmonically unbalanced three phase three wire railway traction loads," *IEEE Trans. on Power Electronics*, pp. 702-710, July 2000.
- [132] P.T. Cheng, S. Bhattacharya, and D.M. Divan, "Operation of the dominant harmonic active filter (DHAF) under realistic utility conditions," in *Proc. IEEE IAS'00*, 2000, pp. 2153-2162.
- [133] G. van Schoor, J.D. van Wyk, and I.S. Shaw, "Modelling of a power network compensated by hybrid power filters with different detuned loads," in *Proc. of IEEE SPC'00*, Oct 2000, pp. 301-306.
- [134] D. Alotaibi, E. Jass, A. Laxar, J. P. Su, S. Gradman, and S. Gradman, "Analysis of Operation for the Combined Filtering System consisting of Passive Filter with Capacitors in Parallel with Diode," in *Proc. PCDM'00*, 2000.
- [135] C. Zhan, M. Wang, Z. Wang and T. Han, "DSP control of power conditioner for improving power quality," in *Proc. IEEE PES Meeting '00*, 2000, pp. 2316-2361.

(Refer Slide Time: 76:01)



[136] L.M. Tolbert, F.Z. Peng and T.G. Habetler, "A multilevel converter-based universal power conditioner," *IEEE Transactions on Industry Applications*, pp. 394-403, March/April 2000.

[137] P. Singh, J.M. Pena, and C.M. Bhatta, "A Novel 3-Phase Hybrid Harmonic and Reactive Power Compensator," in *Proc. IEEE PESC'00, Indio, 2000*, pp.4-26-4-31.

[138] Bhan Singh and Vaidh Vyas, "Modeling and Control of Series Hybrid Power Filter with Self Supporting DC Bus," *Eleventh National Power System Conference*, ISC, Bangalore, Vol.1, Dec. 20-22, 2000, pp.400-404.

[139] D. Grewer, V. Katic, and A. Radic, "Universal Power Quality System- An Extension to Universal Power Quality Conditioner," in *Proc. IEEE PESC'00, Indio, 2000*, pp.4-32-4-38.

[140] D. Grewer, V. Katic, and A. Radic, "Power quality compensation using universal power quality conditioning system," *IEEE Power Engineering Review*, vol. 20, no.12, pp. 38-40, Dec. 2000.

[141] D. Grewer, V. Katic, and A. Radic, "Tackling Supply and Load Imperfections using Universal Power Quality Conditioning System," in *Proc. PCIM'00, 2000*.

[142] L. Alonso, J. Ramirez, J. Dixon and B. Wu, "Series active power filter compensates current harmonics and voltage sags/undershoots/overshoots," *IEEE Proc. on Generation, Transmission and Distribution*, vol. 147, no. 1, pp. 33-38, January 2000.

[143] S.A.O. de Silva, P.F. Dantas-Garcia, P.C. Cortin, and P.F. Seixas, "A comparative analysis of control algorithms for three-phase line-interactive UPS systems with series-parallel active power-line conditioner using IIR method," in *Proc. IEEE PESC'00, 2000*, pp. 1023-1028.

[144] F.Z. Peng, "Power line conditioner using cascade multilevel inverters for voltage regulation, reactive power correction, and harmonic filtering," U. S. Patent 6,073,330, June 13, 2000.

[145] A. Sampa, O. de Silva, P. Dantas-Garcia, P.C. Cortin, and P.F. Seixas, "Three-Phase Line-Interactive UPS Systems with Series-Parallel Active Power Line Conditioning for High Power Quality," in *Proc. IEEE PESC'00, Indio, 2000*, pp.3-120-3-125.

[146] S. Srinivas, I. Bala, K. Shankar and E. Srinivas, "Application of Unified Power Flow Controller for Power Quality Control," in *Proc. IEEE PESC'00, Indio, 2000*, pp.4-165-4-170.

[147] J. Pross and P. H. Sabinovic, "Control Design of an Active Conditioner for Three-Phase Load Compensation," in *Proc. PCIM'00, 2000*.

[148] M. Hays, N. Marnas and I. Orlowski, "Instantaneous-line voltage controlled harmonic compensator," *IEEE IEEECON'00, 2000*, pp. 154-158.

[149] R. El-Hachimi, M. Kazian, and M.M.A. Salama, "Multi-converter approach to active power filtering using current source converters," *IEEE Transactions on Power Delivery*, vol.16, no. 1, pp.18-45, Jan. 2001.

[150] A.D. de Roon and H.D.T. Meulen, "A series-ohmic compensator with combined UPS operation," in *Proc. IEEE International Symposium on Industrial Electronics, ISE'01, 2001*, pp. 2058-2061.

[151] M. Ben, S. P. Das and G. K. Dubey, "Experimental investigation of performance of a single phase UPQC for voltage sensitive and non-linear loads," in *Proc. IEEE PESC'01, 2001*, pp. 218-222.

[152] B.R. Lin and B.R. Yang, "Current/harmonic elimination with a series hybrid active filter," in *Proc. IEEE International Symposium ISE'01, 2001*, pp. 568-570.

[153] C. Zhou, G. Li, Z. Chen and G. Li, "Design and realization of a new hybrid power filter system used in single-phase circuit," in *Proc. IEEE IECON'01, 2001*, pp. 1067-1071.

[154] Beom-Seok Cha, Woo-Chul Lee, Taek-Kuk Lee, and Dong-Seok Hyun, "A fault protection scheme for unified power quality conditioner," in *Proc. IEEE PESC'01, 2001*, pp. 66-71.

[155] T.A. Kandil and J.E. Quincey, "A new approach to voltage and harmonic compensation," in *Proc. IEEE-Canadian Conference on Electrical and Computer Engineering'01, 2001*, pp. 147-152.

[156] R. Cao, L. Zhu, W. Shi, P. Fang and G. Tang, "Series power quality compensator for voltage sags, swell, harmonics and imbalance," in *Proc. IEEE PES Conference and Exposition on Transmission and Distribution'01, 2001*, pp. 543-547.

[157] S. Chen and G. Joo, "A unified series-parallel feed-back control technique for an active power quality conditioner with full digital implementation," in *Proc. IEEE IAS Annual Meeting'01, 2001*, pp. 177-178.

[158] D. Grewer, A. Radic, V. Katic, and J. Kazianic, "Unified power quality conditioner based on current source converter topology," in *Proc. IEEE'01, 2001*.

[159] P. Singh, J.M. Pasa and C.M. Bhatta, "A Novel 3-phase Hybrid Harmonic and Reactive Power Compensator," *IPE Journal*, vol. 11, no. 4, pp. 14-19, Nov-2001.

[160] H. S. Joo, J.C. Yu, and G.D. Wu, "Parallel operation of passive power filter and hybrid power filter for harmonic suppression," *IEEE Proc. on Generation, Transmission and Distribution, Int. 2001*, pp. 8-14.

[161] A.A. El-Damak and M.A. Elmaghrabi, "A passive series active shunt filter for high power applications," *IEEE Trans. on Power Electronics*, vol. 16, no.1, pp. 101-109, 2001.


[162] C. Guohua, L. Dongyao and Q. Zhongqiang, "The special design considerations for series hybrid active power filter," in *Proc. IEEE PESC'01, 2001*, pp. 560-564.

[163] L. Chen and A. von Jouanne, "A comparison and assessment of hybrid filter topologies and control algorithms," in *Proc. IEEE PESC'01, vol.2, 2001*, pp. 565-570.

[164] C. Guohua, L. Dongyao and Q. Zhongqiang, "A novel hybrid active power filter with two passive channels for high power application," in *Proc. IEEE PESC'01, 2001*, pp. 1889-1892.

In this and.

(Refer Slide Time: 76:02)



[165] S. Thang, J. Beecher, J.P. Gaubert, G. Champagnon, "Sliding Mode Control of Parallel Hybrid Filters," in *Proc. IPE'01*, pp. 9.

[166] Zhou-Feng Li, Guangyuan Li, Han and Wang-Daohui, "Multi-control control of multiple non-linear active power filter," in *Proc. International Conference on Electrical Machines and Systems ICEMS'01, 2001*, pp. 534-537.

[167] J. Jacobs, A. Fischer, D. Dreyer and H. G. Vahl, "An optimized hybrid power filter and VAR compensator," in *Proc. IEEE IAS Meeting'01, vol. 4, 2001*, pp. 2412-2418.

[168] R.A.M. Elmaghrabi, F.B. Libera and A.S. Lee, "Development environment for control strategies of hybrid active power filter using Matlab/Simulink and dSPACE/DSP," in *Proc. IEEE Conf. Power Tech'01, 2001*, pp.6-12.

[169] D. Dreyer, J. Jacobs, R. W. De Doncker and H. G. Vahl, "A new hybrid filter to dampen resonances and compensate harmonic currents in industrial power systems with passive filter compensation equipment," *IEEE Proc. on Power Electronics*, vol. 48, no. 4, pp. 431-437, Nov-2001.

[170] Beom-Seok Cha, Woo-Chul Lee, Dong-Seok Hyun, and Taek-Kuk Lee, "An overcurrent protection scheme for series active compensation," in *Proc. IEEE-IECON'01, 2001*, pp. 1589-1594.

[171] D. Bae, V. S. Ramesh and P. K. Marik, "Harmonic filtering of high-power 17-pulse rectifier loads with a selective hybrid filter system," *IEEE Trans. on Industrial Electronics*, vol. 48, no. 6, pp. 1118-1127, Dec. 2001.

[172] J. Jeon, D. Dik, and D. Di Rak, "A New Hybrid Filter versus a Shunt Active Power Filter," in *Proc. IPE'01, 2001*, pp. 11.

[173] J. Pross, V. Adamovic, and J. B. Vagner, "Control Implementation of a Three-Phase Load Compensation Active Conditioner," in *Proc. IPE'01, 2001*, pp.10.

[174] D. Alonso, A. Laine, E. Ruan, S. Admasa, G. Tielke, and I. Piaton, "A New Efficient Filtering System Having Passive Filters with Capacitors in Parallel with Diodes for Large-Rated Harmonic Currents," in *Proc. PCIM'01, 2001*.

[175] F.Z. Peng, "Harmonic sources and filtering approaches," *IEEE Industry Applications Magazine*, vol. 7, no. 4, pp. 18-21, July/Aug 2001.

[176] Y. Wang, J. Yang, Z. Wang, X. Gu, Z. Zeng, W. Wang, Z. Guo and X. Wang, "Rating analysis and design of coupling transformer for single-phase parallel hybrid active filter," in *Proc. IEEE PESC'02, 2002*, pp. 602-606.

[177] B.R. Lin, C.H. Hsu and B.R. Yang, "Control scheme of hybrid active filter for power quality improvement," in *Proc. IEEE International Conf on Industrial Technology, ICIT'02, 2002*, pp. 317-322.

[178] Bo-Ran Lin, Bo-Ran Yang and Hsin-Ru Tai, "Analysis and operation of hybrid active filter for harmonic elimination," *Journal of Electric Power Systems Research*, vol.61, no. 3, pp. 287-290, July 2002.

[179] S. T. Iqbal and P.J. Walsh, "Systematic identification and review of hybrid active filter topologies," in *Proc. IEEE PESC'02, 2002*, pp. 394-399.

[180] S. Kim and P. Epton, "A new hybrid active power filter (APF) topology," *IEEE Trans. Power Electronics*, vol. 17, no. 1, pp. 48-54, Jan. 2002.

[181] H. Akhavan, M. Audo, V. Makhadmeh, V. Kato, J. Yoshizawa, Y. Oishi, T. Mochizuki, S. Fushibuchi, M. Nishikubo and S. Ouchi, "Development of railway static power conditioner used at suburban for Shinkansen," in *Proc. IEEE Power Conversion Conference, Confex'02, 2002*, pp. 1108-1111.

[182] P. Rodriguez, R. Pindado, and J. Bieganski, "Alternative topology for three-phase four-wire power converters applied to a shunt active power filter," in *Proc. IEEE IECON'02, 2002*, pp. 3909-3914.

[183] Z.F. Deng, X. Jiang and D.Q. Zhu, "A novel hybrid filter to cancel the neutral harmonic current," in *Proc. IEEE IAS Meeting'02, vol. 1, 2002*, pp. 59-63.

[184] J. Pross, P. Hammer, J.R. Vazquez and J. Akcasan, "A series-parallel configuration of active power filters for var and harmonic compensation," in *Proc. IEEE IECON'02, 2002*, pp. 2890-2893.

[185] S.A.O. de Silva, P.F. Dantas-Garcia, P.C. Cortin, and P.F. Seixas, "A three-phase line-interactive UPS system implementation with series-parallel active power-line conditioning capabilities," *IEEE Trans. on Industry Applications*, pp. 1581-1590, Nov-Dec. 2002.

[186] S. J. Chung, W. J. Ho, and F. L. Lu, "Parallel operation of open-loop-based three-phase four-wire active power filters," *IEEE Proc. Electric Power Applications*, vol.149, no. 5, pp. 329-336, Sept. 2002.

[187] B.R. Lin, B.R. Yang, and T.L. Hsiang, "Implementation of a hybrid series active filter for harmonic current and voltage compensation," in *Proc. IEEE International Conf on Power Electronics, Machines and Drives'02, 2002*, pp. 588-603.

[188] G. Escobar, A.M. Sankaran, V. Cardenas and P. Mattavelli, "A controller based on resonant filters for a series active filter used to compensate current harmonics and voltage imbalance," in *Proc. IEEE Power Conference on Control Applications, 2002*, pp. 1-12.

[189] K. Sakurai and M. Perera, "Hybrid filter for an alternating current network," U. S. Patent 6,395,963(B1), July 1, 2002.


[190] S. Raskita, T. Niyandu, X. Jianhua and P. Sicaud, "A comparative study of harmonic detection algorithm for active filter and hybrid active filter," in *Proc. IEEE PESC'02, 2002*, pp. 817-821.

[191] C. Guohua, L. Dongyao, Q. Zhongqiang and F. Z. Peng, "A new weak hybrid active power filter using controllable current source," in *Proc. IEEE PESC'02, 2002*, pp. 364-368.

[192] D. Ruan, L. Marnas, J. Dixon and J. Laposkany, "A simple control scheme for hybrid active power filter," *IEEE Proc. GD2*, vol. 149, no. 4, pp. 483-490, July 2002.

[193] M.R. Denevski, M. Dixon and J. Kaskic, "EMC Compliant Harmonic and Reactive Power Compensation using Passive Filter Cascaded with Shunt Active Filter," *EPE Journal*, vol. 12, no. 3, pp. 45-50, June-Aug. 2002.

(Refer Slide Time: 76:02)



[194] S. Senani and P.J. Wolfs, "Analysis and design of a multiple-loop control system for a hybrid active filter," *IEEE Trans. on Industrial Electronics*, pp. 1263-1262, 2002.

[195] Z. Sun, X. Jiang and D. Zhu, "Study of novel traction substation hybrid power quality compensator," in *Proc. IEEE POWERCON 02*, 2002, pp. 480-484.

[196] B.H. Liu, B. R. Yang and H. R. Tsai, "Analysis and operation of hybrid active filter for harmonic elimination," *Electric Power Systems Research*, vol. 62, pp. 191-200, 2002.

[197] Jacobs Joop, DeJen Dirk, and De Donck Rik, "A New Hybrid Filter versus a Shunt Active Power Filter," in *Proc. EPFO2 2002*, Aachen.

[198] S. Rahmani, K. A. Haddad and F. Fnaiech, "A series Hybrid Power Filter to compensate harmonic currents and voltages," in *Proc. IEEE ECON02*, 2002, pp. 644-648.

[199] S. Rahmani, K. A. Haddad and F. Fnaiech, "A new PWM control technique applied to three-phase shunt Hybrid Power Filter," in *Proc. IEEE IECON02*, 2002, pp. 727-732.

[200] S. Rahmani, K. A.Haddad, and F. Fnaiech, "A hybrid structure of series active and passive filters to achieving power quality criteria," in *Proc. IEEE International Conf on Systems, Man and Cybernetics*, 2002, pp. 1-6.

[201] B. N. Singh, "Implementation of a hybrid filter with a potential application to adjustable speed compressor drives for air quality control," *Journal of Electric Power Components & Systems (EPCS)*, vol. 30, no. 11, pp. 1191-1226, Nov. 2002.

[202] D. Rivas, L. Morán, J. Dixon and J. Espinosa, "Improving passive filter compensation performance with active techniques," *IEEE Trans. on Industrial Electronics*, vol. 50, no. 1, pp. 101-110, Feb. 2003.

[203] BA Amados Oury and Alpha Oumar Barry, "Active Filter Analysis by the Harmonic Impedance Compensation Method (Part II)," in *Proc. IEEE-Canadian Conference on Electrical and Computer Engineering*03, May 2003.

[204] Nassar Mendalek, Kamal AHaddad, Louis-A. Dessaint and Silvano Casoni, "A New Regulation Algorithm Applied To A Hybrid Power Filter," in *Proc. IEEE Canadian Conference on Electrical and Computer Engineering*, May 2003.

[205] S. Srinathumong and H. Akagi, "A medium-voltage transformerless AC/DC power conversion system consisting of a diode rectifier and a shunt hybrid filter," *IEEE Trans. on Industry Applications*, vol. 39, no. 3, pp. 874-882, May/June 2003.

[206] G. van Schoot, J.D. van Wyk, and L.S. Shaw, "Tuning and optimization of an artificial neural network controlling a hybrid power filter," *IEEE Trans. on Industrial Electronics* vol. 50, no. 3, pp. 546-553, June 2003.

[207] F. Blarero, S. Martinez, F. Reyes, F. Mar, and P. M. Martinez, "Universal and reconfigurable to UPS active power filter for line conditioning," *IEEE Trans. Power Delivery*, vol. 18, no. 1, pp. 283-290, Jan 2003.

[208] S.J. Chialga, "A three-phase four-wire power conditioner with load-dependent voltage regulation for energy saving," in *Proc. IEEE APEC03*, 2003, pp. 159-164.

[209] P. Jittakosetmit, H. Fujita, H. Akagi, and S. Ogasawara, "Implementation and performance of cooperative control of shunt active filters for harmonic damping throughout a power distribution system," *IEEE Transactions on Industry Applications*, vol. 39, no. 2, pp. 550-564, March/Apr 2003.

[210] Luis F. C. Monteiro, Mauricio Arredes, and João A. Moor Neto, "A Control Strategy for Unified Power Quality Conditioner," in *Proc. IEEE SIEM03*, June 2003.

[211] A. Samim, S. Stevenson and T. Lasson, "Power-electronic solutions to power quality problems," *Journal of Electric Power Systems Research*, vol. 66, pp. 71-82, July 2003.

[212] A. R. Balbhai, H. Karmi, and M. Saeedifard, "A new adaptive harmonic extraction scheme for single-phase active power filters," in *Proc. IEEE International Symp. Circuits and Systems ISCAS 03*, 2003, pp. 206-211.

[213] B. Singh and V. Verma, "Control of hybrid Filter with Self-Supporting DC Bus," *Journal of the Institution of Engineers (India)*, Vol. 83, March 2003, pp. 307-312.

[214] S. Srinathumong and H. Akagi, "A Medium-voltage, Transformerless ac/dc Power Conversion System Consisting of a Diode Rectifier and a Shunt Hybrid Filter," *IEEE Transactions on Industry Applications*, vol. 39, no. 3, pp. 874-882, 2003.

[215] H. Akagi, S. Srinathumong, and Y. Tamai, "Comparisons in Circuit Configuration and Filtering Performance between Hybrid and Pure Shunt Active Filters," in *Conference Record IEEE IAS Annual Meeting*, pp. 1195-1202, 2003.

[216] Bhem Singh and Vishal Verma, "Hybrid of Tandem Connected Series Active and Series Passive Filters for Varying Rectifier Loads," in *Proc. of 13th National Power Systems Conf. NPSC04, IIT Madras*, December 27-30, 2004, Vol. II, pp. 929-935.

[217] B. Singh, V. Verma, A. Chandra and K. AHaddad, "Hybrid filters for power quality improvement," *IEE Proceedings-Generation, Transmission and Distribution*, vol. 152, no. 3, pp. 395-398, May 2005.

[218] Bhem Singh, Vishal Verma and Vign Garg, "Passive hybrid filter for varying rectifier loads" in *Proc. of IEEE Conf. Power Electronics and Drive Systems (PEDSD09)*, Kuala Lumpur, Malaysia, Nov. 20-24, 2009, Vol. 2, pp. 1326-1331.

[219] H. Akagi, "Active Harmonic Filters," *Proceedings of the IEEE*, vol. 83, no. 12, pp. 2128-2141, December 1995.

[220] Bhem Singh and Vishal Verma, "An Indirect Current Control of Hybrid Power Filter for Varying Loads," *IEEE Transactions on Power Delivery*, vol. 21, no. 1, pp. 178-182, January 2006.

[221] Bhem Singh and Vishal Verma, "Indirect Current Control of Series Hybrid Filter: An Experimental Study," in *Proc. of IEEE International Symposium on Industrial Electronics (ISIE-2006)*, Montreal, Quebec, Canada, July 8-12, 2006, pp. 1384-1389.

[222] Bhem Singh and Vishal Verma, "An improved hybrid filter for Compensation of Current and Voltage Harmonics for Varying Rectifier Loads," *International Journal of Electrical Power & Energy Systems*, vol. 29, no. 4, pp. 312-321, May 2007.

[223] Bhem Singh and Bhem Singh, "Design and implementation of a current controlled AC/DC power filter," *IEEE Transactions on Industry Applications*, vol. 43, no. 3, pp. 713-717, September 2007.