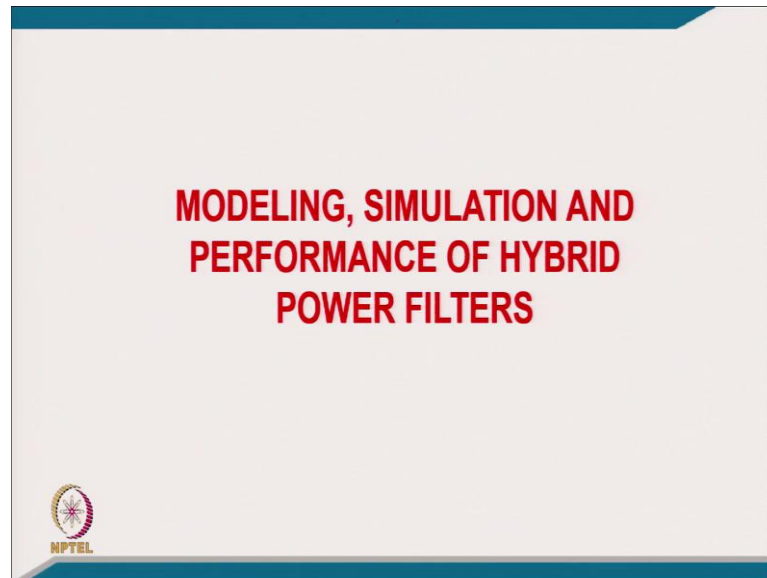


Power Quality
Prof. Bhim Singh
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Lecture - 27
Hybrid Power Filters (contd.)

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Welcome to the course on Power Quality. We were discussing about the Hybrid Power Filter.

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Modeling, Simulation and Performance of Passive Series and Passive Shunt Based Hybrid Power Filter

Series Passive Filter Shunt Passive Filter 25 kW Nonlinear load

TABLE: PARAMETERS OF HYBRID PASSIVE SERIES AND PASSIVE SHUNT FILTER


Series Passive filter				Shunt Passive filter			
				R_{HSF}	3 Ω	R_{HPF}	16 Ω
C_5	70 μF	C_7	60 μF	C_{HSF}	48 μF	C_{HPF}	40 μF
L_5	5.8 mH	L_7	3.4 mH	L_{HSF}	1.8 mH	L_{HPF}	10 mH

The simulation performance of the hybrid power filter are detailed in the following screenshots.

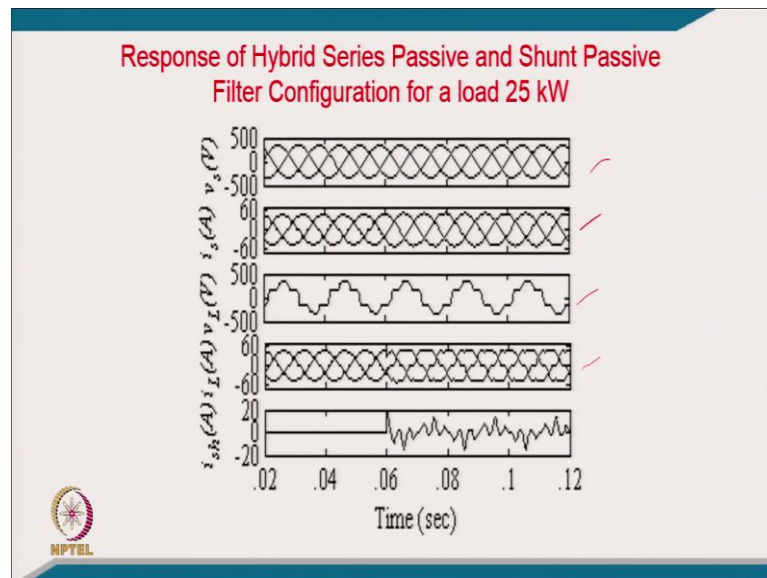
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Modeling, Simulation and Performance of Passive Series and Passive Shunt Based Hybrid Power Filter

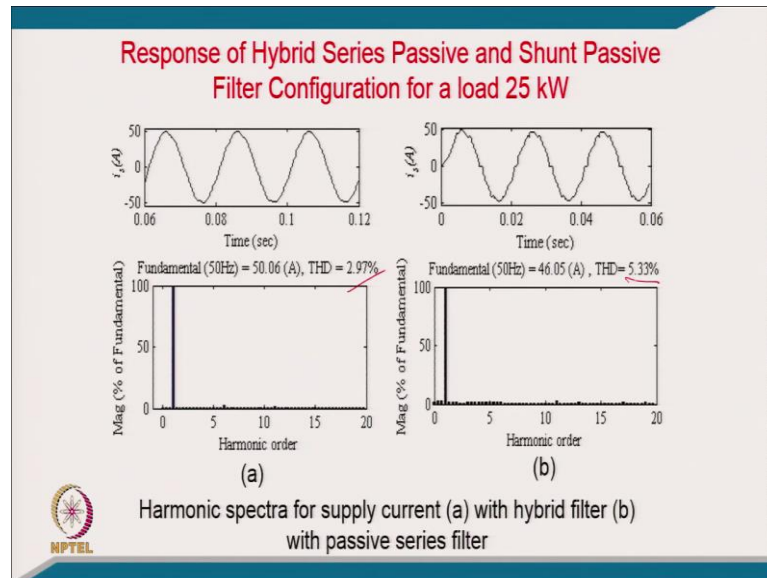
- For the simulation studies the supply voltage is considered as 415 V, 50Hz.
- A voltage fed nonlinear load with load power of 25 kW is considered for simulation study.
- The reactive power for passive shunt filter design is considered approximately 15% of active power of the load.
- The various filter parameters are given in Table.
- Response of hybrid series passive and shunt passive hybrid filter configuration for this load is shown in Fig, in which **from $t_s = 0.2$ s to 0.06 s, only series passive filter compensates**, after that both hybrid of passive series and passive shunt filter compensates the harmonics.



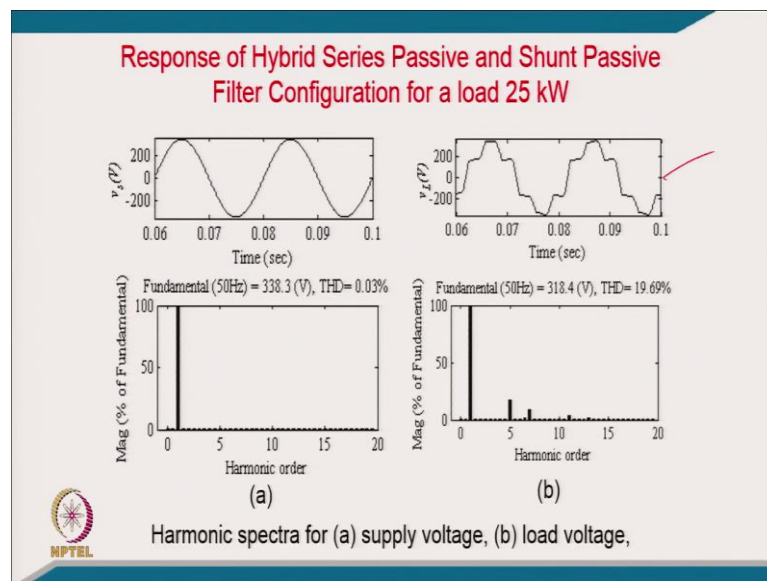
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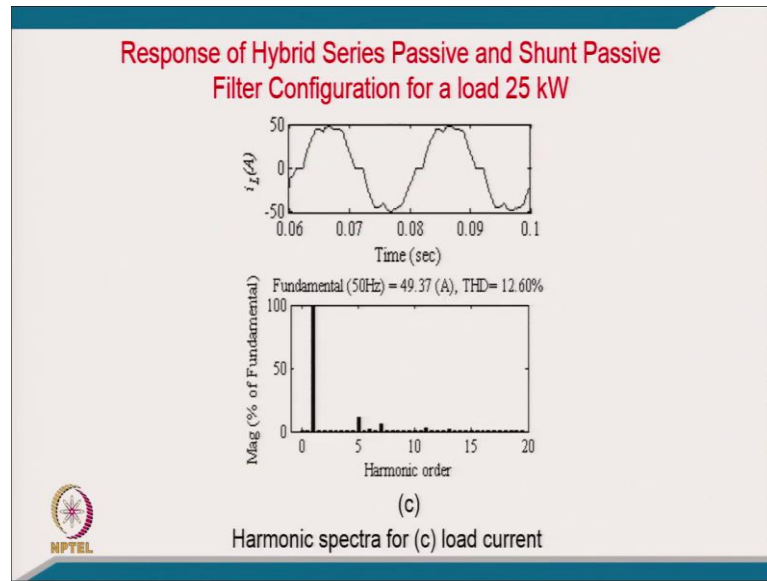
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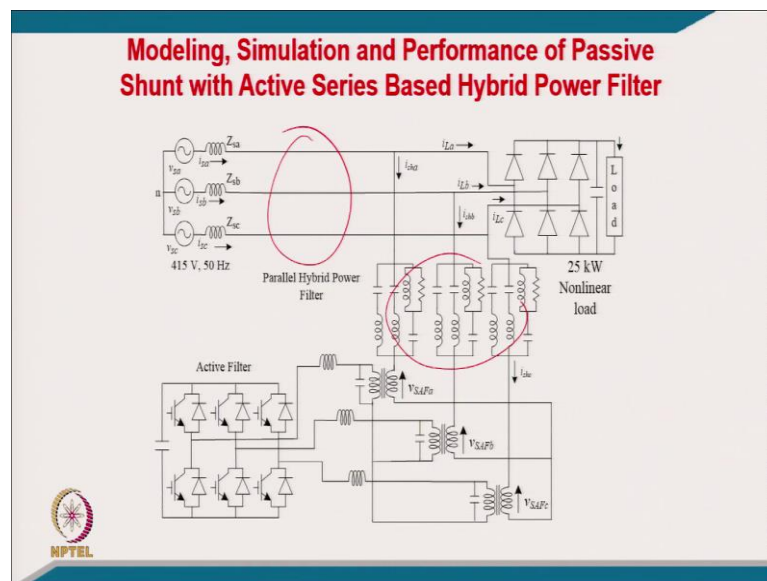
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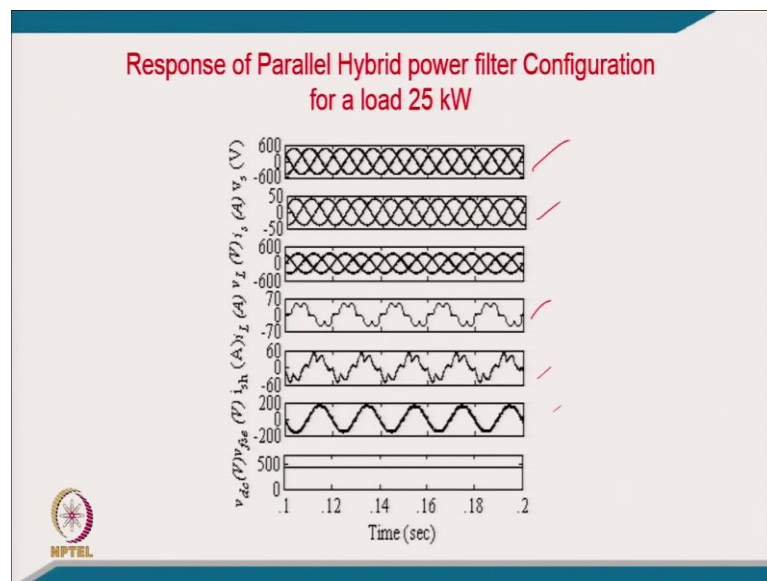
Modeling, Simulation and Performance of Passive Shunt with Active Series Based Hybrid Power Filter

TABLE: PARAMETERS OF PARALLEL HYBRID ACTIVE SERIES WITH PASSIVE SHUNT FILTER

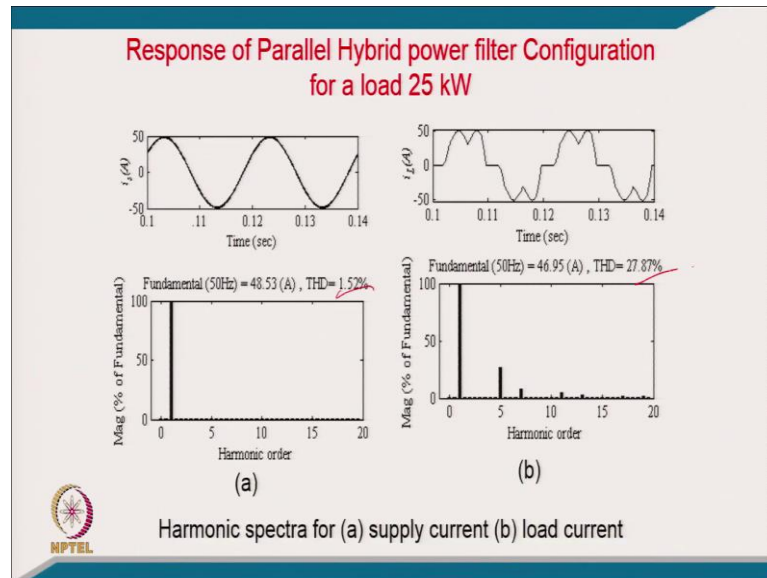
Active Series filter				Passive Shunt filter			
V_{dc}	450 V	R_f	5 Ω	Order n	C (μ F)	L (mH)	R (Ω)
C_{dc}	3000 μ F			5 th	25	16.4	1.29
L_f	3 mH	C_f	10 μ F	7 th	25	8.4	0.9226
				11 th	25	3.4	4.67



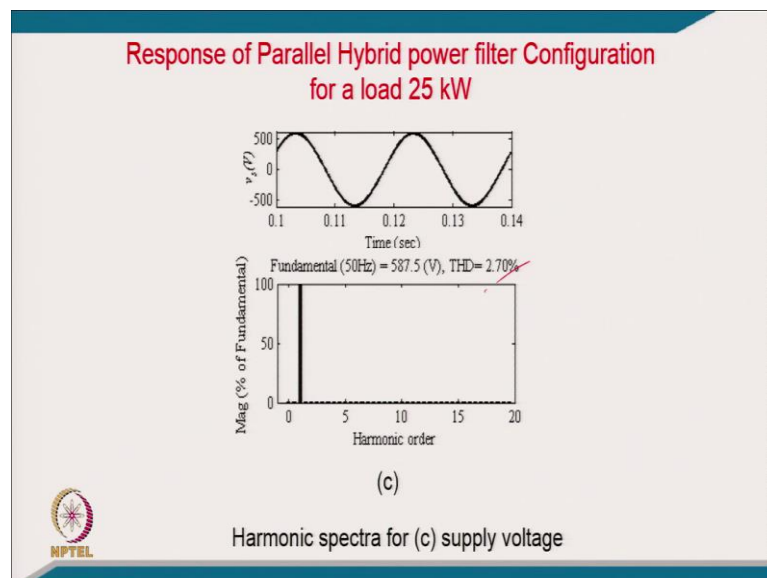
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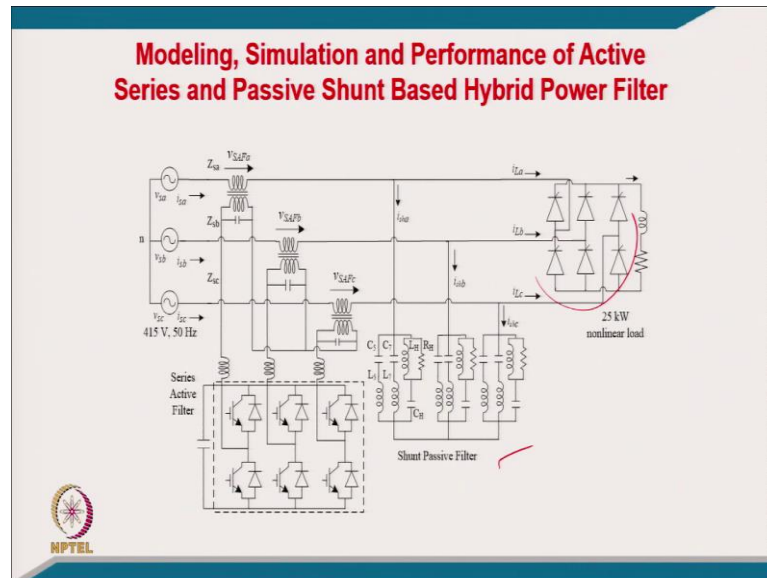
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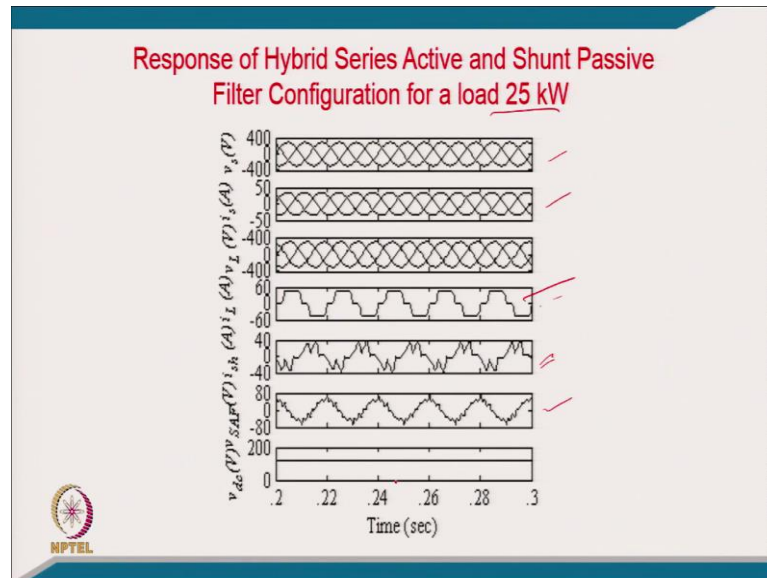
Modeling, Simulation and Performance of Active Series and Passive Shunt Based Hybrid Power Filter

TABLE: PARAMETERS OF HYBRID ACTIVE SERIES AND PASSIVE SHUNT FILTER

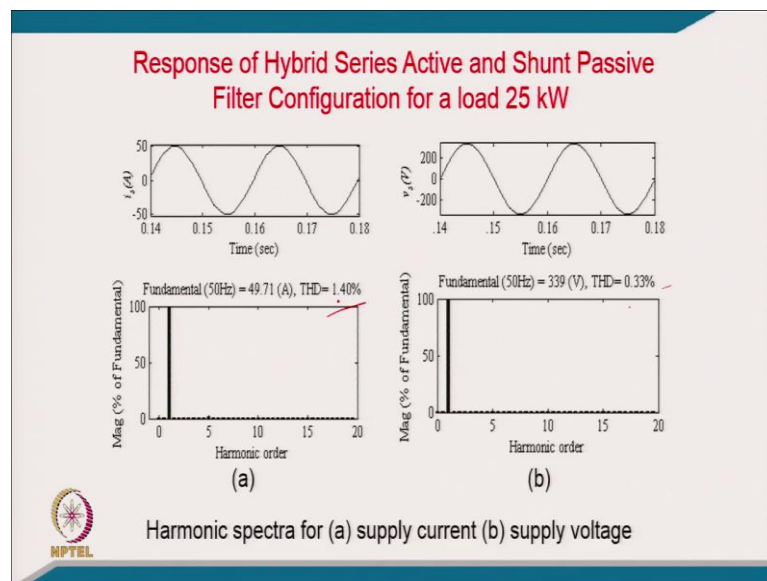
Active Series filter				Passive Shunt filter			
V_{dc}	100 V	R_f	5 Ω	Order n	C (μ F)	L (mH)	R (Ω)
C_{dc}	3000 μ F			5 th	25	16.4	1.29
L_f	3 mH	C_f	10 μ F	7 th	25	8.4	0.9226
				11 th	25	3.4	4.67

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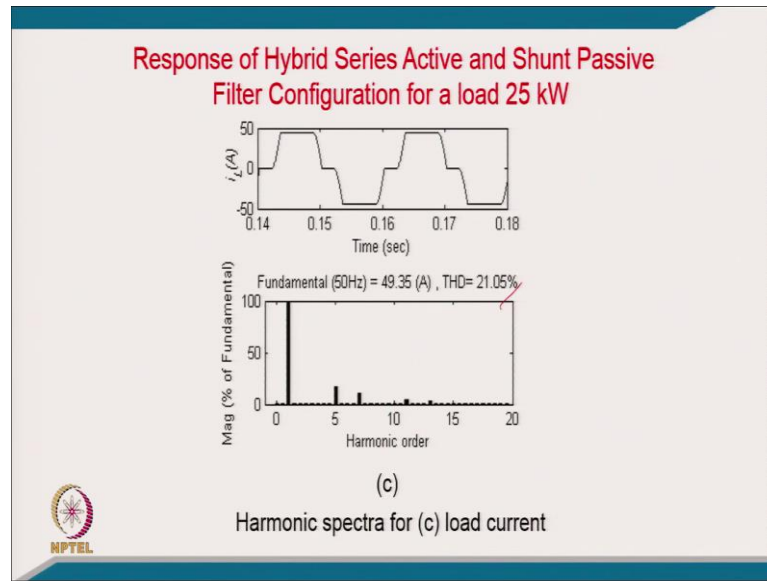


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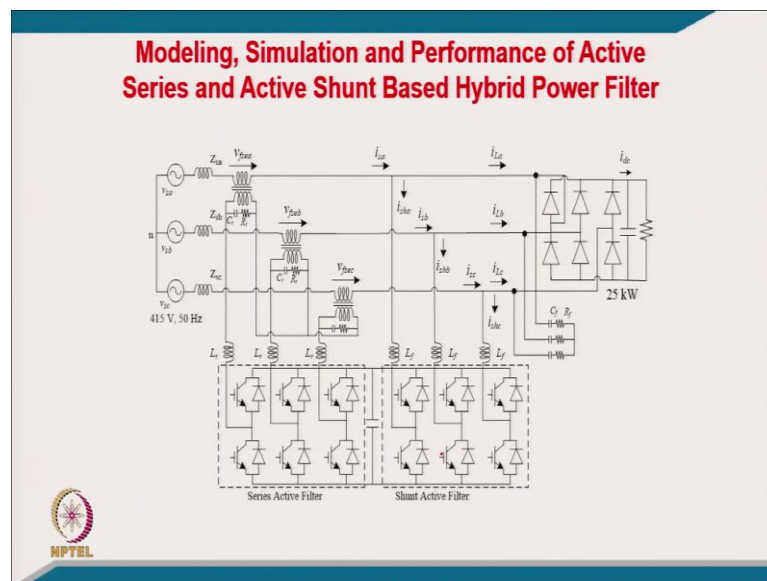


Harmonic spectra for (a) supply current (b) supply voltage

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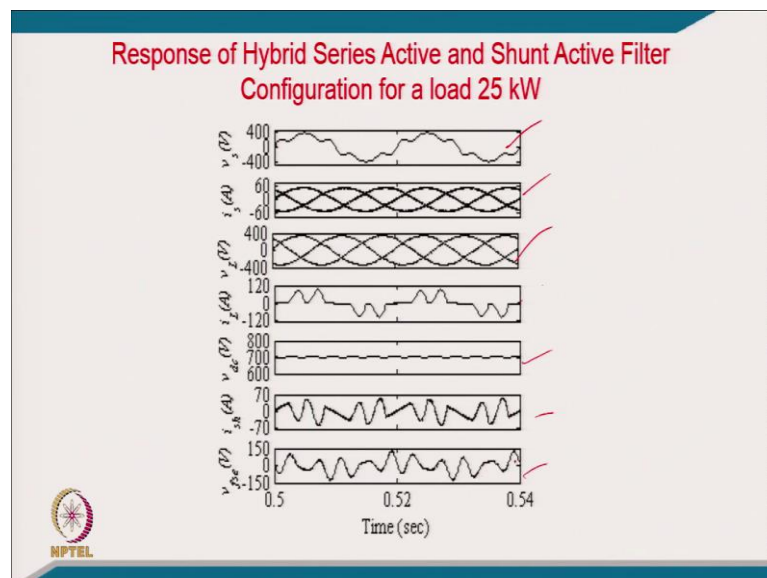
Modeling, Simulation and Performance of Active Series and Active Shunt Based Hybrid Power Filter

TABLE: SIMULATION PARAMETERS OF HYBRID ACTIVE SERIES AND ACTIVE SHUNT FILTER

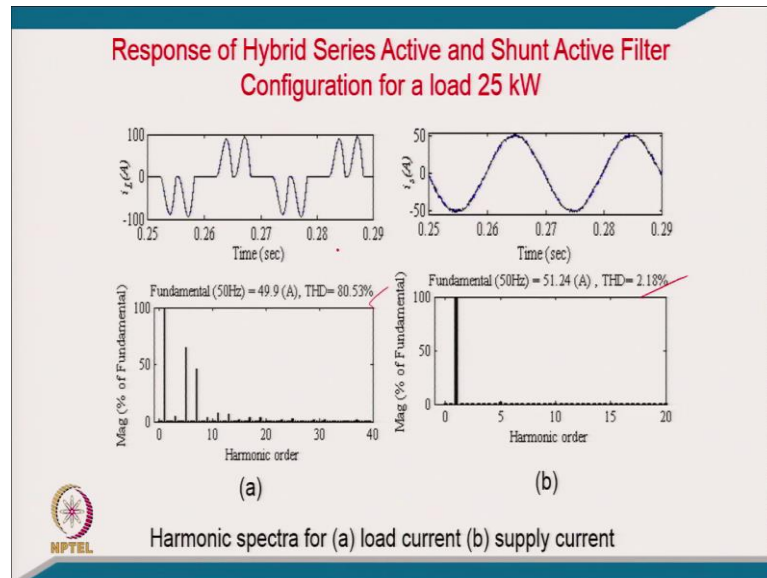
Parameters	Active Series Filter	Active shunt Filter
V_{dc}	700 V	
C_{dc}	5000 μ F	
Interfacing inductor	$L_r = 4$ mH	$L_r = 2$ mH
Ripple filter capacitor	$C_r = 10$ μ F	$C_r = 5$ μ F
Ripple filter resistor	$R_r = 5$ Ω	$R_r = 5$ Ω



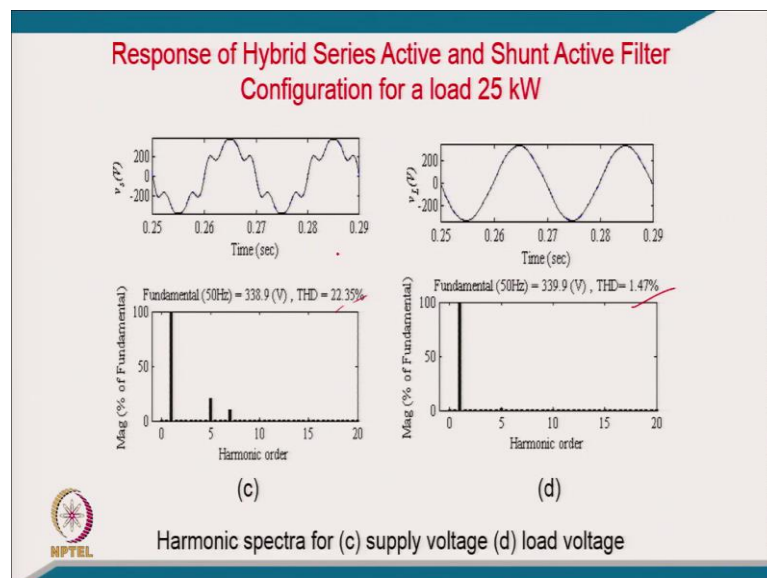
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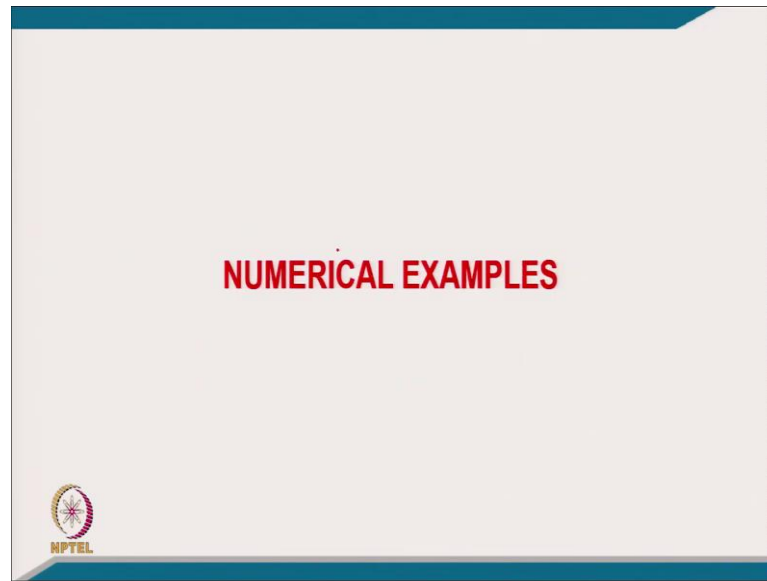
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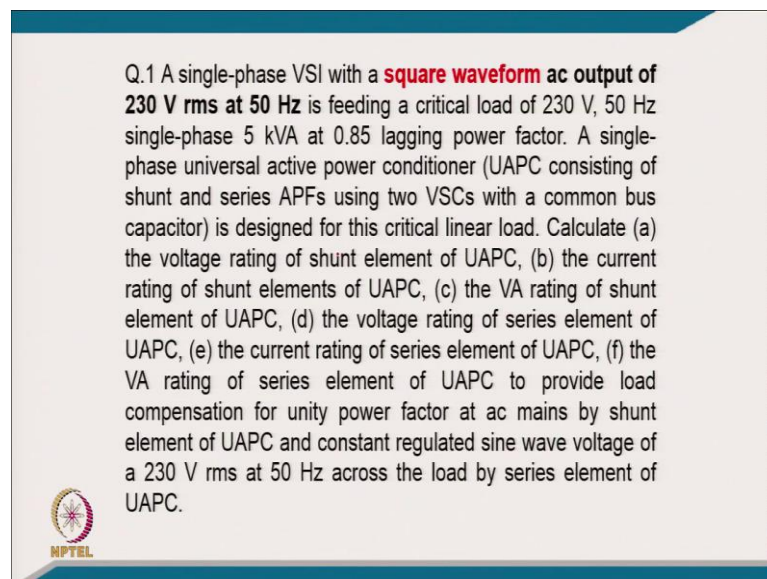


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Now, we will discuss some of the numerical examples.

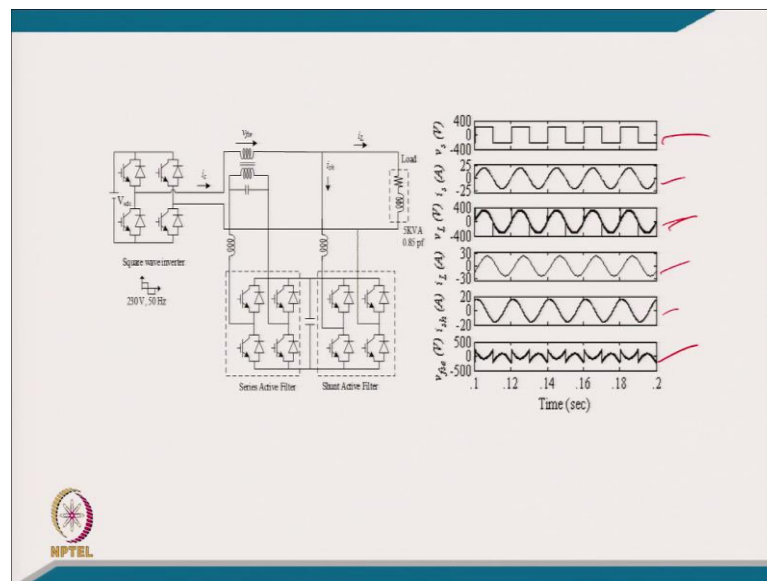
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Coming to the first numerical example, a single phase voltage source inverter with a square wave ac output of 230 volt, 50 hertz is feeding the critical load of 230 volt, 50 hertz single-phase 5 kVA at 0.8 lagging, 0.85 lagging power factor and single-phase universal active power conditioner UAPC consisting of shunt and series active power filter using two VSC with common dc bus capacitor is design for this critical linear load.

Calculate the voltage rating of shunt element of UPAC, Universal Active Power Filter; current rating of the shunt element of u Universal Active Power Filter; voltage rating of the VA rating of the shunt element and voltage rating of series element and current rating of series element and the VA rating of series element of u Universal Active Power Filter to provide the load compensation for unity power factor at ac mains and by shunt element and constant regulated sine voltage of a 230 volt rms 50 hertz across the load by series element of UPAC.

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

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Solution: Given that, $V_s = 230$ V rms square wave, $f = 50$ Hz, a critical load of 230 V, 50 Hz single-phase 5 kVA at 0.85 lagging power factor. The fundamental component of supply voltage for square wave voltage is estimated as,

$$V_{s1} = 0.9 \cdot V_s = 0.9 \cdot 230 = 207 \text{ V.}$$

The load voltage is to be regulated at nominal sine wave voltage hence, $V_L = 230$ V.

The ac load current is as, $I_L = S_L / V_L = 5000 / 230 = 21.739$ A.

In this system, load reactive power compensation is to be provided by 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.



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The load active power is calculated as,

$$P_L = S_L \cdot \text{pf} = 5000 \cdot 0.85 = 4250 \text{ W.}$$

The active power component of load current is estimated as,

$$I_{L1a} = P_L / V_L = 4250 / 230 = 18.478 \text{ A.}$$

The supply current after the compensation is estimated as,

$$I_s = P_L / V_{s1} = 4250 / 207 = 20.531 \text{ A.}$$

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

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



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The shunt element of UAPC is to correct the power factor of the load to unity, hence it supplies the reactive power required for the load, therefore reactive power component of the shunt APF current is estimated as,

$$I_{shr} = \text{Reactive power component of current of the load}$$
$$= I_L \sqrt{1 - PF^2} = 21.739 * 0.527 = 11.452 \text{ A.}$$

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 the shunt APF current is estimated as,

$$I_{sha} = I_s - I_{L1a} = (20.531 - 18.478) \text{ A} = 2.053 \text{ A.}$$

The net current rating of shunt APF is estimated as,

$$I_{sh} = \sqrt{I_{sha}^2 + I_{shr}^2} = \sqrt{(2.053)^2 + 11.452^2} = 11.635 \text{ A.}$$


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

$$S_{sh} = V_{ish} * I_{sh} = 230 * 11.635 = 2675.956 \text{ VA.}$$


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

The supply voltage is square wave of $V_s = 230 \text{ V rms}$ and the load voltage at PCC 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.

The voltage rating of series APF,


$$V_{fse} = \sqrt{\frac{1}{\pi} \int_0^{\pi} (230 - 230\sqrt{2}\sin\theta)^2 d\theta} = 102.696 \text{ V}$$

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

$$I_{se} = I_s = 20.531 \text{ A.}$$



(Refer Slide Time: 23:43)

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

$$S_{se} = V_{ise} * I_{se} = 102.696 * 20.531 = 2108.458 \text{ VA.}$$


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Q.2 A single-phase VSI with **quasi-square waveform ac output of 230 V rms at 50 Hz** is feeding a critical load of 230 V, 50 Hz single-phase 5 kVA at 0.85 lagging power factor. 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 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 active filter of UAPC, (e) the current rating of series element of UAPC, (f) the VA rating of series element of UAPC to provide load compensation for unity power factor at ac mains by shunt element of UAPC and constant regulated sine wave voltage of a 220 V rms at 50 Hz across the load by series element of UAPC.

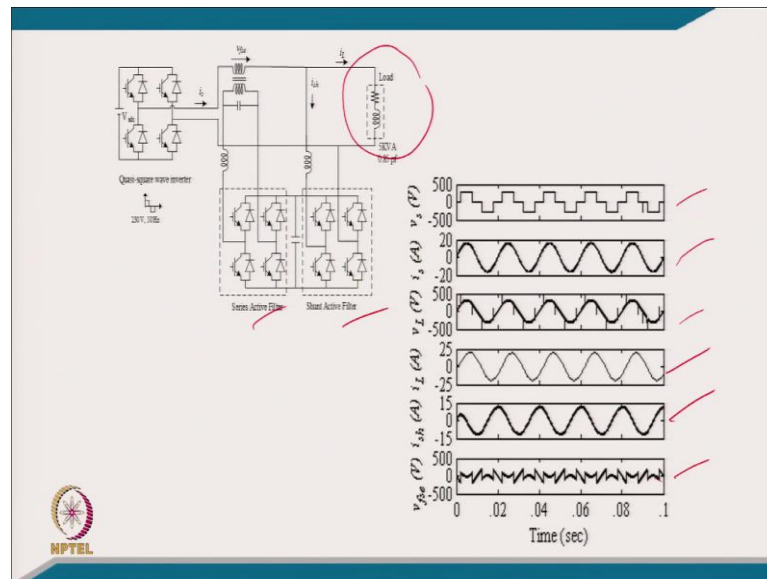


Coming to another example. A single-phase voltage source inverter with the quasi-square waveform ac output of 230 volt rms at 50 hertz is feeding a critical load of 230 volt 50 hertz single-phase 5 kVA at 0.85 lagging power factor. A single-phase universal active power conditioner or consisting of shunt and series active power filter using two voltage source converter with common bus capacitor shown in the figure is design for critical linear load.

Calculate the voltage rating of shunt element of universal active power filter; b, the current rating of shunt element of the universal active power filter; c, the VA rating of the shunt element of universal active power filter and d, the voltage rating of the series active power filter of universal active power filter.

And e, the current rating of series element of series universal active power filter; f, is the VA rating of the series active filter to provide the load compensation of for unity power factor that ac mains and by shunt element of universal active power filter and constant regulator voltage sine wave volt 220 volt rms at the across the load by series element of typically of universal active power filter.

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

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Solution: Given that, $V_s = 230$ V rms quasi-square wave, $f = 50$ Hz, a critical load of 230 V, 50 Hz single-phase 5 kVA at 0.85 lagging power factor.

The ac load current is as,

$$I_L = 5000/230 = 21.739 \text{ A.}$$

In this system, load reactive power compensation is to be provided by 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 active power is calculated as,

$$P_L = S_L * \text{pf} = 5000 * 0.85 = 4250 \text{ W.}$$


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The active power component of load current is estimated as,

$$I_{L1a} = P_L/V_L = 4250/230 = 18.478 \text{ A.}$$

The amplitude of quasi-square wave is estimated as,

$$V_{sdc} = V_s / (\sqrt{2/3}) = 281.691 \text{ V.}$$

The fundamental supply voltage for quasi-square wave is estimated as,

$$V_{s1} = (\sqrt{6}/\pi) * V_{sdc} = 219.634 \text{ V.}$$


The supply current after compensation is estimated as,

$$I_s = P_L/V_{s1} = 4250/219.634 = 19.35 \text{ A.}$$

(a) The voltage rating of shunt element of UAPC is equal to ac load voltage of

$$V_{fsh} = 230 \text{ V.}$$

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



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

$$I_{shr} = \text{Reactive power component of the load current} \\ = I_L \sqrt{1 - PF^2} = 21.739 * 0.527 = 11.457 \text{ A.}$$


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

$$I_{sha} = I_s - I_{L1a} = (19.35 - 18.478) \text{ A} = 0.872 \text{ A.}$$

The net current rating of shunt APF is estimated as,

$$I_{sh} = \sqrt{I_{sha}^2 + I_{shr}^2} = \sqrt{0.872^2 + 11.457^2} = 11.49 \text{ A.}$$

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

$$S_{sh} = V_{fsh} * I_{sh} = 230 * 11.49 = 2642.734 \text{ VA.}$$


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(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 is a sine wave of $V_L = 230 \text{ V}$.

The amplitude of quasi-square wave is as, $V_{sdc} = 281.691 \text{ V}$. Therefore the series APF must inject the difference of these two voltages to provide the required voltage at the load end.

The voltage rating of series APF is as,


$$V_{fse} = \sqrt{\frac{(1/\pi) \int_0^{\pi/6} (-230\sqrt{2}\sin\theta)^2 d\theta + \int_{\pi/6}^{5\pi/6} (281.691 - 230\sqrt{2}\sin\theta)^2 d\theta + \int_{5\pi/6}^{\pi} (-230\sqrt{2}\sin\theta)^2 d\theta}{\pi}} = 69.052 \text{ V}$$

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

$$I_{se} = I_s = 5000 * 0.85 / 219.634 = 19.35 \text{ A.}$$



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

$$S_{se} = V_{ise} \cdot I_{se} = 69.052 \cdot 19.35 = 1336.161 \text{ VA.}$$


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Q3. A single-phase active hybrid filter (consisting of three branch passive shunt filter and a series APF using VSC with bus capacitor) is designed for a critical load of 230 V, 50 Hz single-phase thyristor bridge with constant dc current of 20 A at 30° firing angle of its thyristors. Calculate (a) the elements values of the passive shunt filter, (b) the voltage, (c) current and (d) kVA rating of both (i) series APF and (ii) the passive shunt filter used in the hybrid filter to provide harmonics and reactive power compensation for unity power factor at ac mains.

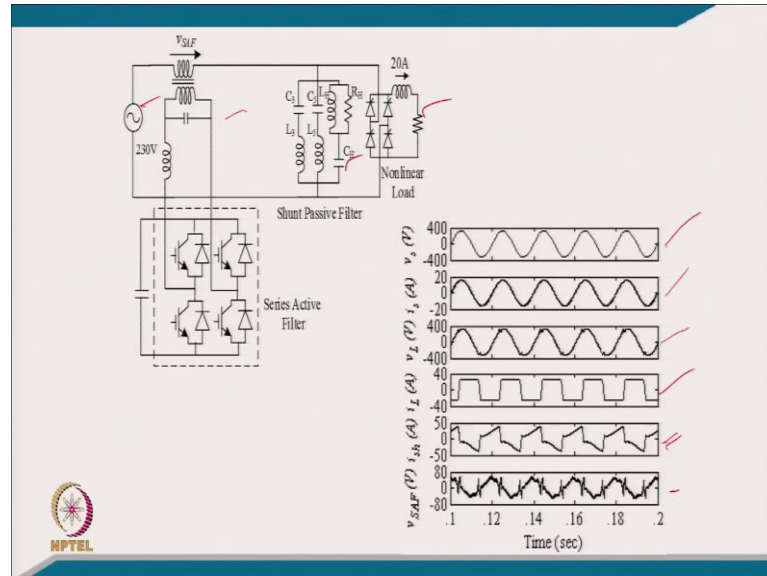


Coming to example 3, a single-phase active hybrid filter consisting of three branch passive shunt filter and a series active filter using a voltage source converter with the dc bus, designed for a critical load of 230 volt 50 hertz. Single-phase thyristor bridge with constant dc current of twenty ampere with 30 degree fire angle of its thyristor.

Calculate the element value of the passive shunt filter; the voltage rating; current and current rating and the kVA rating of both series active filter and passive shunt filter used

in hybrid filter to provide the harmonics and reactive power compensation for unity power factor at a t mains; at a c mains like.

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Solution: Given that, $V_s = 230$ V rms, $f = 50$ Hz, a nonlinear load of 230 V, 50 Hz single-phase thyristor bridge converter with constant dc current of 20 A at 30° firing angle of its thyristors.

The ac load rms current is as, $i_L = I_{dc} = 20$ A.

The fundamental rms input current of the thyristor bridge converter ,

$$I_{1T} = (2\sqrt{2}/\pi)I_L = 0.9 \times 20 = 18 \text{ A.}$$

The fundamental active power component of load current,

$$I_{L1a} = I_{L1} \cos \alpha = 0.9 I_{dc} \cos 30^\circ = 15.588 \text{ A.}$$

The fundamental active power of the load,

$$P_1 = V_{s1} I_{L1} \cos \theta_1 = V_{s1} I_{L1a} = 230 \times 15.588 = 3585.315 \text{ W.}$$

The fundamental reactive power of the load,

$$Q_1 = V_{s1} I_{L1} \sin \theta_1 = V_{s1} I_{L1} \sin \alpha = 230 \times 18 \times 0.5 = 2070 \text{ VAR.}$$

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

$$C = Q/(3V_s^2\omega) = 2070/(3*230^2*314) = 41.519 \mu\text{F}.$$
$$C_3 = C_5 = C_H = C = 41.519 \mu\text{F}.$$

Therefore, the value of an inductor for 3rd harmonic tuned filter is as,

$$L_3 = 1/(\omega_3^2 C_3) = 27.115 \text{ mH}.$$


The resistance of the inductor of 3rd harmonic tuned filter is as,

$$R_3 = X_3/Q_3 = 1.278 \Omega. \text{ (Considering } Q_3 = 20)$$

The value of an inductor of 5th harmonic tuned filter is as,

$$L_5 = 1/(\omega_5^2 C_5) = 9.762 \text{ mH}.$$

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

$$R_5 = X_5/Q_5 = 0.767 \Omega. \text{ (Considering } Q_5 = 20)$$


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The value of an inductor for high pass damped harmonic filter (tuned at 7th harmonic) is as,

$$L_H = 1/(\omega_7^2 C_H) = 4.98 \text{ mH}.$$


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

$$R_H = X_H/Q_H = 10.952 \Omega. \text{ (Considering } Q_H = 1)$$

The 3th harmonic load current to flow in to 3th harmonic tuned filter,

$$I_3 = I_{1T}/3 = 18/3 = 6\text{A}.$$

The 3th harmonic voltage at the load end and across the passive filter,

$$V_3 = I_3 * R_3 = 6 * 1.278 = 7.668 \text{ V}.$$


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The 5th harmonic load current to flow in to 5th harmonic tuned filter,

$$I_5 = I_{1T}/5 = 18/5 = 3.6 \text{ A.}$$

The 5th harmonic voltage at the load end and across the passive filter,

$$V_5 = I_5 * R_5 = 3.6 * 0.767 = 2.76 \text{ V.}$$


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

$$I_H = \sqrt{[I_L^2 - I_{1T}^2 - I_3^2 - I_5^2]} = \sqrt{[20^2 - 18^2 - 6^2 - 3.6^2]} = 5.2 \text{ A.}$$

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

$$V_H = I_H * R_H = 5.2 * 10.952 = 56.950 \text{ V.}$$

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



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$$V_{LH} = \sqrt{(V_3^2 + V_5^2 + V_H^2)} = 57.531 \text{ V.}$$

(a) The voltage rating of the series active filter is as,

$$V_{SAF} = V_{LH} = \sqrt{(V_3^2 + V_5^2 + V_H^2)} = 57.531 \text{ V.}$$


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

$$I_{SAF} = I_s = \text{The fundamental active power component of load current,}$$
$$I_{L1a} = I_{L1} \cos\alpha = 0.9 I_{dc} \cos 60^\circ = 15.588 \text{ A.}$$

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

$$S_{APF} = V_{SAF} * I_{SAF} = 57.531 * 15.588 = 896.812 \text{ VA.}$$

The pu rating of the series APF is as,

$$S_{APFpu} = S_{APF}/S_L = 896.812 / (230 * 20) = 0.195 = 19.5\% \text{ of the load rating.}$$


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(ii) The various ratings of the passive filter are as follows.

(a) The voltage rating of the shunt passive filter,
 $V_{PF} = \sqrt{(230^2 + 57.531^2)} = 237.086 \text{ V.}$

(b) The current rating of the shunt passive filter is computed as,
Total harmonics and reactive power component of load current is as,
 $I_{sh} = \sqrt{(I_L^2 - I_{L1a}^2)} = \sqrt{(20^2 - 15.588^2)} = 12.53 \text{ A.}$


(c) The VA rating of shunt passive filter,
 $S_{sh} = V_{fsh} * I_{sh} = 237.086 * 12.53 \text{ VA} = 2970.679 \text{ VA} = 2.971 \text{ kVA.}$

The pu rating of the shunt passive filter is as,
 $S_{PFpu} = S_{PF} / S_L = 2970.679 / (230 * 20) = 0.646 = 64.58\% \text{ of the load rating.}$



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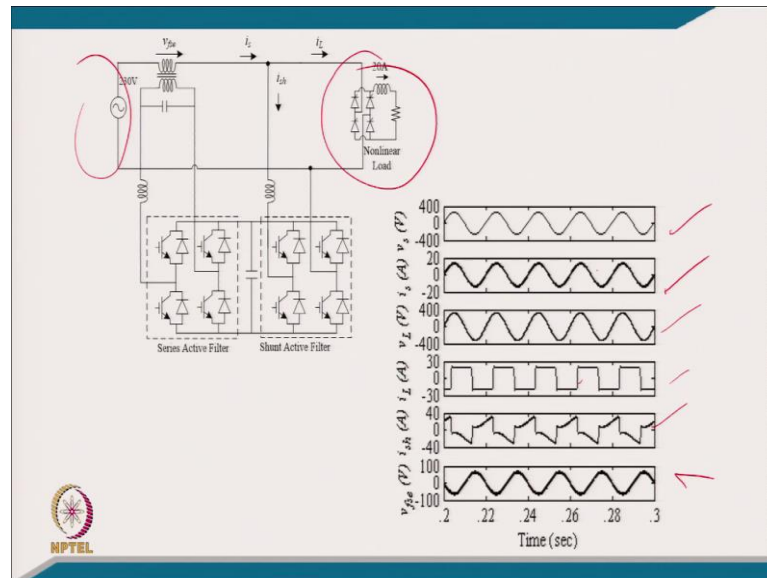
Q4.A single-phase universal active power conditioner (consisting of shunt and series APFs using two VSCs with a common bus capacitor as shown in Fig.) is designed for a typical load of 230 V, 50 Hz single-phase thyristor bridge with constant dc current of 20 A at 60° firing angle of its thyristors. If there is a voltage fluctuations of +10% and -20% in supply system with base value of 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 UAPC to provide harmonics and reactive power compensation for unity power factor at ac mains with constant regulated sine wave voltage of 230 V at 50 Hz across the load by series APF.



Coming to like a fourth numerical problem, a single-phase universal active power conditioner consisting of series and shunt active filters using two voltage source converter with common dc bus capacitor is designed for a typical load of 230 volt, 50 hertz single-phase thyristor bridge with the constant current of 20 ampere at 60 degree fire angle of its thyristor and if there is a voltage fluctuation of 10 percent plus and 20 percent minus in supply voltage with the base value of 230 volt.

Calculate the voltage rating of the shunt element; current rating of shunt element; VA rating of the shunt element series voltage rating of series element and current rating of series element and the VA rating of series element to provide the harmonic and reactive power compensation for unity power factor at ac main and constant regulated sine wave voltage of 230 volt 50 hertz across the load by series active filter.

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

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Solution: Given that, supply voltage, $V_s = 230$ V rms, frequency of supply, $f = 50$ Hz, a nonlinear load of 230 V, 50 Hz single-phase thyristor bridge converter with constant dc current of 20 A at 60° firing angle of its thyristors. There is a voltage fluctuation of +10% and -20% in supply system with base value of 230 V. 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 UPQC-P. Under maximum voltage dip, the maximum rating for both the VSCs are realized. The various rating calculations are as follows,

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The ac load rms current is as, $I_L = 20$ A.


The fundamental active power component of load current,
 $I_{L1a} = I_{L1} \cos\alpha = 0.9 * 20 * \cos 60^\circ = 9$ A.

The active power consumed by the load is as,
 $P_L = V_s * I_{L1a} = 230 * 9 = 2070$ W.

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

The supply current under maximum voltage variation (-20% sag) is as,
 $I_s' = P_L / V_s' = 2070 / 184 = 11.25$ A.

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



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(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 of shunt filter is as,

$$I_{shr} = \sqrt{(I_L^2 - I_{L1a}^2)} = \sqrt{(20^2 - 9^2)} = 17.86$$
 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. Under voltage sag the active power component of shunt APF current is calculated as,

$$I_{sha} = I_s' - I_{L1a} = (11.25 - 9) = 2.25$$
 A.

The net current rating of shunt active filter is calculated as,

$$I_{sh} = \sqrt{(I_{sha}^2 + I_{shr}^2)} = \sqrt{(2.25^2 + 17.86^2)} = 18.00$$
 A.

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

$$S_{sh} = V_{fsh} * I_{sh} = 230 * 18 \text{ VA} = 4140 \text{ VA}.$$

(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 provide the required voltage at the load end.

$$\text{The voltage rating of series APF, } V_{ise} = 230 * 0.20 = 46 \text{ V}.$$

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

$$I_{se} = I_s = 11.25 \text{ A}.$$

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

$$S_{se} = V_{ise} * I_{se} = 46 * 11.25 \text{ VA} = 517.5 \text{ VA}.$$

