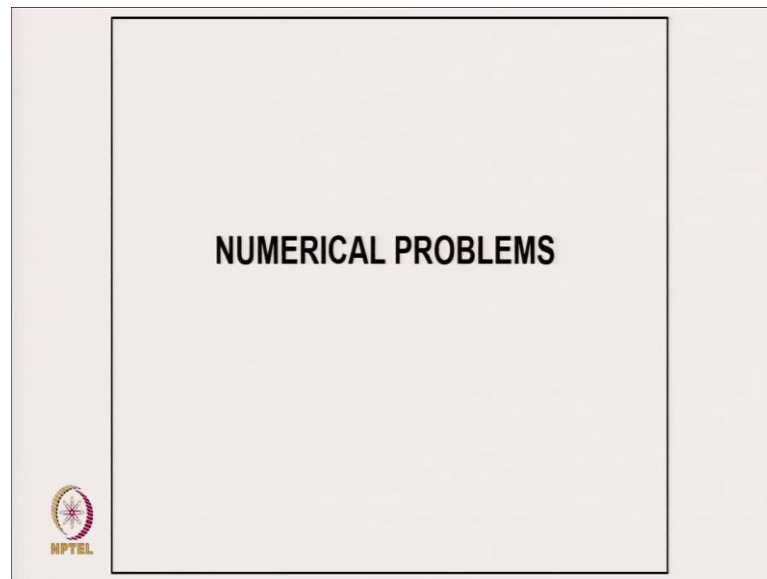


Power Quality
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Lecture - 31
Improved Power Quality Converters- AC-DC Boost Converters (Contd.)

(Refer Slide Time: 00:17)



Welcome to the course on Power Quality. We will discuss the numerical problems on Improved Power Quality Boost Converter.

(Refer Slide Time: 00:28)

1. Find the optimum value of (a) the DC side inductor and (b) the DC link capacitor for a **single-switch boost PFC AC-DC** converter with the following specification (i) the rated power 1000 W, (ii) the output voltage 400 V, (iii) the output voltage ripple < 0.02 pu, (iv) the inductor current ripple < 0.05 pu, (v) the line frequency 50 Hz, (vi) the supply voltage 230 V (rms), (vii) switching frequency 40 kHz. under the **continuous conduction mode (CCM)** operation of the DC side inductor.

The slide contains a circuit diagram on the left and a set of waveforms on the right. The circuit diagram shows a single-phase AC supply (230 V, 50 Hz) connected to a boost converter. The converter consists of a diode bridge rectifier, a boost inductor (L), a boost switch (MOSFET), and a diode. The output is connected to a load. The control system includes a PI Voltage Controller, a Reference Current Generator, and a PWM Current Controller. The waveforms on the right show the input AC voltage (V_i), the DC link voltage (V_{dc}), the inductor current (I_L), the boost switch current (I_{sw}), and the output voltage (V_o) over a 0.6 ms period.

Coming to the Example-1. Find the optimum value of (a) DC side inductor and (b) DC link capacitor, for a single switch power factor correction AC-DC converter with the following specification (i) the rated power of 1000 watt, (ii) the output voltage 400 volt, (iii) the output voltage ripple less than 2%, (iv) the inductor current ripple less than 5%, (v) the line frequency 50 hertz, (vi) supply voltage 230 volts, (vii) switching frequency 40 kilohertz, under the continuous conduction mode operation of the DC side inductor.

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Solution. Given that: $P_0=1000\text{W}$, $V_0=400\text{V}$, $V_s=230\text{V}_{\text{rms}}$, $f_s=40\text{kHz}$, $f=50\text{Hz}$, $V_{in} = 0.9^*V_s = 207\text{V}$.

$$I_0 = \frac{P_0}{V_0} = \frac{1000}{400} = 2.5\text{A} \quad D = \frac{V_0 - V_{in}}{V_0} = \frac{400 - 207}{400} = 0.4825 \quad I_n = \frac{P_0}{V_{in}} = \frac{1000}{207} = 4.83\text{A}$$

Hence optimum value of DC side capacitor:

$$C_d = \frac{I_0}{2\omega\Delta V_0} = \frac{2.5}{2 \times 314 \times \Delta V_0} = \frac{2.5}{2 \times 314 \times 0.02 \times 400} = 497.3\mu\text{F}$$

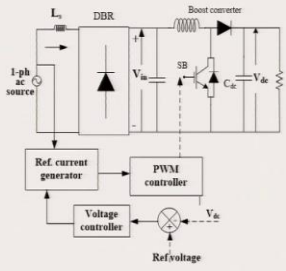
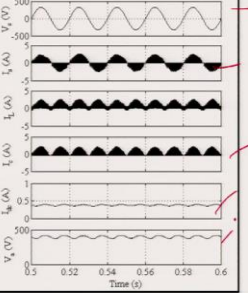

DC side inductor is calculated as,

$$L_0 = \frac{V_{in} \cdot D}{f_s \times \Delta I_n} = \frac{207 \cdot 0.4825}{40000 \times 0.05 \times 4.83} = 10.34\text{mH}$$


The solution for Example-1 is given in the abovemention slides.

(Refer Slide Time: 02:26)

2. Find the value of (a) the DC side inductor and (b) the DC link capacitor for a **single-switch boost PFC** AC-DC converter with the following specification (i) the rated power 150 W, (ii) the output voltage 400V, (iii) the output voltage ripple 0.05 pu, (iv) the line frequency 50 Hz, (v) the supply voltage 230 V (rms), (vi) the maximum switching frequency 20 kHz under the **boundary condition mode** of conduction (BCM) of the DC side inductor.

Coming to Example-2, find the value of (a) the DC side inductor and (b) the DC link capacitor for a switch-single switch boost converter AC-DC converter with following specifications, (i) the rated power of 150 W, (ii) the output voltage 400 V, (iii) the output voltage ripples less than 5%, (iv) the line frequency 50 Hz and voltage of 230 V, (v) the maximum switching frequency 20 kilo hertz under the boundary condition mode of the DC side.

(Refer Slide Time: 03:13)

Solution. Given that: $P_0=150\text{W}$, $V_0=400\text{V}$, $V_{\text{ripple}}=0.05\text{pu}$,
 $V_s = 230\text{V rms}$, $f_s=20\text{ kHz}$, $f=50\text{Hz}$


$$R = \frac{V_0}{I_0} = 1.06\text{k}\Omega \qquad I_0 = \frac{P_0}{V_0} = \frac{150}{400} = 0.375\text{A}$$

$$D = \frac{V_0 - V_{in}}{V_0} = \frac{400 - 207}{400} = 0.4825$$

For BCM the parameters are calculated as follows,

$$L_{\text{min}} = D \times (1-D)^2 \times \frac{R}{2f_s} = 0.4825 \times (1-0.4825)^2 \times \frac{1060}{2 \times 20000} = 3.43\text{mH}$$

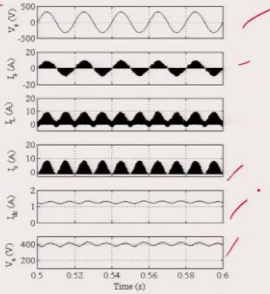

Design of DC link capacitor

$$C_d = \frac{I_0}{2\omega\Delta V} = \frac{0.375}{2 \times 314 \times 0.05 \times 400} = 29.84\mu\text{F}$$


The solution for Example-2 is given in the abovemention slides.

(Refer Slide Time: 03:54)

3. Find the value of (a) the DC side inductor and (b) the DC link capacitor for a **single-switch boost PFC** AC-DC converter with the following specification (i) the rated power 500 W, (ii) the output voltage 400V, (iii) the output voltage ripple < 0.05 pu, (iv) the line frequency 50Hz, (v) the supply voltage 230V (rms), (vi) the switching frequency 20 kHz under the **discontinuous conduction mode (DCM)** of the DC side inductor.

Coming to the Example-3, find the value of (a) DC side inductor, and (b) DC link capacitor of a single switch boost converter with the following specifications, (i) the rated power of 500 W, (ii) the output voltage 400 V, (iii) output voltage ripple less than 5%, (iv) the frequency 50 Hz (v) the voltage 230 V and switching frequency 20 kHz. Under discontinuous conduction mode of the DC side inductor.

(Refer Slide Time: 04:25)

Solution. Given that: $P_o=500\text{W}$, $V_o=400\text{V}$, $V_{\text{ripple}}=0.05\text{pu}$,
 $V_s = 230\text{V rms}$, $f_s=20\text{ kHz}$, $f=50\text{Hz}$

$$I_o = \frac{P_o}{V_o} = \frac{500}{400} = 1.25\text{A} \qquad R = \frac{V_o}{I_o} = 320\Omega$$


$$D = \frac{V_o - V_n}{V_o} = \frac{400 - 207}{400} = 0.4825$$

For DCM the parameters are calculated as follows,

$$L_{\text{min}} = D \times (1-D)^2 \times \frac{R}{2f_s} = 0.4825 \times (1-0.4825)^2 \times \frac{320}{2 \times 20000} = 1.03\text{mH}$$

Hence, the value of inductor should be less than 1.03mH to ensure DCM.

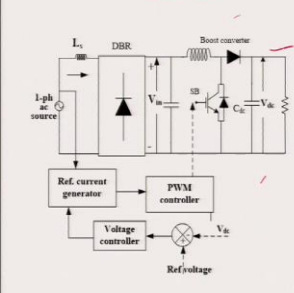
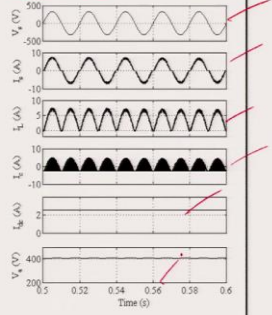

Design of DC link capacitor

$$C_d = \frac{I_o}{2\omega \Delta V_o} = \frac{1.25}{2 \times 314 \times 0.05 \times 400} = 99.47\mu\text{F}$$


The solution for Example-3 is given in the abovemention slides.

(Refer Slide Time: 04:49)

4. Calculate the value of (a) the output voltage ripple and (b) the inductor current ripple for a single-switch boost PFC AC-DC converter with the following specifications: (i) rated power 1000 W, (ii) output DC voltage 400 V, (iii) the DC side capacitor of 1500μF, (iv) the boost inductor of 5mH, (v) the line frequency 50 Hz, (vi) a supply voltage 230 V(rms), (vii) switching frequency 20 kHz (viii) CCM operation.

Coming to Example-4, calculate the value of (a) the output voltage ripple and (b) the inductor current ripple for a single-switch boost PFC converter with the following specifications, (i) rated power 1000 W, (ii) output DC voltage 400 V, (iii) DC side capacitor 1500 μF , (iv) the boost inductor of 5 mH, (v) the line frequency of 50 Hz, (vi) supply voltage of 230 V and the switching frequency of 20 kHz, and (vii) the CCM operation.

(Refer Slide Time: 05:39)


Solution. Given that: $P_o=1000\text{W}$, $V_o=400\text{V}$, $V_s=230\text{V rms}$,
 $C_d=1500\mu\text{F}$, $L_o=5\text{mH}$, $f_s=20\text{kHz}$, $f=50\text{Hz}$, $V_{in} = 0.9 \cdot V_s = 207\text{V}$

$$I_i = \frac{P_o}{V_{in}} = \frac{1000}{207} = 4.83\text{A} \quad R = \frac{V_o}{I_o} = 160\Omega \quad I_o = \frac{P_o}{V_o} = \frac{1000}{400} = 2.5\text{A}$$

$$D = \frac{V_o - V_{in}}{V_o} = \frac{400 - 207}{400} = 0.4825 \quad C_o = \frac{I_o}{2\omega\Delta V_o} = \frac{2.5}{2 \times 314 \times \Delta V_o}$$

Since the capacitor value is given. Hence,

$$1500 \times 10^{-6} = \frac{2.5}{2 \times 314 \times \Delta V_o}$$

$$\Delta V_o = 2.65\text{V}$$


(Refer Slide Time: 05:58)


Percentage ripple in output voltage

$$\% \Delta V_o = \frac{2.65}{400} = 0.6631\%$$

$$L_o = \frac{V_{in} \cdot D}{f_s \times \Delta I_L} = \frac{207 \cdot 0.4825}{20000 \times \Delta I_L} = 5 \times 10^{-3}$$

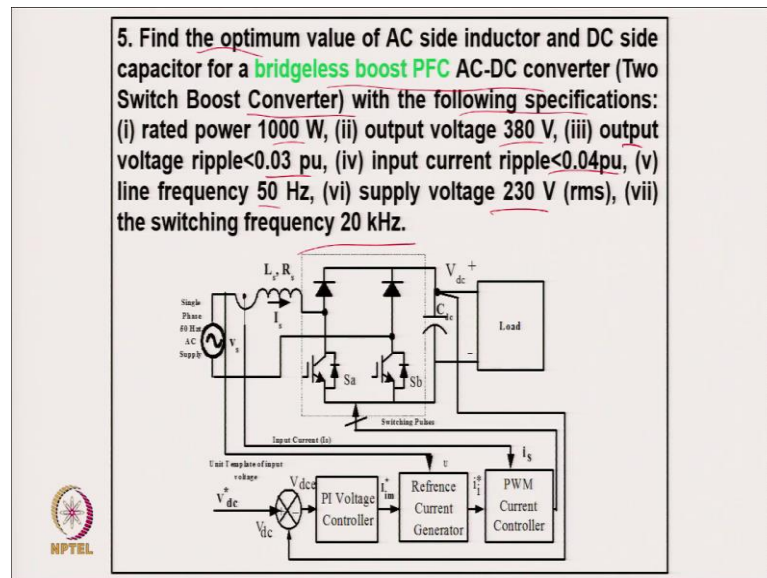
$$\Delta I_L = \frac{207 \cdot 0.4825}{20000 \times 5 \times 10^{-3}} = 1\text{A}$$

Percentage ripple in input current $\% \Delta I_i = \frac{1}{4.83} = 20.7\%$



The solution for Example-4 is given in the abovemention slides.

(Refer Slide Time: 06:19)



Coming to Example-5, find the optimum value of AC side inductor and DC side capacitor for bridgeless boost PFC converter (two switch boost converter) with the following specification, (i) rated power of 1000 W, (ii) output voltage 380 V, (iii) output ripples 3%, (iv) input current ripple 4%, (v) supply voltage of 230V/50 Hz and (vi) the switching frequency of 20 kHz.

(Refer Slide Time: 06:53)

Solution. Given that: $P_o=1000\text{W}$, $V_o=380\text{V}$, $\% \Delta V_o=3\%$, $\% \Delta I_i=4\%$, $V_s=230\text{V rms}$, $f_s=20\text{kHz}$, $f=50\text{Hz}$.

Rectified input voltage, $V_{in} = 0.9 \cdot V_s = 207\text{V}$

$$I_o = \frac{P_o}{V_o} = \frac{1000}{380} = 2.63\text{A} \quad I_i = \frac{P_o}{V_{in}} = \frac{1000}{207} = 4.83\text{A}$$

$$D = \frac{V_o - V_{in}}{V_o} = \frac{380 - 207}{380} = 0.455$$

$$C_d = \frac{I_o}{2\omega \Delta V_o} = \frac{2.63}{2 \times 314 \times 0.03 \times 380} = 367.36\mu\text{F}$$

$$L_n = \frac{V_{in} D}{f_s \times \Delta I_i} = \frac{207 \times 0.455}{20000 \times 0.04 \times 4.83} = 0.024\text{H}$$

The solution for Example-5 is given in the abovemention slides.

(Refer Slide Time: 07:41)

6. Calculate the value of (a) the output voltage ripple and (b) the inductor current ripple for a **two-switch boost PFC AC-DC converter (Bridgeless PFC Converter)** with the following specifications: (i) rated power 1000 W, (ii) output voltage 400 V, (iii) the DC side capacitor of 1500 μ F, (iv) the boost inductor of 5mH, (v) the line frequency 50 Hz, (vi) a supply voltage 230 V(rms), (vii) the switching frequency 20 kHz.

Coming to Example-6, calculate the value of (a) the output voltage ripple and (b) the input current ripple, of a two switch PFC boost AC-DC converter with a following specifications (i) rated power 1000 W, (ii) output voltage 400 V, (iii) DC side capacitor 1500 μ F, (iv) the boost inductor 5mH, (v) line frequency of 50 Hz and supply voltage of 230 V, and (vi) switching frequency 20 kHz.

(Refer Slide Time: 08:08)

Solution. Given that: $P_o=1000\text{W}$, $V_o=400\text{V}$, $V_s=230\text{V rms}$,
 $C_d=1500\mu\text{F}$, $L_o=5\text{mH}$, $f_s=20\text{kHz}$, $f=50\text{Hz}$, $V_{in} = 0.9 \cdot V_s = 207\text{V}$

$$I_o = \frac{P_o}{V_o} = \frac{1000}{400} = 2.5\text{A}$$

$$I_l = \frac{P_o}{V_{in}} = \frac{1000}{207} = 4.83\text{A} \quad R = \frac{V_o}{I_o} = 160\Omega$$

$$D = \frac{V_o - V_{in}}{V_o} = \frac{400 - 207}{400} = 0.4825$$

$$C_d = \frac{I_o}{2\omega\Delta V_o} = \frac{2.5}{2 \times 314 \times \Delta V_o}$$

(Refer Slide Time: 08:50)

Since the capacitor value is given. Hence,

$$1500 \times 10^{-6} = \frac{2.5}{2 \times 314 \times \Delta V_0}$$


$$\Delta V_0 = 2.65V$$

Percentage ripple in output voltage $\% \Delta V_0 = \frac{2.65}{400} = 0.6631\%$

$$L_{in} = \frac{V_o D}{f_s \times \Delta I_L} = \frac{207 \times 0.4825}{20000 \times \Delta I_L}$$

$$\Delta I_L = \frac{207 \times 0.4825}{20000 \times 5 \times 10^{-3}} = 0.99A$$

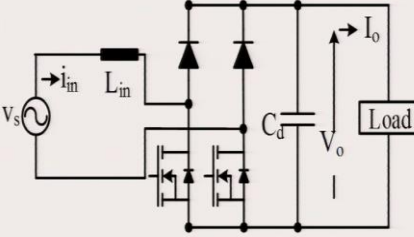

Percentage ripple in input current $\% \Delta I_L = \frac{0.99}{4.83} = 20.67\%$



The solution for Example-6 is given in the abovemention slides.

(Refer Slide Time: 09:07)

7. Find the value of (a) the AC side inductor and (b) the DC link capacitor for a **two-switch boost PFC AC-DC converter (Bridgeless)** with the following specification (i) the rated power 250 W, (ii) the output voltage 400V, (iii) the output voltage ripple <math><0.05 pu</math>, (iv) the line frequency 50 Hz, (v) the supply voltage 230 V (rms), (vi) the maximum switching frequency 20 kHz under the **boundary condition mode of conduction (BCM)** of the DC side inductor.

Coming to Example-7, find the value of (a) AC side inductor, and (b) the DC link capacitor of two switch boost PFC AC-DC converter with the following specification, (i) the rated power of 250 W, (ii) output voltage of 400 V, (iii) the output voltage ripple less than 5%, (iv) line frequency 50Hz, (v) the supply voltage 230 V, and (vi) the maximum switching frequency 20 kHz, under the boundary condition mode (BCM) of the DC side inductor of this bridgeless boost converter.

(Refer Slide Time: 09:35)

Solution. Given that: $P_o=250W$, $V_o=400V$, $f_s=20kHz$, $f=50Hz$


$$I_o = \frac{P_o}{V_o} = \frac{250}{400} = 0.625A$$

$$R = \frac{V_o}{I_o} = 640\Omega$$

$$D = \frac{V_o - V_n}{V_o} = \frac{400 - 207}{400} = 0.4825$$

For BCM the parameters are calculated as follows,

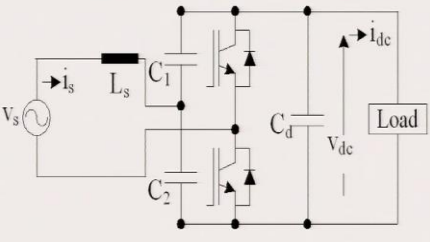

$$C_d = \frac{I_o}{2\omega\Delta V_c} = \frac{0.625}{2 \times 314 \times 0.05 \times 400} = 49.73\mu F$$

$$L_{min} = D \times (1-D)^2 \times \frac{R}{2f_s} = 0.4825 \times (1-0.4825)^2 \times \frac{640}{2 \times 20000} = 2.06mH$$


The solution for Example-7 is given in the abovemention slides.

(Refer Slide Time: 10:05)


8. A single-phase bi-directional boost PFC AC-DC half bridge converter (also known as voltage source converter, VSC) draws 1000 W from 230 V; 50 Hz mains for a resistive load. The switching frequency is 20 kHz and AC inductor is 3 mH. The power-factor is corrected close to unity and PWM modulation index is 0.8. Determine (a) an output DC voltage, (b) the value of resistance of DC load, (c) the AC mains current, and (d) the phase shift in fundamental component of PWM voltage and AC supply voltage.

Coming to the Example-8, a single phase bidirectional boost PFC AC-DC converter half bridge (also known as a voltage source converter, VSC) draws 1000 W from 230 V, 50Hz mains for a resistive load, the switching frequency 20 kHz, AC inductor is 3mH. The power factor is corrected close to unity and the modulation index is 0.8. Determine (a) the output DC voltage, (b) the value of resistance of DC load, (c) AC mains current, (d) phase shift of fundamental component of PWM voltage and AC supply current.

(Refer Slide Time: 10:36)

Solution. Given that: $P=1000\text{W}$, $V_s=230\text{V}$, 50Hz , power factor=1, $L_0=3\text{mH}$, $m=0.8$, $f_s=20\text{kHz}$.

$$I_{s1} = \frac{P}{V_s \cos\theta} = \frac{1000}{230 \times 1} = 4.34\text{A}$$
$$X_s = \omega L_s = 314 \times 3 \times 10^{-3} = 0.942\Omega$$
$$V_{\text{con}} = \sqrt{V_s^2 + V_{L1}^2} = 230.036\text{V}$$
$$V_{L1} = X_s \times I_{s1} = 0.942 \times 4.34 = 4.088\text{V}$$


(Refer Slide Time: 11:25)


For the half bridge AC-DC converter, the total DC link voltage is calculated as

$$V_{\text{dc}} = \frac{2 \cdot \sqrt{2} \times V_{\text{con}}}{m} = \frac{2 \cdot \sqrt{2} \times 230.036}{0.8} = 813.3\text{V}$$

The value of resistive DC load

$$R_{\text{dc}} = \frac{V_{\text{dc}}^2}{P} = \frac{813.3^2}{1000} = 661.5\Omega$$

The phase shift in fundamental component of PWM voltage and ac supply voltage

$$\delta = \sin^{-1} \left(\frac{X_s \times P}{V_s \times V_{\text{con}}} \right) = 1.02^\circ$$


The solution for Example-8 is given in the abovemention slides.

(Refer Slide Time: 11:40)

9. A single-phase VSC based AC-DC bridge converter (also known as Voltage Source Converter) is used in a solar PV grid interfaced system with power flow of 5000 W connected to a 230 V, 50 Hz mains. The switching frequency is 20 kHz and AC inductor is 2.5 mH. The power factor is corrected close to unity and maximum PWM modulation index is 1.0 to operate it in linear range. Determine (a) the minimum input solar PV array DC voltage for power flow from the DC solar PV array to the AC grid, (b) the AC mains current. Calculate (c) the power angle between the grid voltage and the fundamental voltage of VSC and the grid current.

Coming to Example-9, a single phase voltage source converter based AC-DC bridge converter is used in a solar power grid interface system with the power flow of 5000 W and connected to 230V/50Hz, the switching frequency 20 kHz and AC inductor 2.5 mH. The power factor is corrected close to unity and maximum power maximum PWM modulation index is one to operate in linear range. Determine (a) the minimum input solar PV array voltage for power flow from DC solar array to the AC grid (b) the AC mains current, (c) the power angle between the grid voltage and the fundamental voltage of the voltage source converter and the grid current.

(Refer Slide Time: 12:33)

Solution. Given that: $P=5000\text{W}$, $V_s=230\text{V}$, 50Hz , power factor=1.0, $L_s=2.5\text{mH}$, $m=1$, $f_s=20\text{kHz}$.

$$I_{s1} = \frac{P}{V_s \cos \theta} = \frac{5000}{230 \times 1} = 21.739\text{A}$$

$$X_s = \omega L_s = 314 \times 2.5 \times 10^{-3} = 0.785\Omega$$

$$V_{L1} = X_s \times I_{s1} = 17.065\text{V}$$

$$V_{con} = \sqrt{V_s^2 + V_{L1}^2} = 230.63\text{V}$$

The DC link voltage $V_{dc} = \frac{\sqrt{2} \times V_{con}}{m} = \frac{\sqrt{2} \times 230}{1} = 326.16$ ✓

The phase shift in fundamental component of PWM voltage and ac supply voltage


$$\delta = \sin^{-1} \left(\frac{X_s \times P}{V_s \times V_{con}} \right) = 4.24^\circ$$

The solution for Example-9 is given in the abovemention slides.

(Refer Slide Time: 13:33)

10. A single-phase bi-directional boost PFC AC-DC bridge converter (also known as Voltage Source Converter, VSC) has power flow of 4000 W in either direction for battery energy storage system (BESS) of 360 V connected to a 230 V, 50 Hz mains. The switching frequency is 20 kHz and AC inductor is 3.5 mH. The power-factor is corrected close to unity. The converter is controlled in such a way that AC mains current is either in phase or out of phase from AC mains voltage. Determine modulation indices under charging and discharging modes at full power. Calculate the power angle between the grid voltage and fundamental voltage of VSC and the grid current in both modes of charging and discharging of the battery at full power.

Solution. Given that: $P=4000\text{W}$, $V_s=230\text{V}$, 50Hz , power factor=1.0, $V_{dc}=360$.



Coming to Example-10, a single phase bidirectional PFC boost AC-DC bridge converter has a power flow of 4000 W in either direction for battery energy storage system of 360 V connected to the 230V/50Hz mains and switching frequency of 20 kHz and AC inductor is 3.5 mH. The power factor is corrected to close to unity and converter is controlled in such a way that AC mains current is either in phase or out of phase from the AC mains voltage. Determine the modulation indices under the charging and recharging mode at full power. Calculate the power angle between the grid voltage and the fundamental voltage of the voltage source converter and the grid current in both mode charging and discharging.

(Refer Slide Time: 14:25)

$$I_{s1} = \frac{P}{V_s \cos\theta} = \frac{4000}{230 \times 1} = 17.39\text{A}$$

$$X_s = \omega L_s = 314 \times 3.5 \times 10^{-3} = 1.099\Omega$$

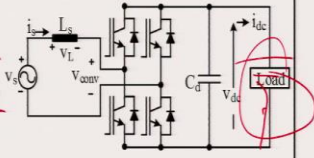

$$V_{L1} = X_s \times I_{s1} = 1.099 \times 17.39 = 19.11\text{V}$$

$$V_{con} = \sqrt{V_s^2 + V_{L1}^2} = 230.79\text{V}$$

The DC link voltage $V_{dc} = \frac{\sqrt{2} \times V_{con}}{m}$

$$m = \frac{\sqrt{2} \times V_{con}}{V_{dc}} = 0.9066$$

The phase shift in fundamental component of PWM voltage and ac supply voltage

$$\delta = \sin^{-1} \left(\frac{X_s \times P}{V_s \times V_{con}} \right) = 4.75^\circ$$



The solution for Example-10 is given in the abovemention slides.

(Refer Slide Time: 15:31)

12. Design a single-phase power-factor corrected AC-DC forward boost converter in CCM (Continuous Current Mode of conduction approach) with high frequency transformer isolation operating at 50 kHz with following specifications: input: $V_i=100V-140V$ rms with nominal $120V$, 50Hz, single-phase AC supply, DC output: $V_o=160V-270 V$ adjustable with nominal value of $230 V$, $P_o=450 W$ with output voltage-ripple less than 2%.

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Coming to Example-11, design a single phase power factor corrected AC-DC forward boost converter in continuous conduction mode with the high frequency transformer isolation operating at 50 kHz with the following specifications, the input voltage varies from 100 V to 140 V RMS and nominal voltage of 120 V/50Hz, single phase AC supply and DC output 160 V- 270 V adjustable with the nominal voltage of 230 V and 450 W with the output voltage ripple of less than 2%.

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Solution. For forward boost converter, the output voltage equation is given as,
 Given that $V_o=160-270V$
 And the nominal output voltage, $V_{onom} = 230 V$
 And the nominal input voltage, $V_{inom} = 120 V$
 Rectified voltage range is from $V_{in1} = 0.9 \cdot 100 = 90 V$ to $V_{in2} = 0.9 \cdot 140 = 126 V$


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$P_o = 450\text{W}$, and $I_o = \frac{P_o}{V_o} = \frac{450}{230} = 1.95\text{A}$ $R_o = \frac{V_o}{I_o} = \frac{230}{1.95} = 117.75\Omega$
 $I = \frac{P_o}{V_i} = \frac{450}{0.9 \times 120} = 4.16\text{A}$
 The output voltage is given by $V_o = \frac{V_m(N_2/N_1)}{(1-D)}$
 Hence, the range of duty-cycle, $0.05 \leq D \leq 0.95$
 Now, to find out the turns ratio, $D=0.95$ is taken for maximum output voltage, $V_o=270$ and minimum rectified voltage $V_{m1}=90\text{V}$.
 Hence, $\frac{270}{90} = \frac{(N_2/N_1)}{1-0.95} \Rightarrow \frac{N_2}{N_1} = 0.15 \approx 1$
 Now put the ratio for minimum output voltage, $V_o=160\text{V}$ and maximum rectified voltage, $V_{m2}=126\text{V}$.
 $\frac{160}{126} = 1 \times \frac{1}{1-D}$

(Refer Slide Time: 16:36)



$D = 0.78$, which is greater than the minimum duty-ratio.
 Hence, turns-ratio is taken equal to 1
 Hence, $V_o = \frac{V_m \times 1}{(1-D)} \Rightarrow \frac{230}{0.9 \times 120} = \frac{1}{(1-D)} \Rightarrow D = 0.53$
 Now the design parameters are calculated for CCM as,
 $L_i = \frac{V_m D}{f_s \Delta i_m} = \frac{108 \times 0.53}{50000 \times 0.05 \times 4.16} = 5.50\text{mH}$
 $L_{\text{min}} = \frac{V_m D}{f_s \Delta i_o} = \frac{108 \times 0.53}{50000 \times 0.05 \times 1.95} = 11.74\text{mH}$
 The design of DC link capacitor is given as,
 $C_o = \frac{P_o}{2\omega \delta V_{\text{avg}}^2} = \frac{450}{2 \times 314.15 \times 0.02 \times 160^2} = 1.4\text{mF}$

The solution for Example-11 is given in the abovemention slides.

(Refer Slide Time: 16:51)

13. Design a single-phase power-factor corrected AC-DC half-bridge boost converter in DCM (Discontinuous Current Mode of operation also known as voltage follower approach) with high frequency transformer isolation operating at 50 kHz with following specifications: input: $V_i = 100\text{ V} - 140\text{ V}$ rms with nominal value 120V, 50Hz, single-phase AC supply, DC output: $V_o = 160\text{V} - 270\text{V}$ adjustable with nominal value of 230 V, $P_o = 200\text{ W}$ with output voltage-ripple less than 2%.

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Coming to the Example-12, design a single phase power factor corrected half bridge boost converter in discontinuous mode with high frequency transformer isolation operating at 50 kHz with the following specification, input voltage of 100 V to 140 V RMS with the nominal voltage of 120V/50Hz single phase AC supply, DC output is 160 V – 270 V with nominal value of 230 V and power output 200 W with output voltage ripple less than 2%.

(Refer Slide Time: 17:24)

Solution. Given that $V_o = 160 - 270\text{V}$
And the nominal output voltage, $V_{\text{onom}} = 230\text{ V}$
And the nominal input voltage, $V_{\text{inom}} = 120\text{ V}$
Rectified voltage range is from $V_{\text{in1}} = 0.9 \times 100 = 90\text{ V}$ to $V_{\text{in2}} = 0.9 \times 140 = 126\text{ V}$

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$P_o = 200 \text{ W}$, and $I_o = \frac{P_o}{V_o} = \frac{200}{230} = 0.8695 \text{ A}$ $R_o = \frac{V_o}{I_o} = \frac{230}{0.8695} = 264.5 \Omega$

$I = \frac{P_o}{V_i} = \frac{200}{0.9 \times 120} = 1.85 \text{ A}$

The output voltage is given by $V_o = \frac{V_m (N_2/N_1)}{2(1-D)}$


Hence, the range of duty-cycle, $0.52 \leq D \leq 0.95$

Now, to find out the turns ratio, $D=0.95$ is taken for maximum output voltage, $V_o=270$ and minimum rectified voltage $V_{m1}=90\text{V}$.

Hence, $\frac{270}{90} = \frac{(N_2/N_1)}{2(1-0.95)} \rightarrow \frac{N_2}{N_1} = 0.3 \approx 1$

Now put the ratio for minimum output voltage, $V_o=160\text{V}$ and maximum rectified voltage, $V_{m2}=126\text{V}$.

$\frac{160}{126} = 1 \times \frac{1}{2(1-D)}$



(Refer Slide Time: 18:29)

$D = 0.6$, which is greater than the minimum duty-ratio. Hence, turns-ratio is taken equal to 1


Hence, $V_o = \frac{V_m \times 1}{2(1-D)} \rightarrow \frac{230}{0.9 \times 120} = \frac{1}{2(1-D)} \Rightarrow D = 0.7652$

Now the design parameters are calculated as,

$L_{min} = \frac{(1-0.7652)^2 \times 264.5}{2 \times 50000 \times 1^2} = 145.8 \mu\text{H}$

Hence the inductance has the value less than the calculated value to ensure DCM.

$C_o = \frac{P_o}{2\omega \delta V_{o\min}^2} = \frac{200}{2 \times 314.15 \times 0.02 \times 160^2} = 622 \mu\text{F}$



The solution for Example-12 is given in the abovemention slides.

(Refer Slide Time: 19:02)

15. Design a single-phase power-factor corrected AC-DC half-bridge boost converter in CCM (Continuous Current Mode of conduction approach) with high frequency transformer isolation operating at 50 kHz with following specifications: input: $V_i=100-140$ V rms with nominal value 120V, 50Hz, single-phase AC supply, DC output: $V_o=160-270$ V adjustable with nominal value of 230 V, $P_o=350$ W with output voltage-ripple less than 2%.

NPTEL

Coming to Example-13, design a single phase power factor corrected half bridge boost converter in CCM with the high frequency transformer isolation operating 50 kHz with the following specifications, input voltage of 100 V–140 V RMS with the nominal voltage of 120 V/50 Hz single phase AC supply, output DC voltage of 160 V-270 V with nominal voltage of 230 V, output power 350 W and output ripple less than 2%.

(Refer Slide Time: 19:36)

Solution. Given that $V_o=160-270$ V

And the nominal output voltage, $V_{onom} = 230$ V

And the nominal input voltage, $V_{inom} = 120$ V

Rectified voltage range is from $V_{in1} = 0.9 \cdot 100 = 90$ V to $V_{in2} = 0.9 \cdot 140 = 126$ V

NPTEL

(Refer Slide Time: 19:52)

$P_o = 350 \text{ W}$, and $I_o = \frac{P_o}{V_o} = \frac{350}{230} = 1.521 \text{ A}$
 $I_i = \frac{P_o}{V_i} = \frac{350}{0.9 \times 120} = 3.24 \text{ A}$


The output voltage is given by $V_o = \frac{V_{in}(N_2/N_1)}{2(1-D)}$

Where, the range of duty-cycle, $0.52 \leq D \leq 0.95$

Now, to find out the turns ratio, $D=0.95$ is taken for maximum output voltage, $V_o=270$ and minimum rectified voltage $V_{in1}=90\text{V}$.

Hence, $\frac{270}{90} = \frac{(N_2/N_1)}{2(1-0.95)} \rightarrow \frac{N_2}{N_1} = 0.3 \approx 1$

Now put the ratio for minimum output voltage, $V_o=160\text{V}$ and maximum rectified voltage, $V_{in2}=126\text{V}$

$$\frac{160}{126} = 1 \times \frac{1}{2(1-D)}$$


(Refer Slide Time: 20:26)


$D = 0.6$, which is greater than the minimum duty-ratio.
 Hence, turns-ratio is taken equal to 1

Hence, $V_o = \frac{V_{in} \times 1}{2(1-D)} \Rightarrow \frac{230}{0.9 \times 120} = \frac{1}{2(1-D)} \Rightarrow D = 0.7652$

Now the design parameters are calculated as,

$$L_{min} = \frac{V_o D}{4f_s \Delta i_o} = \frac{108 \times 0.7652}{4 \times 50000 \times 0.05 \times 3.24} = 2.55 \text{ mH}$$

Hence the inductance has this value to ensure CCM.

$$C_o = \frac{P_o}{2\omega \delta V_{omr}^2} = \frac{350}{2 \times 314.15 \times 0.02 \times 160^2} = 1.1 \text{ mF}$$


The solution for Example-13 is given in the above mention slides.

(Refer Slide Time: 20:55)

17. Design a single-phase power-factor corrected AC-DC push-pull boost converter in DCM (Discontinuous Current Mode of operation also known as voltage follower approach) with high frequency transformer isolation operating at 50 kHz with following specifications: input: $V_i=100\text{ V}-140\text{ V}$ rms with 120V nominal, 50Hz, single-phase AC supply, DC output: $V_o=160\text{ V}-270\text{ V}$ adjustable with nominal value of 230 V, $P_o=1500\text{ W}$ with output voltage-ripple less than 2%.

The diagram shows a power-factor corrected AC-DC converter. It starts with an AC input source connected to a series inductor L_s . The current i_s flows through L_s and a diode bridge rectifier. The output of the rectifier is connected to a boost inductor L . The other end of L is connected to a push-pull bridge consisting of two MOSFETs. The secondary winding of a high-frequency transformer (labeled 'HF Isolation') is connected to the bridge. The primary winding has N_1 turns, and the secondary has N_2 turns. The secondary-side diode current is i_d . The output of the transformer is connected to a filter capacitor C_c and a load. The output voltage is V_o . A feedback loop is shown with a voltage divider (resistors V_c and V_{ref}) and a Voltage Controller connected to a PWM Pulse Generator.

Coming to Example-14, design a single phase power factor corrected push pull boost converter in DCM with the high frequency transformer isolation operating at 50 kHz with the following specification, input voltage: 100 V-140 V with the nominal rating of 120V/50Hz single phase AC supply, DC voltage of 160 V-270 V with nominal voltage of 230 V and output power of 1500 W with the voltage ripples less than 2%.

(Refer Slide Time: 21:27)

Solution. Given that $V_o=160-270\text{ V}$

And the nominal output voltage, $V_{\text{nom}} = 230\text{ V}$

And the nominal input voltage, $V_{\text{in}} = 120\text{ V}$

Rectified voltage range is from $V_{\text{in1}} = 0.9 \cdot 100 = 90\text{ V}$ to $V_{\text{in2}} = 0.9 \cdot 140 = 126\text{ V}$

The slide contains handwritten text in red ink providing the solution to the design problem. It lists the given output voltage range, nominal output voltage, nominal input voltage, and the resulting rectified voltage range. The NPTEL logo is visible in the bottom left corner.

(Refer Slide Time: 21:44)

$P_o = 1500 \text{ W}$, and $I_o = \frac{P_o}{V_o} = \frac{1500}{230} = 6.52 \text{ A}$
 $I = \frac{P_o}{V_i} = \frac{1500}{0.9 \times 120} = 13.88 \text{ A}$


The output voltage is given by $V_o = \frac{V_{in}(N_2/N_1)}{2(1-D)}$

Hence, the range of duty-cycle, $0.52 \leq D \leq 0.95$
 Now, to find out the turns ratio, $D=0.95$ is taken for maximum output voltage, $V_o=270$ and minimum rectified voltage $V_{in1}=90\text{V}$.

Hence, $\frac{270}{90} = \frac{(N_2/N_1)}{2(1-0.95)} \Rightarrow \frac{N_2}{N_1} = 0.3 \approx 1$

Now put the ratio for minimum output voltage, $V_o=160\text{V}$ and maximum rectified voltage, $V_{in2}=126\text{V}$.

$\frac{160}{126} = 1 \times \frac{1}{2(1-D)}$



(Refer Slide Time: 22:17)

$D = 0.6$, which is greater than the minimum duty-ratio.
 Hence, turns-ratio is taken equal to 1


Hence, $V_o = \frac{V_{in} \times 1}{2(1-D)} \Rightarrow \frac{230}{0.9 \times 120} = \frac{1}{2(1-D)} \Rightarrow D = 0.7652$

Now the design parameters are calculated as,

$L_{min} = \frac{(1-0.7652)^2 \times 35.27}{2 \times 50000 \times 1^2} = 19.44 \mu\text{H}$

Hence the value of inductance should be less than the rated value to ensure DCM.

$C_o = \frac{P_o}{2\omega \delta V_{o\min}^2} = \frac{1500}{2 \times 314.15 \times 0.02 \times 160^2} = 4.67 \text{ mF}$



The solution for Example-14 is given in the above mention slides.

(Refer Slide Time: 22:48)

20. Design a single-phase power-factor corrected AC-DC bridge boost converter in DCM (Discontinuous Current Mode of operation also known as voltage follower approach) with high frequency transformer isolation operating at 50 kHz with following specifications: input: $V_i=100\text{ V}-140\text{ V rms}$, 50Hz, single-phase AC supply, DC output: $V_o=160\text{V}-270\text{ V}$ adjustable with nominal value of 220 V, $P_o=500\text{ W}$ with output voltage-ripple less than 2%.

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Coming to Example-15, design a single phase PFC AC-DC bridge boost converter in DCM with the high frequency transformer isolation at 50 kHz with the following specifications, input voltage of 100 V – 140 V, 50Hz single phase AC supply, DC output voltage equal to 160 V – 270 V at 500 W with output voltage less than 2%.

(Refer Slide Time: 23:18)

Solution. Given that $V_o=160-270\text{V}$
And the nominal output voltage, $V_{\text{onom}} = 220\text{ V}$
And the nominal input voltage, $V_{\text{inom}} = 120\text{ V}$
Rectified voltage range is from $V_{\text{in1}} = 0.9 \cdot 100 = 90\text{ V}$ to $V_{\text{in2}} = 0.9 \cdot 140 = 126\text{ V}$

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(Refer Slide Time: 23:42)

$P_o = 500 \text{ W}$, and $I_o = \frac{P_o}{V_o} = \frac{500}{220} = 2.27 \text{ A}$ $I_i = \frac{P_o}{V_i} = \frac{500}{0.9 \times 120} = 4.6296 \text{ A}$
 $I_{\text{ripple}} = 0.05 \times 2.27 = 0.1135 \text{ A}$

The output voltage is given by $V_o = \frac{V_{in}(N_2/N_1)}{2(1-D)}$


Hence, the range of duty-cycle $0.55 \leq D \leq 0.95$

Now, to find out the turns ratio, $D=0.95$ is taken for maximum output voltage, $V_o=270$ and minimum rectified voltage $V_{in1}=90\text{V}$.

Hence, $\frac{270}{90} = \frac{(N_2/N_1)}{2(1-0.95)} \rightarrow \frac{N_2}{N_1} = 0.3 \approx 1$

Now put the ratio for minimum output voltage, $V_o=160\text{V}$ and maximum rectified voltage, $V_{in2}=126\text{V}$.

$\frac{160}{126} = 1 \times \frac{1}{2(1-D)}$



(Refer Slide Time: 24:25)

$D = 0.6$, which is greater than the minimum duty-ratio.
Hence, turns-ratio is taken equal to 1


Hence, $V_o = \frac{V_{in} \times 1}{2(1-D)} \Rightarrow \frac{220}{0.9 \times 120} = \frac{1}{2(1-D)} \Rightarrow D = 0.7545$

Now the design parameters are calculated as,

$L_{\text{min}} = \frac{(1-0.7545)^2 \times 96.91}{2 \times 50000 \times 1^2} = 58.40 \mu\text{H}$

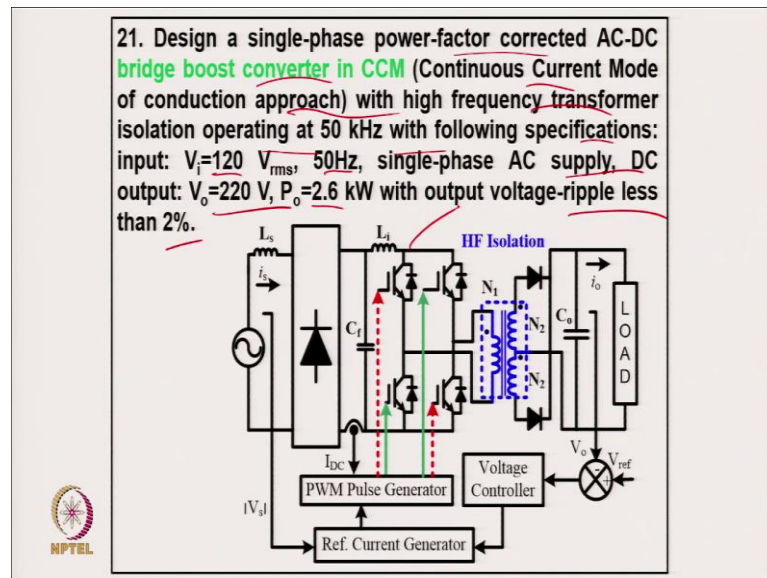
Hence the value of inductance should be less than the rated value to ensure DCM.

$C_o = \frac{P_o}{2\omega \delta V_{\text{omin}}^2} = \frac{500}{2 \times 314.15 \times 0.02 \times 160^2} = 1.56 \text{ mF}$



The solution for Example-15 is given in the above mention slides.

(Refer Slide Time: 24:52)



Coming to Example-16, design a single phase power factor corrected AC-DC bridge boost converter in CCM with the high frequency transformer isolation operating at 50kHz with the following specifications, input voltage of 120 V/50 Hz single phase AC supply, output voltage of 220 V at power of 2.6 kW with the output voltage ripple of 2%.

(Refer Slide Time: 25:20)

Solution. Given that $\Delta V_o = 0.02 \times 220 = 4.4\text{ V}$ $P_o = 2600\text{ W}$

And the nominal output voltage, $V_{\text{onom}} = 220\text{ V}$

And the nominal input voltage, $V_{\text{inom}} = 120\text{ V}$

Rectified voltage range is $V_{\text{in}} = 0.9 \times 120 = 108\text{ V}$.

$$I_o = \frac{P_o}{V_o} = \frac{2600}{220} = 11.81\text{ A}$$

$$I_i = \frac{P_o}{V_i} = \frac{2600}{0.9 \times 120} = 24.07\text{ A}$$

(Refer Slide Time: 25:48)

The output voltage is given by $V_o = \frac{V_{in} (N_2/N_1)}{2(1-D)}$

Hence, the range of duty-cycle $0.55 \leq D \leq 0.95$

Now, the turns ratio at $D=0.95$ is given as,


$$\frac{220}{108} = \frac{(N_2/N_1)}{2(1-0.95)} \rightarrow \frac{N_2}{N_1} = 0.2$$

Similarly, the turns ratio at $D=0.55$ is given as,

$$\frac{220}{108} = \frac{(N_2/N_1)}{2(1-0.55)} \rightarrow \frac{N_2}{N_1} = 1.83$$

Hence design of boost converter.

For $D = 0.55$, $L_1 = \frac{(D-0.5)V_{in}}{f_s \Delta I_m} = \frac{(0.55-0.5) \times 108}{50000 \times 24.07 \times 0.05} = 89.73 \mu\text{H}$




(Refer Slide Time: 26:16)

For $D = 0.95$,

$$L_1 = \frac{(D-0.5)V_{in}}{f_s \Delta I_m} = \frac{(0.95-0.5) \times 108}{50000 \times 24.07 \times 0.05} = 807.64 \mu\text{H}$$

Hence to ensure CCM, the value of $L_1 = 1\text{mH}$ is selected.

$$C_o = \frac{I_o}{2\omega \Delta V_o} = \frac{11.81}{2 \times 314.15 \times 4.4} = 4.27\text{mF}$$


The solution for Example-16 is given in the above mention slides.

(Refer Slide Time: 26:32)


22. Design a single-phase power-factor corrected AC-DC bridge boost converter in BCM (Boundary Condition Mode of conduction approach) with high frequency transformer isolation operating at 50 kHz with following specifications: input: $V_i=120$ V_{rms}, 50Hz, single-phase AC supply, DC output: $V_o=230$ V, $P_o=1.5$ kW with output voltage-ripple less than 2%.

Sol. Given that $\Delta V_o=0.02 \times 230=4.6$ V $P_o = 1500$ W

And the nominal output voltage, $V_{onom} = 230$ V

And the nominal input voltage, $V_{inom} = 120$ V

Rectified voltage range is $V_{in} = 0.9 \times 120 = 108$ V.

$$I_o = \frac{P_o}{V_o} = \frac{1500}{230} = 6.52 \text{ A} \qquad I_i = \frac{P_o}{V} = \frac{1500}{0.9 \times 120} = 13.89 \text{ A}$$


Coming to Example-17, a single phase power factor corrected AC-DC bridge boost converter in BCM with the high frequency transformer isolation operating 50kHz with the following specifications, input voltage of 120V/50 Hz single phase AC supply, and DC voltage of 230V and output power 1.5 kW with output ripple of 2%.

(Refer Slide Time: 27:21)

The output voltage is given by $V_o = \frac{V_{in} (N_2/N_1)}{2(1-D)}$

Hence, the range of duty-cycle $0.55 \leq D \leq 0.95$

Now, the turns ratio at $D=0.95$ is given as,


$$\frac{230}{108} = \frac{1}{2} \times \frac{(N_2/N_1)}{1-0.95} \Rightarrow \frac{N_2}{N_1} = 0.21$$

Similarly, the turns ratio at $D=0.55$ is given as,

$$\frac{230}{108} = \frac{1}{2} \times \frac{(N_2/N_1)}{1-0.55} \Rightarrow \frac{N_2}{N_1} = 1.91$$

Hence design of boost converter

For $D = 0.55$, $L_{min} = \frac{(1-0.55)^2 \times 35.27}{2 \times 50000 \times 1.91^2} = 19.57 \mu\text{H}$




(Refer Slide Time: 27:51)

For $D = 0.95$,

$$L_{\min} = \frac{(1-0.95)^2 \times 85.27}{2 \times 50000 \times 0.2129^2} = 19.45 \mu\text{H}$$

Hence to ensure BCM, the value of $L_{\min} = 19.45 \mu\text{H}$ is selected.


$$C_o = \frac{I_o}{2\omega \Delta V_o} = \frac{6.52}{2 \times 314.15 \times 4.6} = 2.25 \text{mF}$$


The solution for Example-17 is given in the above mention slides.

(Refer Slide Time: 28:12)

Summary


- The major shortcomings of conventional AC-DC converters like high current and voltage distortions, low efficiency, and heavy AC/DC filters are resolved by employing improved power quality converters (IPQC).
- The IPQC is classified based on the type of power converter topology, nature of the supply system, and control of power circuitry. Further, a comprehensive analysis of various control algorithms of IPQC is presented.
- The operational analysis of various types of single phase unidirectional/bidirectional boost converter IPQC's are discussed with their design procedure.
- A number of practical examples of boost IPQC are given with a view of proper design exposure while considering improved power quality performance.



With this, we would like to summarize, the major short comings of the conventional AC-DC converter like high current and voltage distortion, lower efficiency and heavy AC-DC filters are resolved by employing the improved power quality converters, and the improved power quality converter is classified based on the type of power converter topology, nature of supply system and control of power circuitry.

Further a comprehensive analysis of various control algorithm of IPQCs are presented here and operational analysis of various type of single phase unidirectional, bidirectional boost IPQCs are discussed with the design procedure and number of practical examples of boost improve power quality converters are given with the view of proper design exposure while considering the improved power quality performance.


(Refer Slide Time: 28:59)



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These are the references.

Thank you.