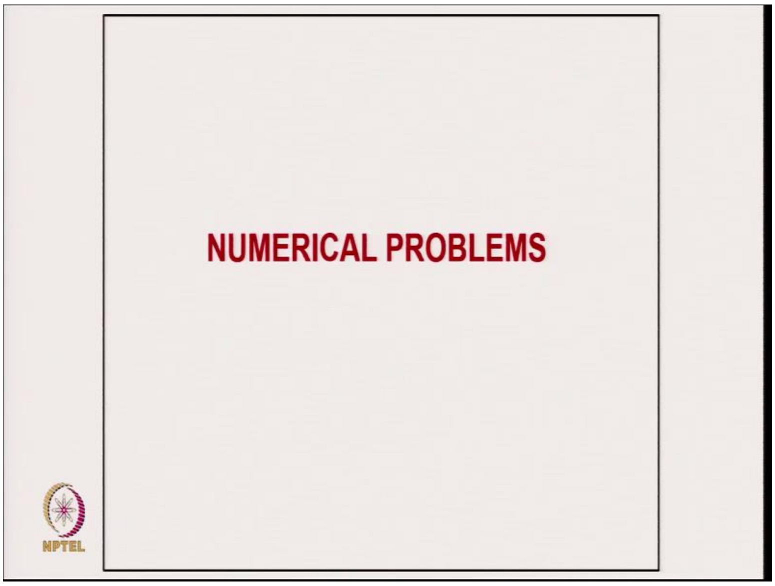
Power Quality
Prof. Bhim Singh
Department of Electrical Engineering
Indian Institute of Technology, Delhi

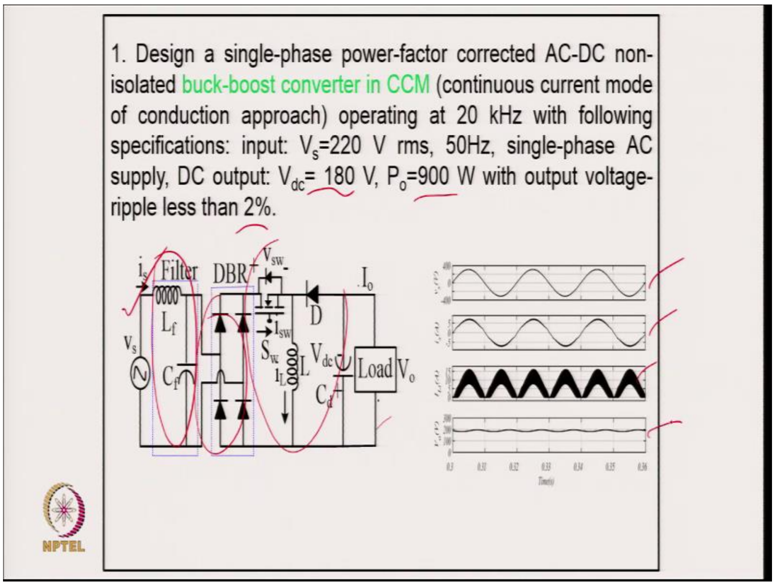
Numerical Problem
Lecture - 35
Improved Power Quality Converters - AC-DC Buck-Boost Converters (Contd.)

(Refer Slide Time: 00:17)



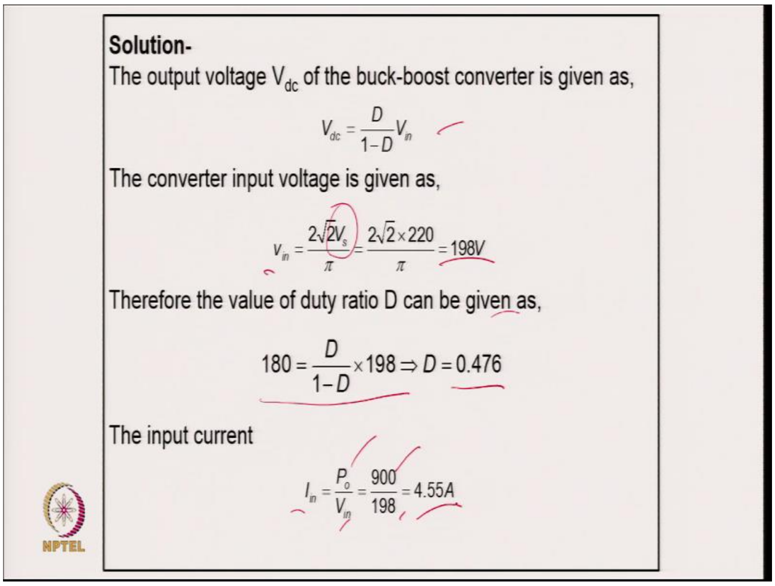
Welcome to the course on Power Quality. We will discuss the numerical examples on the single-phase power factor corrected buck-boost converter.

(Refer Slide Time: 00:36)

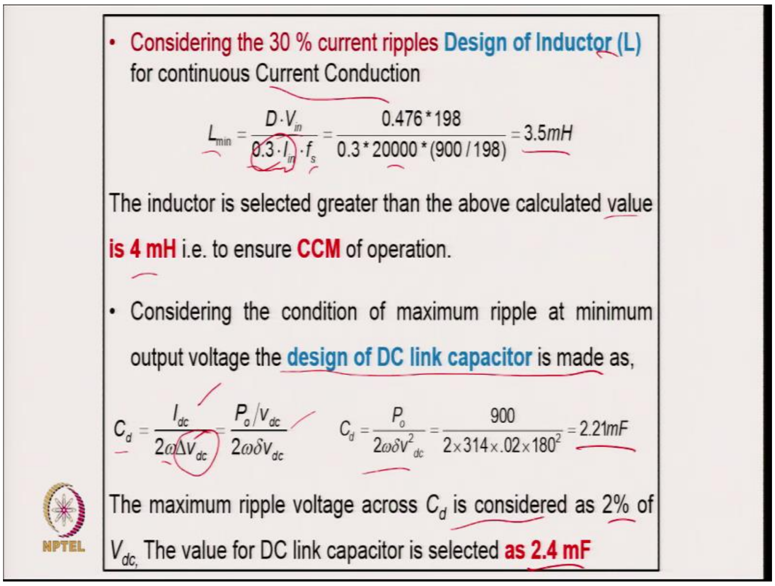


Starting with the first problem. Design a single-phase power-factor corrected AC-DC non-isolated buck-boost converter in continuous conduction mode operating at 20 kHz with the following specifications: Input voltage = 220 V RMS, frequency of 50 Hz, single-phase AC supply, the DC output of 180 V and power output 900 W with the output voltage-ripple less than 2 %.

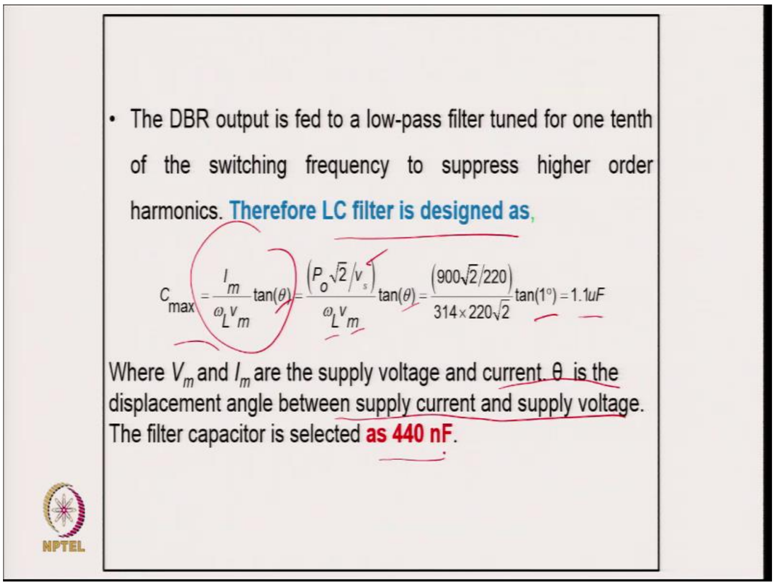
(Refer Slide Time: 01:47)



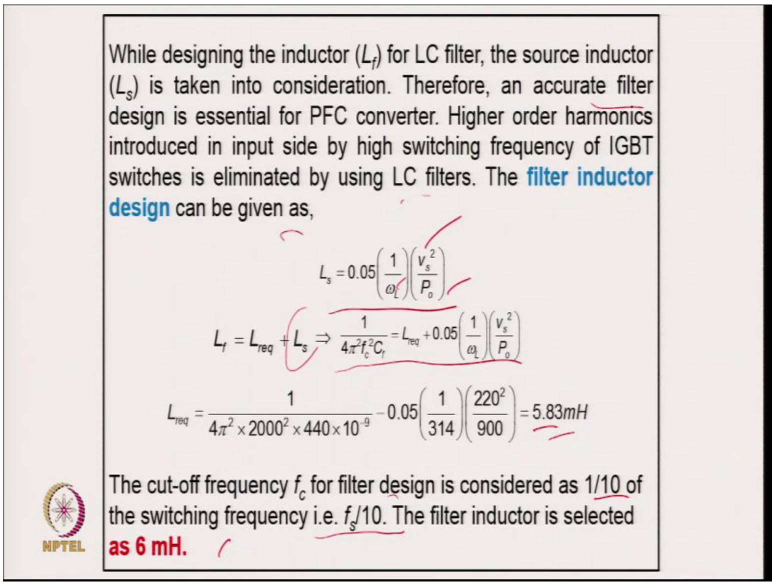
(Refer Slide Time: 02:45)



(Refer Slide Time: 04:05)



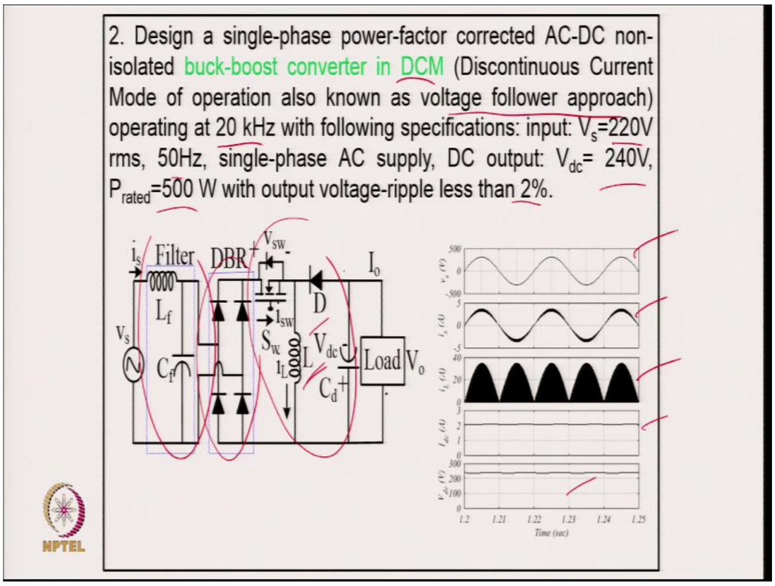
(Refer Slide Time: 04:57)



While the designing the filter inductor, the source inductor is taken into consideration. An accurate filter design is essential for power factor correction converter, as the higher order harmonics induced at supply by the switching of solid state switch is eliminated by the LC filter.

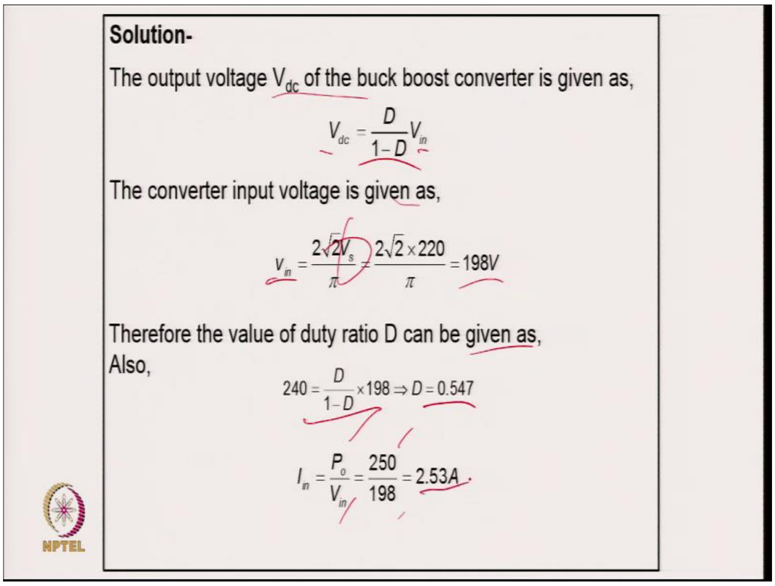
The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 06:03)

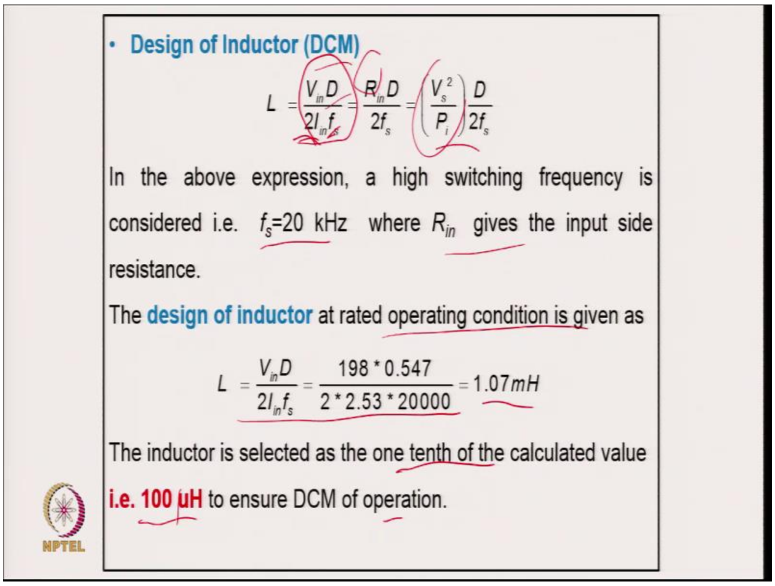


Coming to the 2[nd] example. Design a single-phase power factor corrected AC-DC non-isolated buck-boost converter in discontinuous current mode operation, operating at 20 kHz with the following specifications: Input voltage of 220 V, 50 Hz, single-phase supply, and DC output of 240 V, and power related is 500 W with the output voltage-ripple of less than 2%.

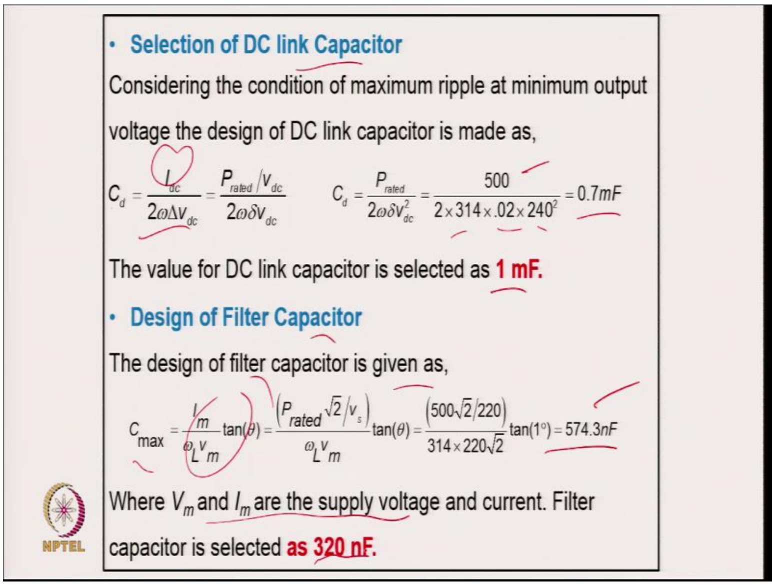
(Refer Slide Time: 07:27)



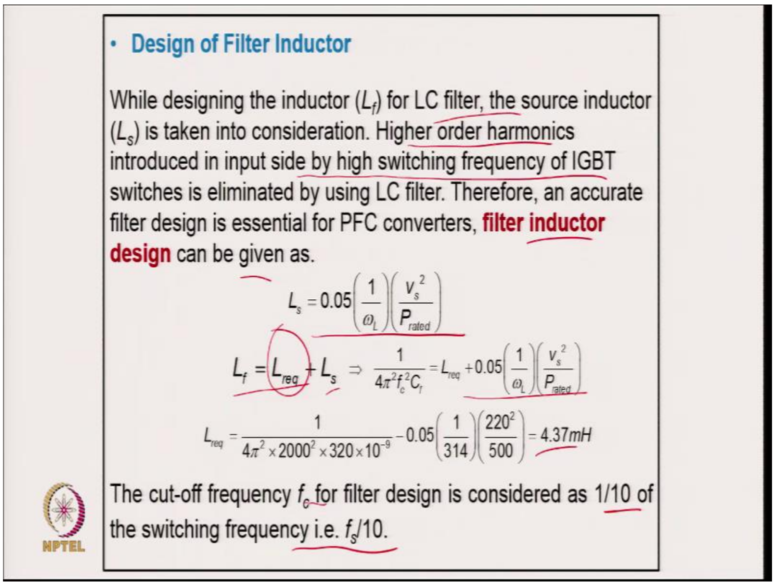
(Refer Slide Time: 08:26)



(Refer Slide Time: 09:49)

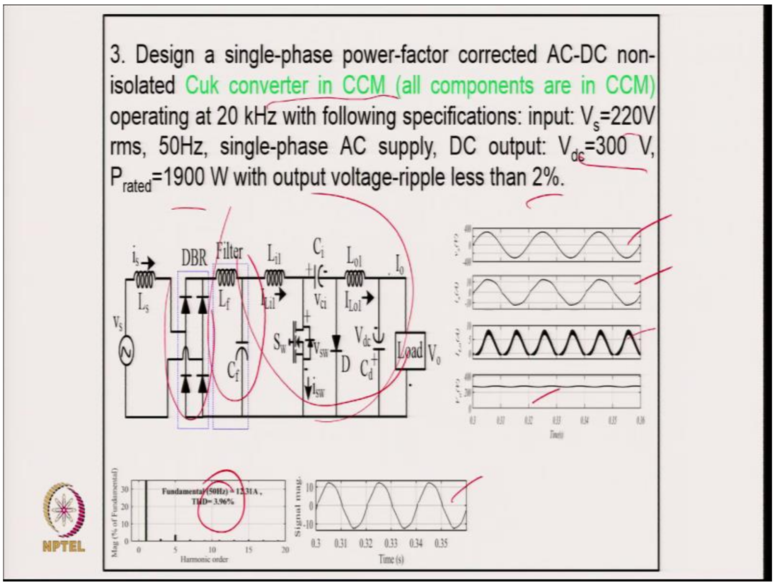


(Refer Slide Time: 10:54)



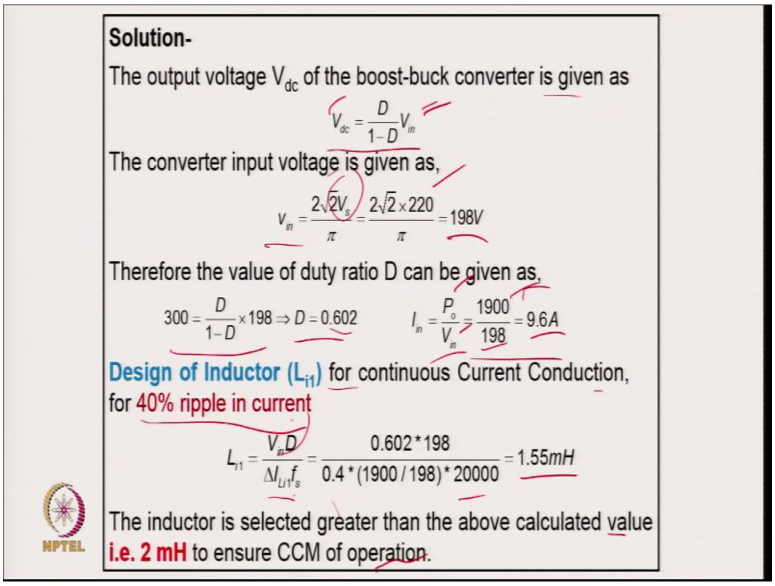
The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 11:42)



Coming to the 3rd example. Design a single-phase power factor corrected AC-DC non-isolated Cuk converter operating in continuous conduction mode at 20 kHz with the following specification: Supply voltage = 220 V/50 Hz, single-phase AC supply, and DC output voltage 300 V, and power is 1900 W with output ripple of 2%.

(Refer Slide Time: 13:06)



(Refer Slide Time: 15:01)

Design of Inductor (L_{o1}) for continuous Current Conduction, for **30% ripple in current**

$$L_{o1} = \frac{V_{dc}(1-D)}{\Delta I_{Lo1} f_s} = \frac{300*(1-0.602)}{0.3*(1900/300)*20000} = 3.14mH$$

The inductor is selected **as 3.5 mH** to ensure CCM of operation.

The voltage across the capacitor C_1 is given as,

$$V_{C1} = \frac{V_{in}}{(1-D)} = \frac{198}{0.4} = 495$$

Considering the condition of 10% ripple, **the design of intermediate capacitor C_1** is made as,

$$C_1 = \frac{I_{in}(1-D)}{\Delta V_{C1} f_s} = \frac{9.6*(1-0.602)}{0.1*495*20000} = 3.9\mu F$$

The value for intermediate capacitor is selected **as 4 uF**

(Refer Slide Time: 16:36)

Considering the condition of maximum ripple at minimum output voltage the **design of DC link capacitor** is made as,

$$C_d = \frac{I_{dc}}{2\omega\Delta V_{dc}} = \frac{P_{rated}/V_{dc}}{2\omega\delta V_{dc}} \quad C_d = \frac{P_{rated}}{2\omega\delta V^2_{dc}} = \frac{1900}{2\times 314\times .02\times 300^2} = 1.68mF$$

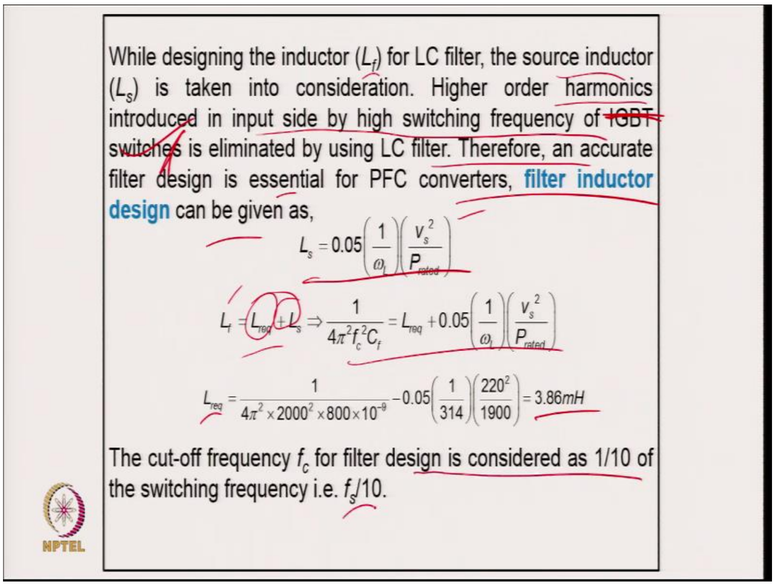
The maximum ripple voltage across C_d is considered as 2% of $V_{dc,}$ The value for DC link capacitor is selected **as 2 mF.**

The DBR output is fed to a low-pass filter tuned for one tenth of the switching frequency to suppress higher order harmonics. Therefore **design of this LC filter** can be given as,

$$C_{max} = \frac{I_m}{\omega_L V_m}\tan(\theta) = \frac{\left(P_{rated}\sqrt{2}/v_s\right)}{\omega_L V_m}\tan(\theta) = \frac{\left(1900\sqrt{2}/220\right)}{314\times 220\sqrt{2}}\tan(1^\circ) = 2.2uF$$

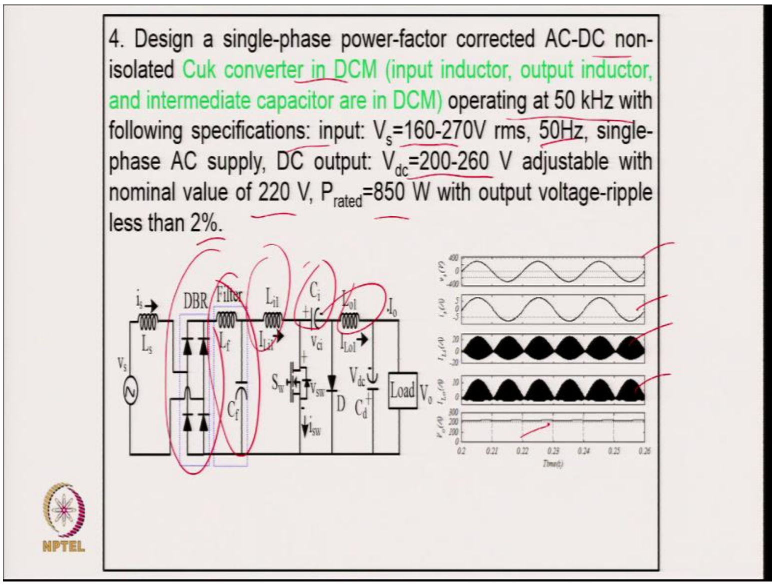
Where V_m and I_m are the supply voltage and current.
Filter capacitor value is taken **as 800nF.**

(Refer Slide Time: 17:40)



The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 18:23)



Coming to the 4th example. Design a single-phase power factor corrected AC-DC non-isolated Cuk converter in discontinuous conduction mode operating at 50 kHz with following specifications: Supply voltage = 160-270 V RMS, 50 Hz, single-phase supply, DC output voltage = 200 to 260 V adjustable with the nominal of 220 V, power output is 850 W with the output voltage-ripple of less than 2 %.

(Refer Slide Time: 19:54)

Solution-

The output voltage V_{dc} of the Cuk converter is given as,

$$V_{dc} = \frac{D}{1-D} V_{in}$$

Design of Inductor (L_i) for Discontinuous Current Conduction,

$$L_{ic} = \frac{V_{in} D}{2 I_{in} f_s} = \frac{R_{in} D}{2 f_s} = \left(\frac{V_s^2}{P_i}\right) \frac{D}{2 f_s}$$

At minimum supply voltage and maximum DC link voltage, the critical value of L_i is calculated as,

$$L_{ic260} = \frac{1}{2 f_s} \left(\frac{V_{smin}{}^2}{P_{rated}}\right) \left(\frac{V_{dcmax}}{\sqrt{2} V_{smin} + V_{dcmax}}\right)$$

$$= \frac{1}{2*50000} \left(\frac{160^2}{850}\right) \left(\frac{260}{\sqrt{2}*160+260}\right) = 161 \mu H$$

(Refer Slide Time: 20:34)

At minimum supply voltage and minimum DC link voltage, the critical value of L_i is calculated as,

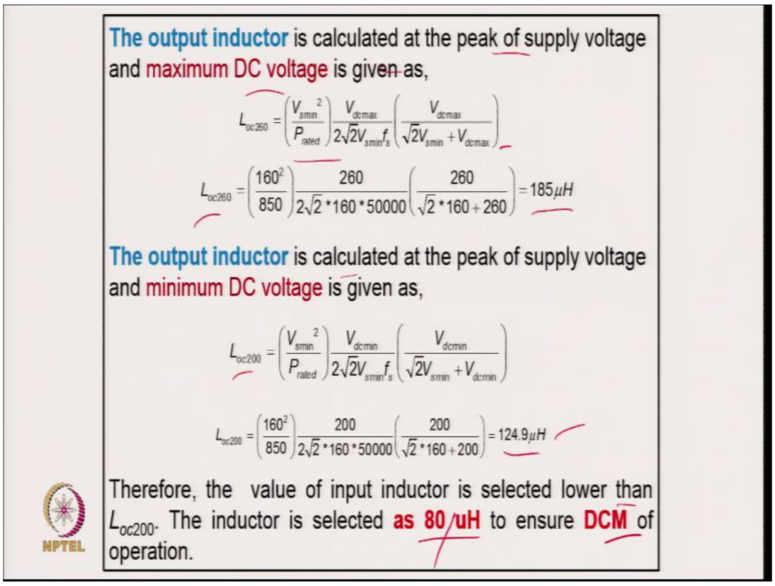
$$L_{ic200} = \frac{1}{2 f_s} \left(\frac{V_{smin}{}^2}{P_{rated}}\right) \left(\frac{V_{dcmin}}{\sqrt{2} V_{smin} + V_{dcmin}}\right)$$

$$= \frac{1}{2*50000} \left(\frac{160^2}{850}\right) \left(\frac{200}{\sqrt{2}*160+200}\right) = 141.3 \mu H$$

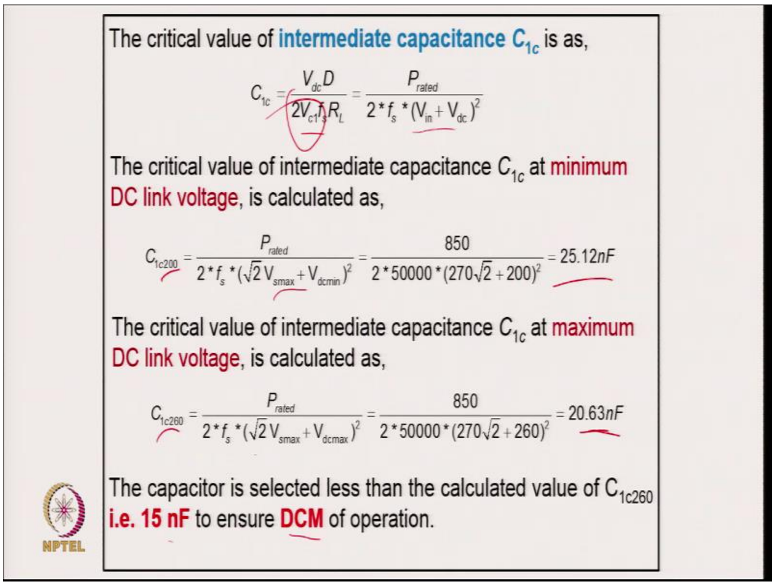
In the above expression, a high switching frequency is considered i.e. f_s=20 kHz where R_{in} gives the input side resistance, As per the required design the rated input power and rated DC link are considered at minimum supply voltage (i.e., V_{smin} = 160 V).

Therefore, the critical value of input inductor is selected lower than L_{ic200}. The inductor is selected **as 100 uH** to ensure **DCM** operation.

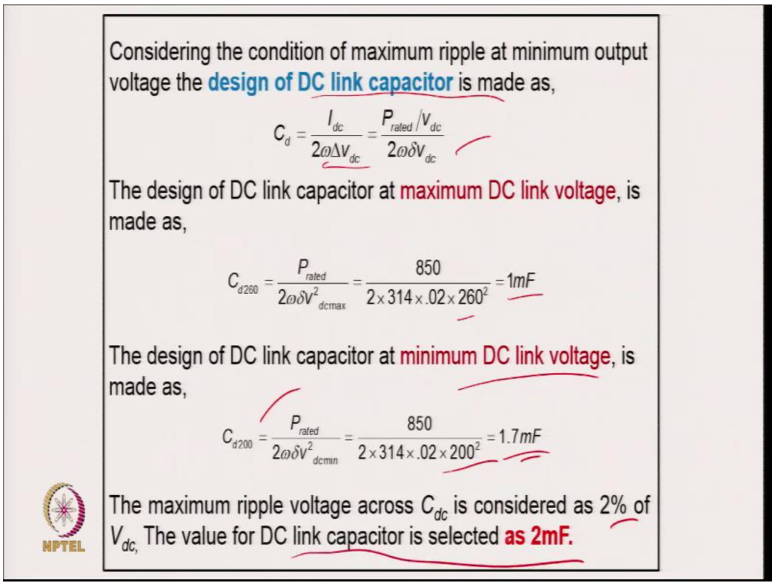
(Refer Slide Time: 21:30)



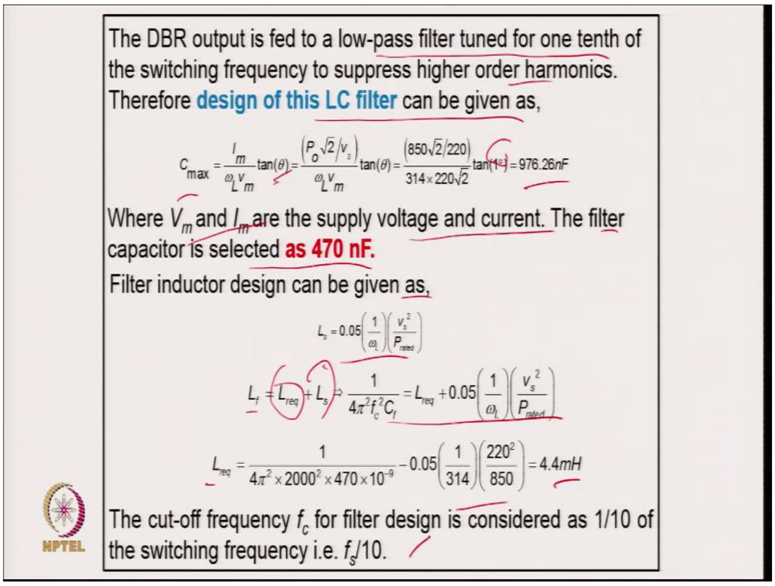
(Refer Slide Time: 22:16)



(Refer Slide Time: 22:57)

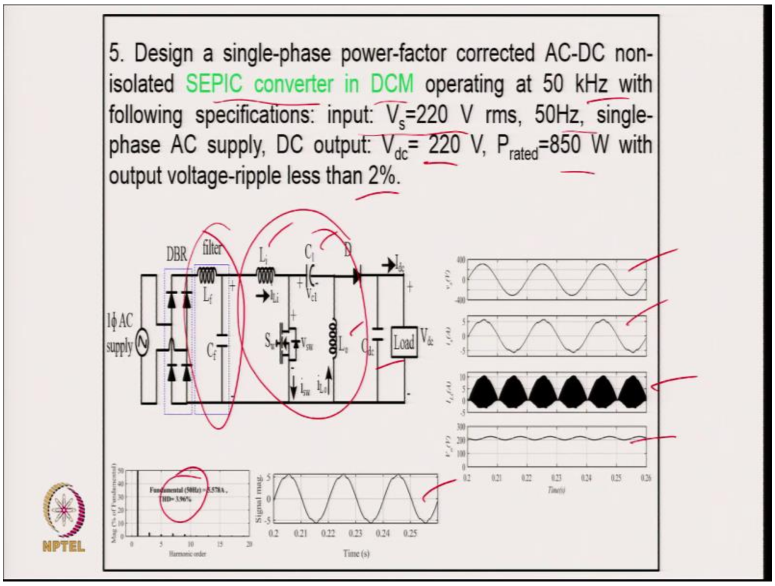


(Refer Slide Time: 23:32)



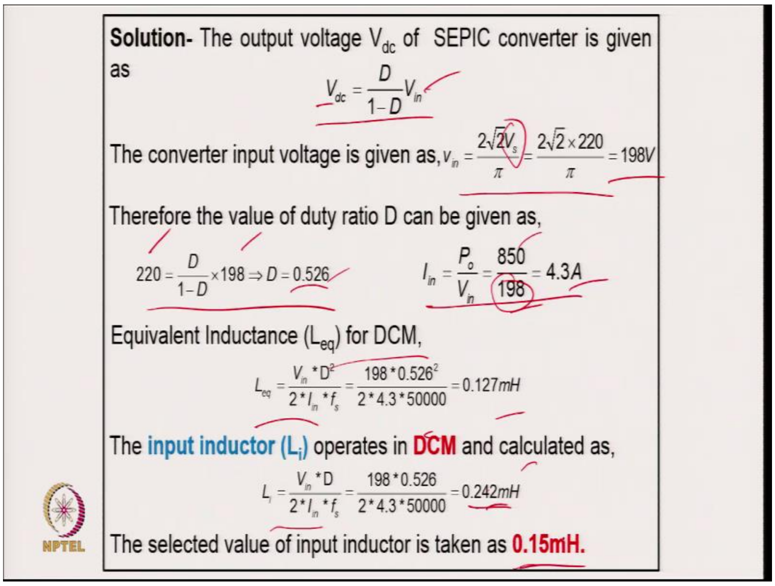
The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 24:33)

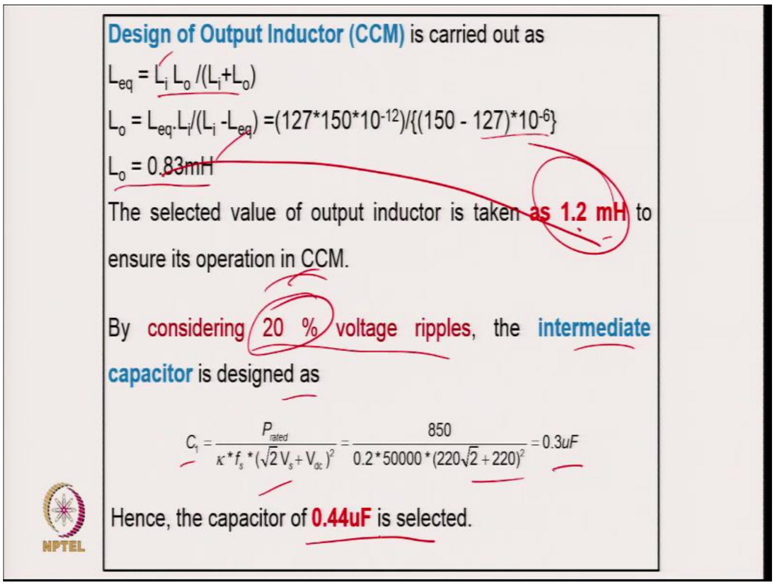


Coming to 5th example. Design a single-phase power factor corrected AC-DC non-isolated SEPIC converter operating in discontinuous conduction mode at 50 kHz with the following specifications: Supply voltage = 220 V RMS/ 50 Hz, single-phase supply, and output voltage is 220 V, and rated power is 850 W with the output voltage-ripple of less than 2 %.

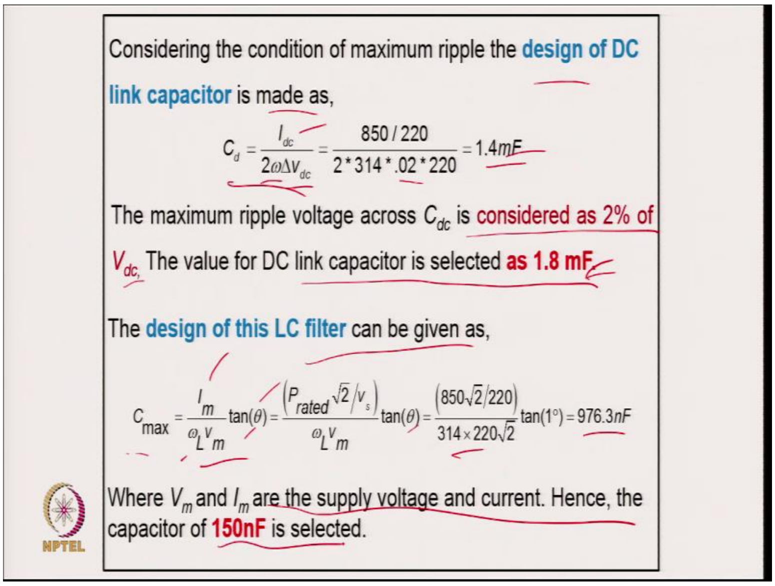
(Refer Slide Time: 25:50)



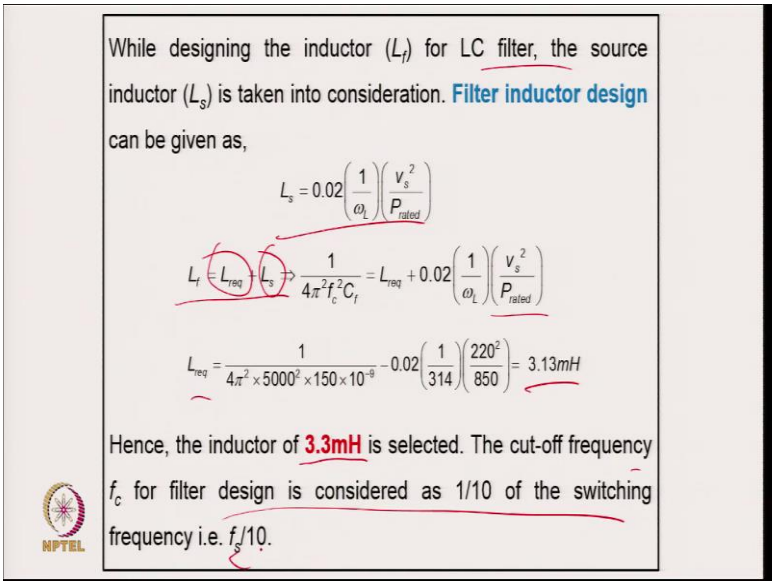
(Refer Slide Time: 27:03)



(Refer Slide Time: 27:54)

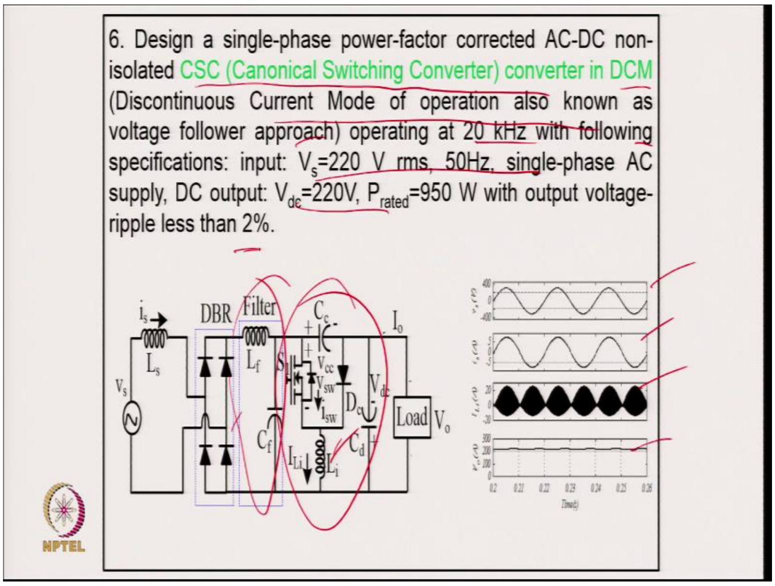


(Refer Slide Time: 28:48)



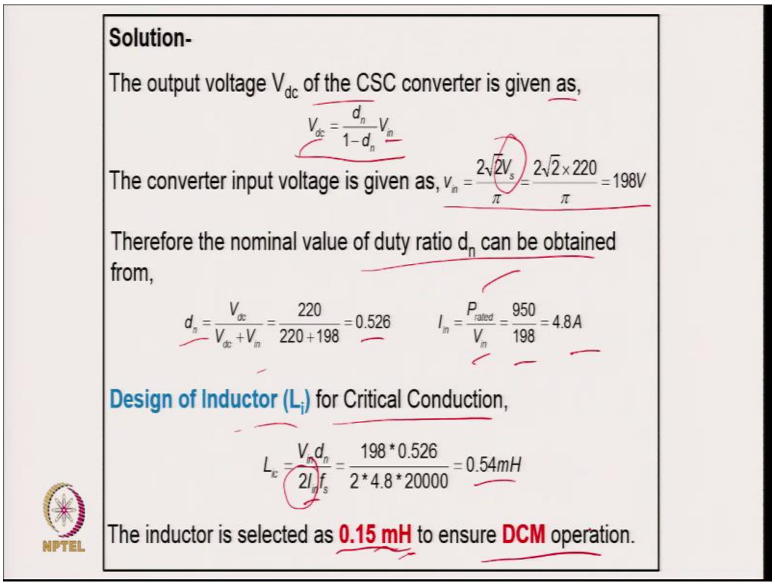
The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 29:17)

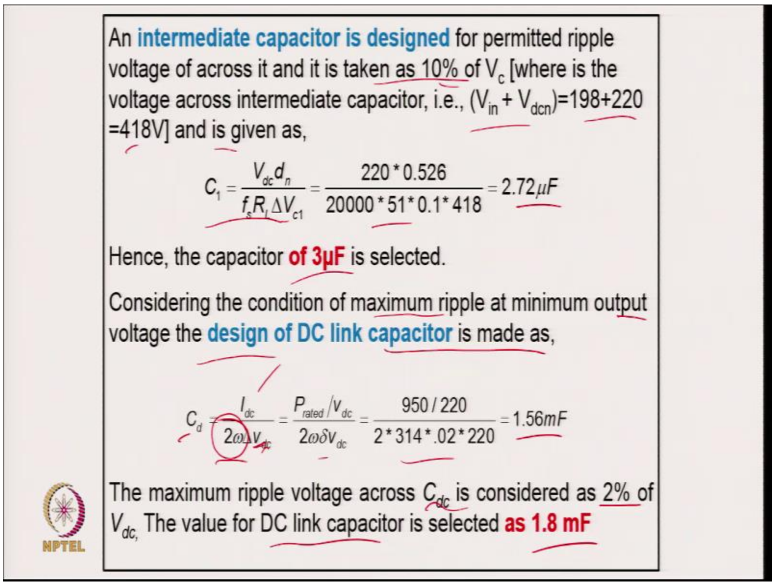


Coming to the 6[th] example. Design a single-phase power factor corrected AC-DC non-isolated CSC converter operating in discontinuous current mode at 20 kHz with the following specifications: supply voltage = 220 V/ 50 Hz, single-phase AC supply, and output is 220 V, power is 950 W with output voltage-ripple of 2 %.

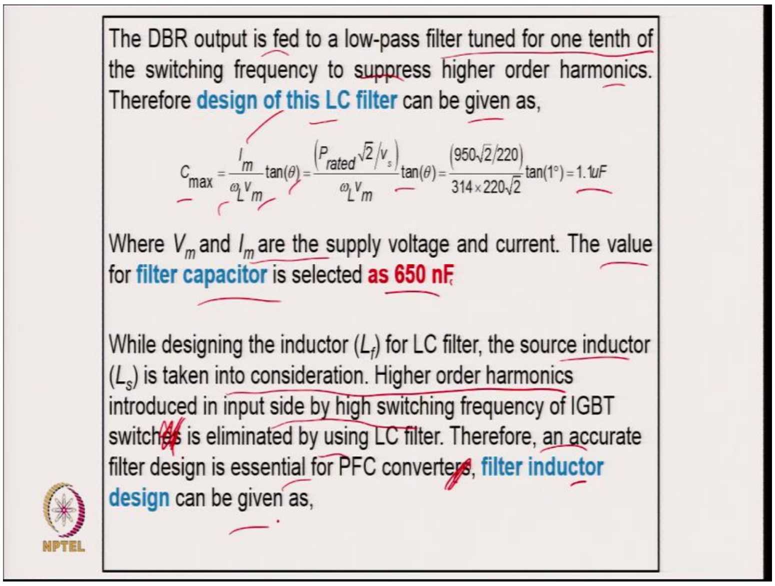
(Refer Slide Time: 30:23)



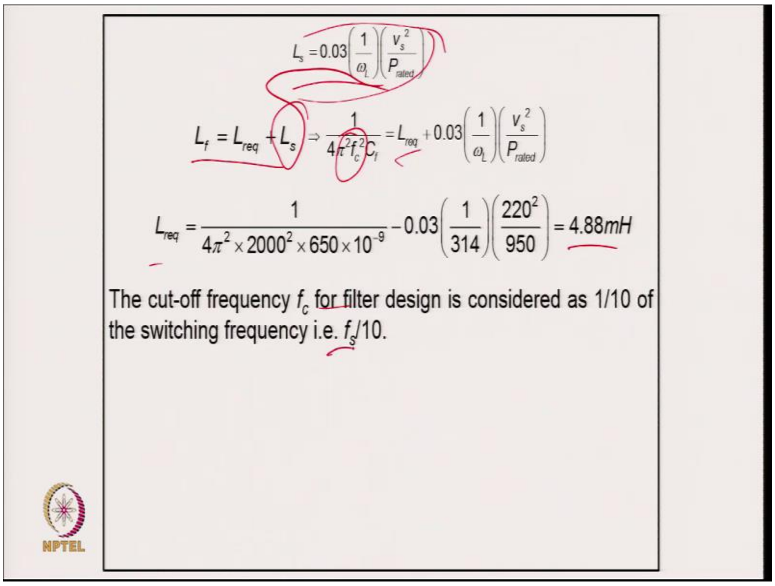
(Refer Slide Time: 31:49)



(Refer Slide Time: 32:43)

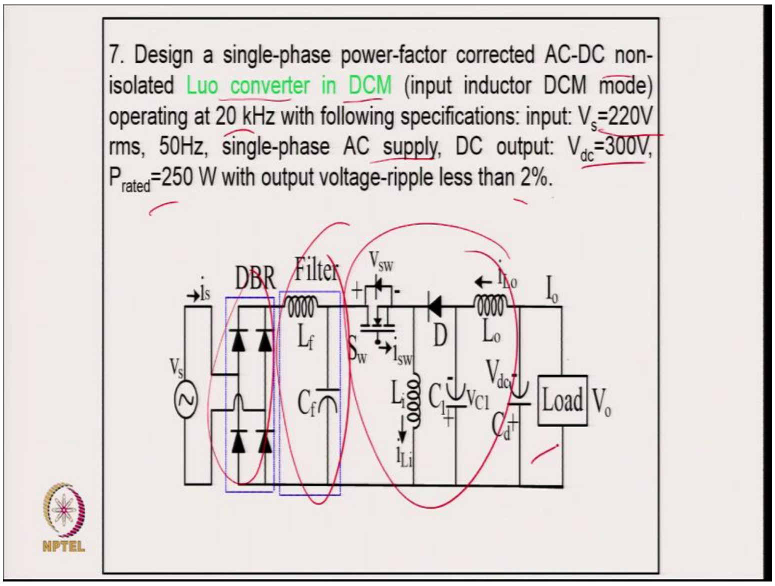


(Refer Slide Time: 33:44)



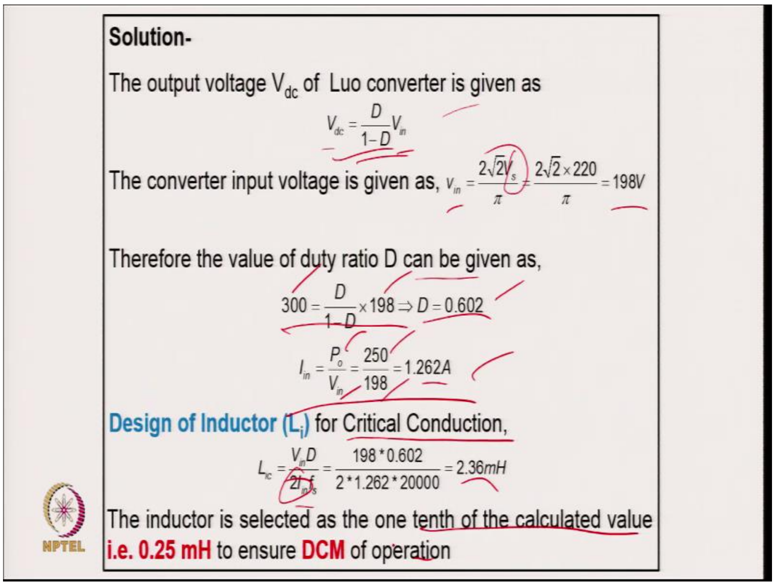
The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 34:11)

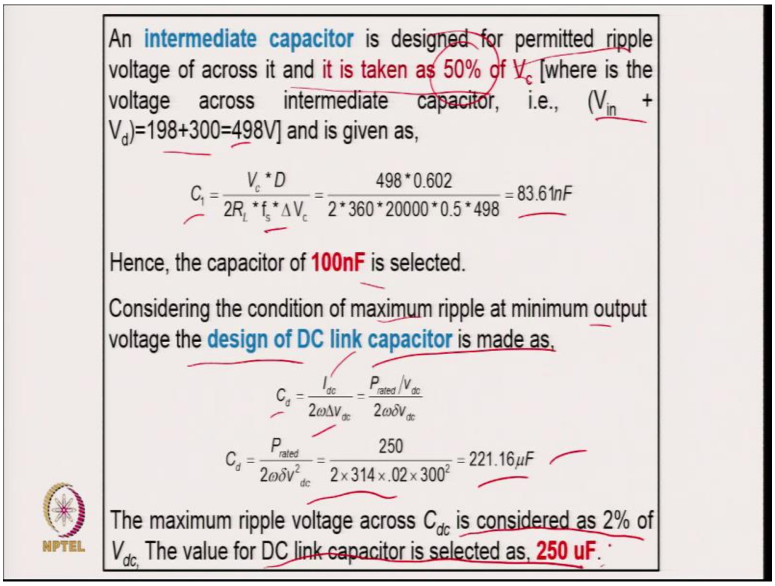


Coming to 7[th] example. Design a single-phase power factor corrected AC-DC non-isolated Luo converter operating in discontinuous conduction mode at 20 kHz with the following specifications: supply voltage = 220 V/50 Hz, single-phase AC supply, DC output voltage of 300 V, rated power of 250 W, and output voltage-ripple 2 %.

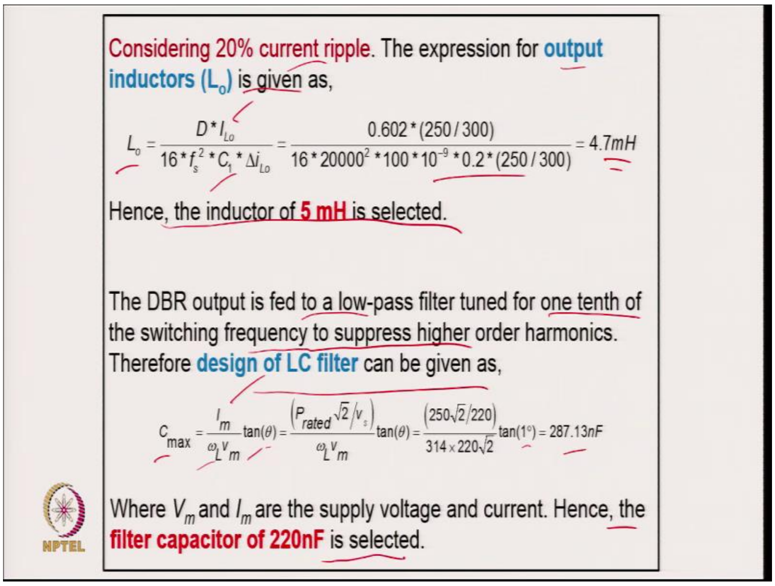
(Refer Slide Time: 34:49)



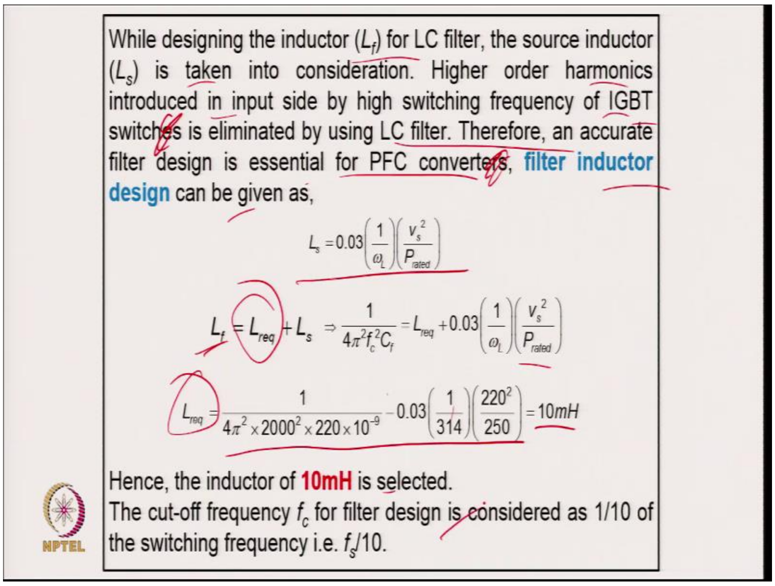
(Refer Slide Time: 35:57)



(Refer Slide Time: 36:51)

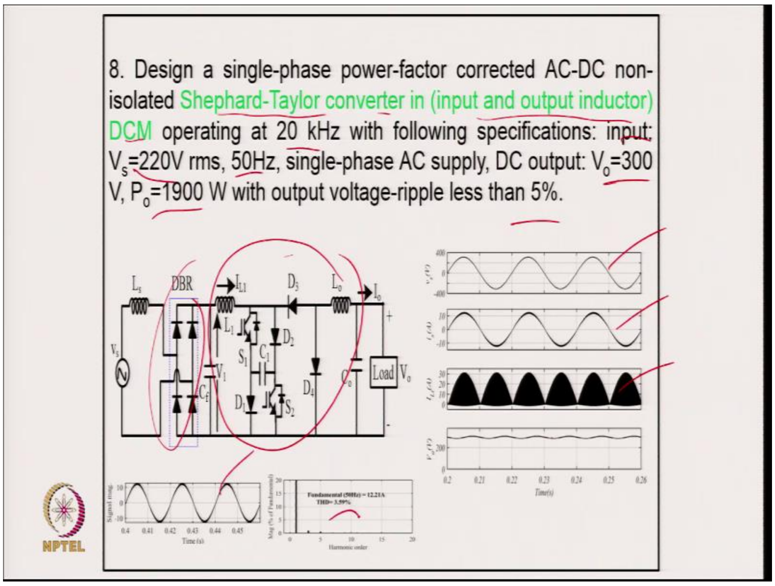


(Refer Slide Time: 37:46)



The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 38:26)



Coming to 8th example. Design a single-phase power factor corrected AC-DC non-isolated Sheppard Taylor converter in DCM operating at 20 kHz with the following specifications: supply voltage = 220 V/50 Hz, single-phase AC supply, DC output voltage of 300 V, and power is 1900 W, with output ripple of less than 5%.

(Refer Slide Time: 39:31)

Solution- The output voltage V_0 of Sheppard-Taylor converter is given as

$$V_o = \frac{D}{1-D} V_{in}$$

The converter input voltage is given as,

$$V_{in} = \frac{2\sqrt{2}V_s}{\pi} = \frac{2\sqrt{2}\times 220}{\pi} = 198V$$

Therefore the value of duty ratio D can be given as,

$$300 = \frac{D}{1-D}\times 198 \Rightarrow D = 0.602$$

$$I_{in} = \frac{P_{rated}}{V_{in}} = \frac{1900}{198} = 9.6A$$

Design of Inductor (L_1) for discontinuous Current Conduction,

$$L_{1c} = \frac{V_{in} * D}{2 * I_{in} * f_s} = \frac{198 * 0.602}{2 * 9.6 * 20000} = 0.31mH$$

Hence, the input inductor is selected as **0.1 mH** to operate in DCM.

(Refer Slide Time: 40:42)

An **intermediate capacitors** are designed for permitted ripple voltage of across it and it is taken as 45% of V_c [where is the voltage across intermediate capacitor, i.e., (V_{in} + V_d)=198+300=498V] and is given as,

$$C_1 = \frac{V_o * D}{\kappa * R_L * f_s * (V_o + V_{in})} = \frac{300 * 0.602}{0.45 * 47.4 * 20000 * 498} = 0.85uF$$

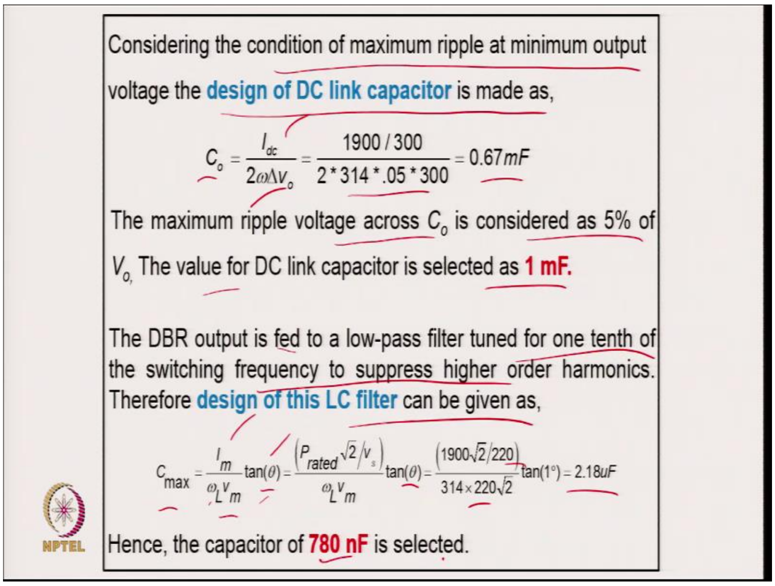
Hence, the capacitor of **1uF** is selected.

Design of Output Inductor (L) (DCM Mode)

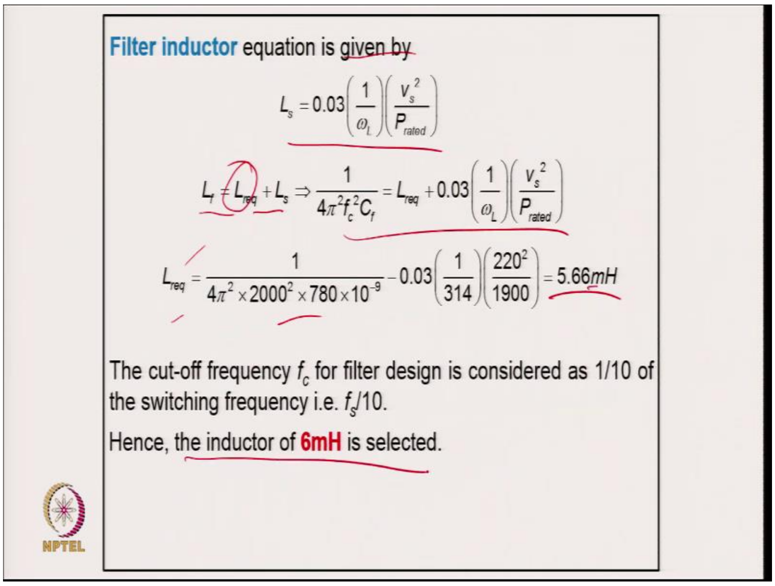
$$L_{oc} = \frac{V_o * (1-D)}{2 * I_0 * f_s} = \frac{300 * (1-0.602)}{2 * 6.33 * 20000} = 0.472mH$$

Hence, the output inductor is selected of the order of 1/3rd of L_{oc} as **0.16mH** to operate in DCM.

(Refer Slide Time: 41:46)

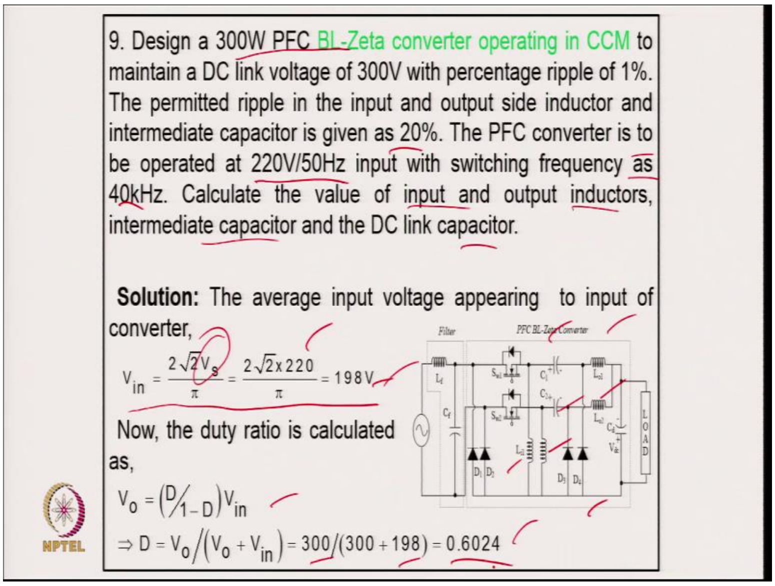


(Refer Slide Time: 42:49)



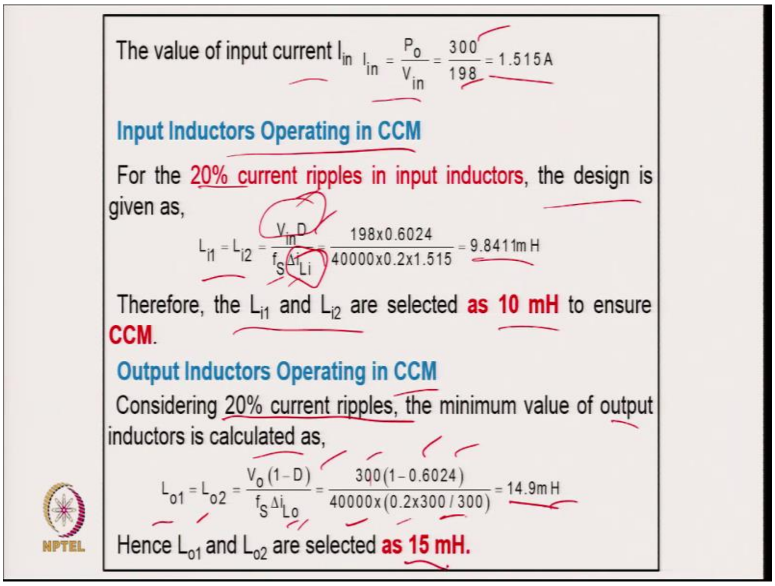
The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 43:13)

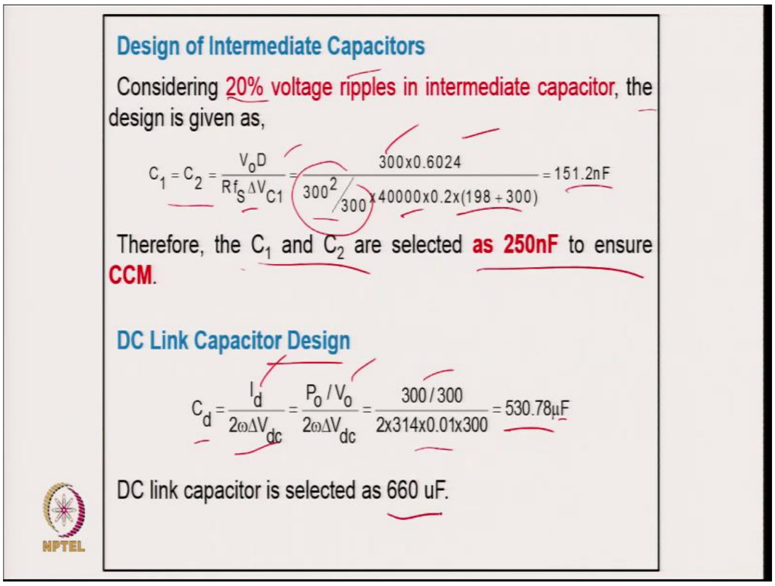


Coming to 9th example. Design a 300 W power factor corrected bridgeless zeta converter operating in continuous conduction mode to maintain the DC link voltage of 300 V with a percentage ripple of 1%. The permitted ripple in the input and output side inductors, and intermediate capacitor is 20%. The power factor correction converter is operated at 220V/50 Hz input, and the switching frequency is 40 kHz. Calculate the value of input and output inductors, intermediate capacitor and DC link capacitor.

(Refer Slide Time: 44:28)

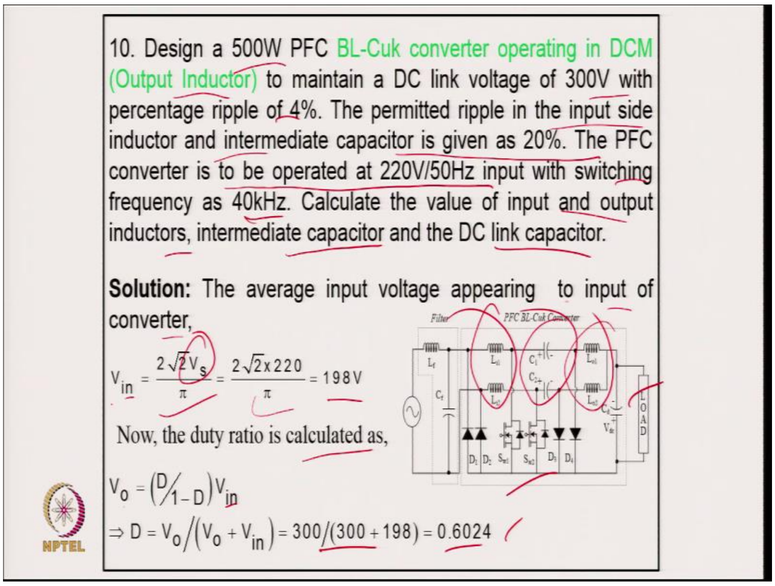


(Refer Slide Time: 45:44)



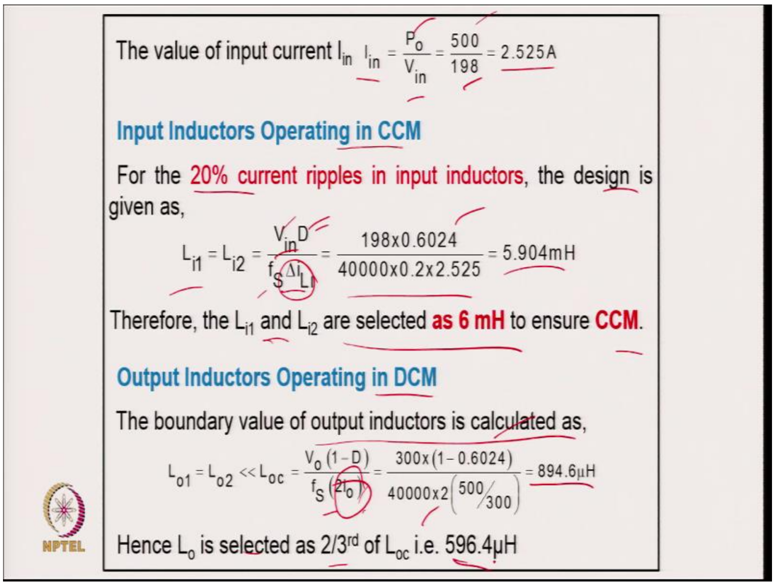
The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 46:36)

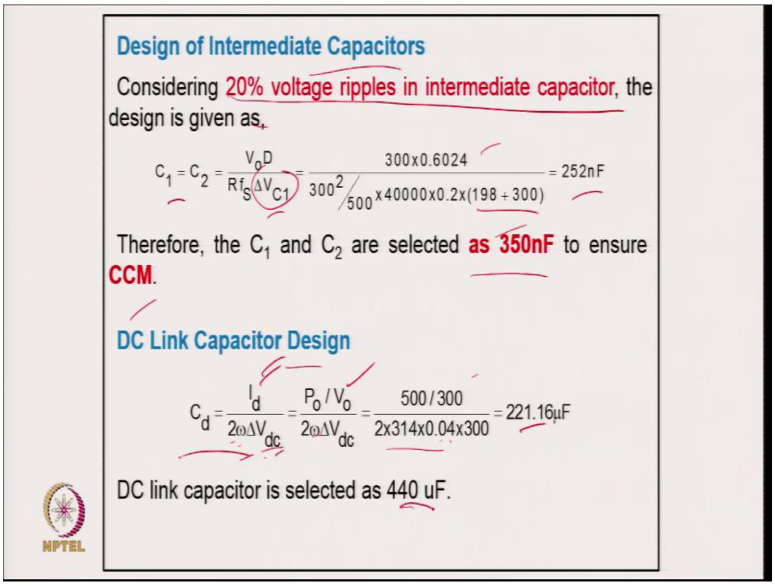


Coming to 10th example. Design a 500 W power factor corrected (PFC) bridgeless Cuk converter operating in discontinuous conduction mode (for output inductor only) to maintain the DC link voltage of 300 V with the percentage ripple of 4%. The percentage ripple in the input inductor and intermediate capacitor is 20%. The PFC converter is operating at 220 V/50 Hz, and switching frequency is 40 kHz. Calculate the value of input and output inductors, intermediate capacitor, and the output DC link capacitor.

(Refer Slide Time: 48:11)

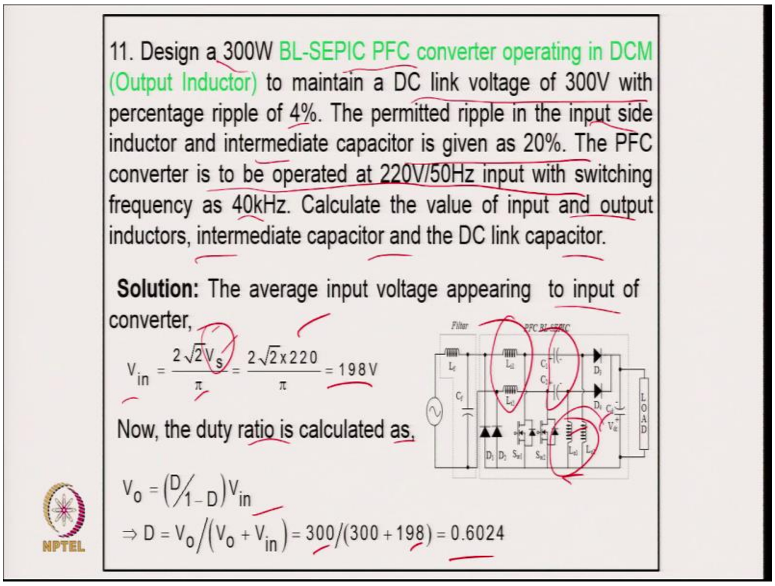


(Refer Slide Time: 49:47)

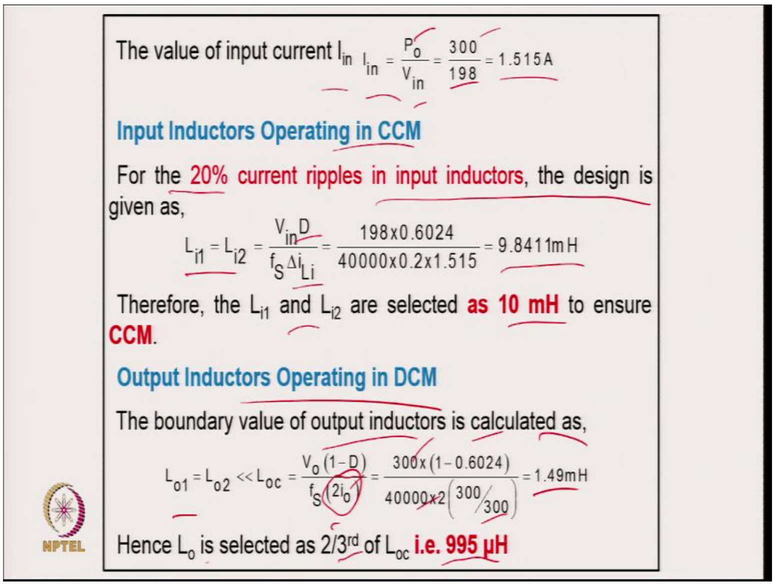


The solution of this problem is given in the abovemention slides.

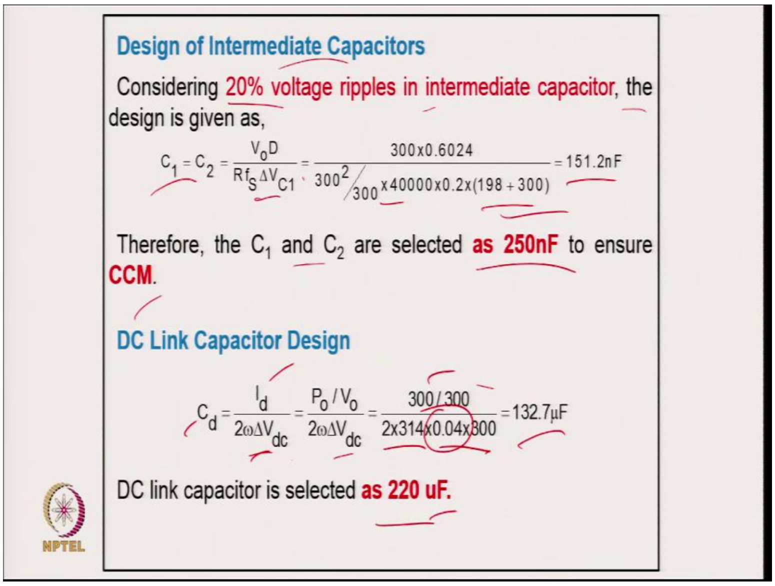
(Refer Slide Time: 50:57)



(Refer Slide Time: 52:31)

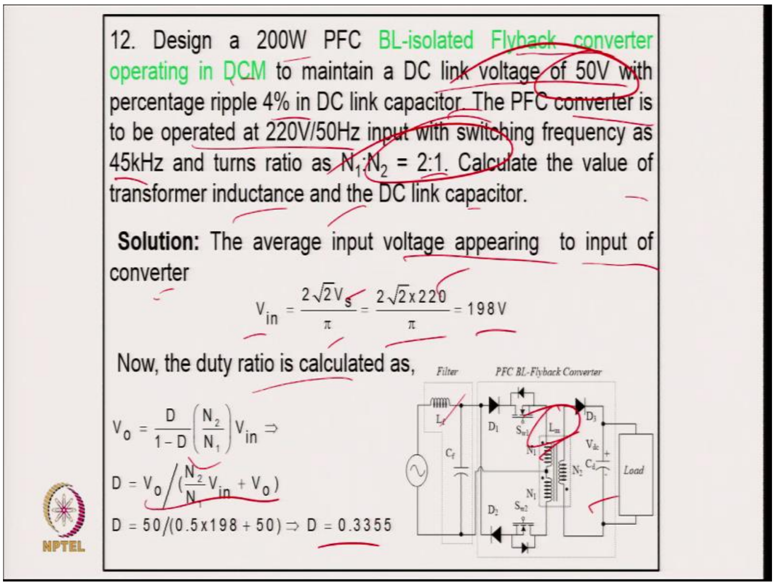


(Refer Slide Time: 54:04)



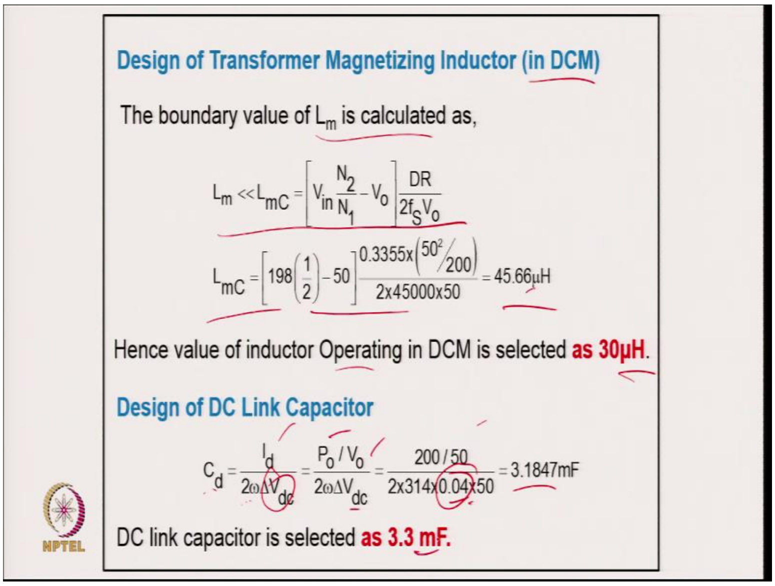
The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 55:00)



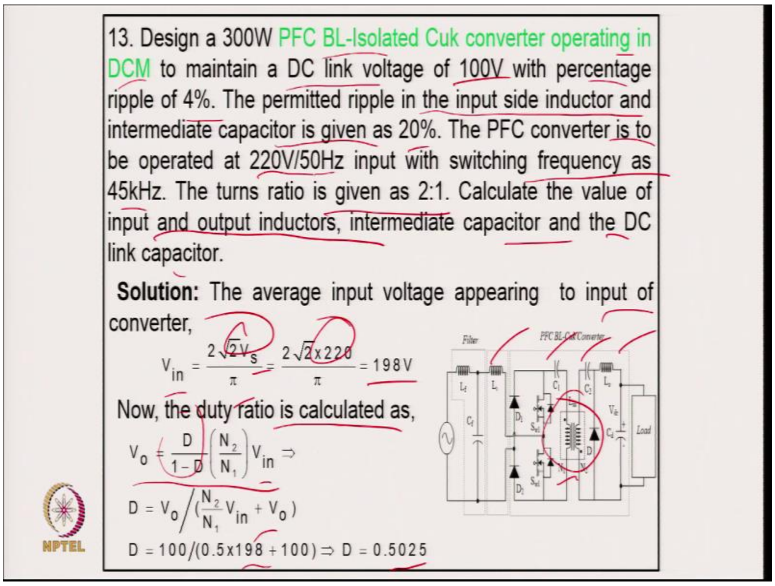
Coming to 12th example. Design a 200 W power factor corrected (PFC) bridgeless flyback converter operating in discontinuous mode to maintain the DC link voltage of 50 V with the percentage ripple of 4 % in DC link voltage. The PFC converter is operating with the input supply of 220 V/50 Hz, and switching frequency of 45 kHz, and the turns ratio is 2:1. Calculate the transformer inductance and DC link capacitor.

(Refer Slide Time: 56:12)

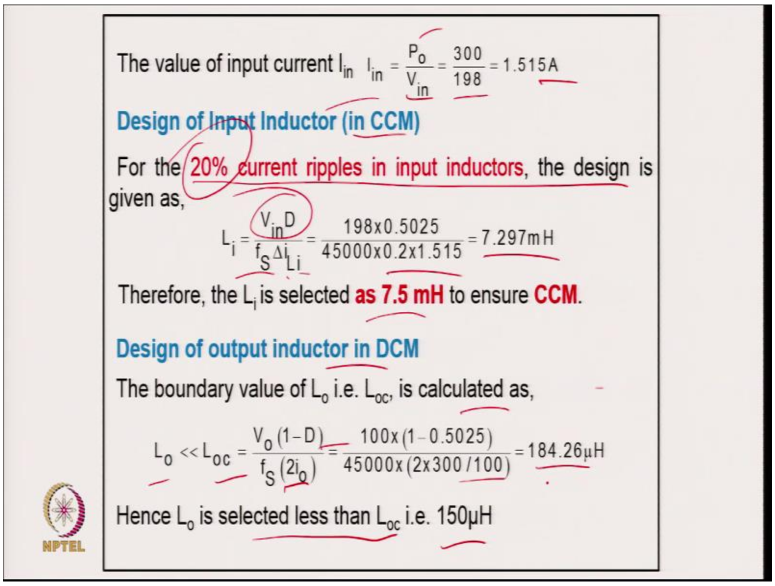


The solution of this problem is given in the abovemention slides.

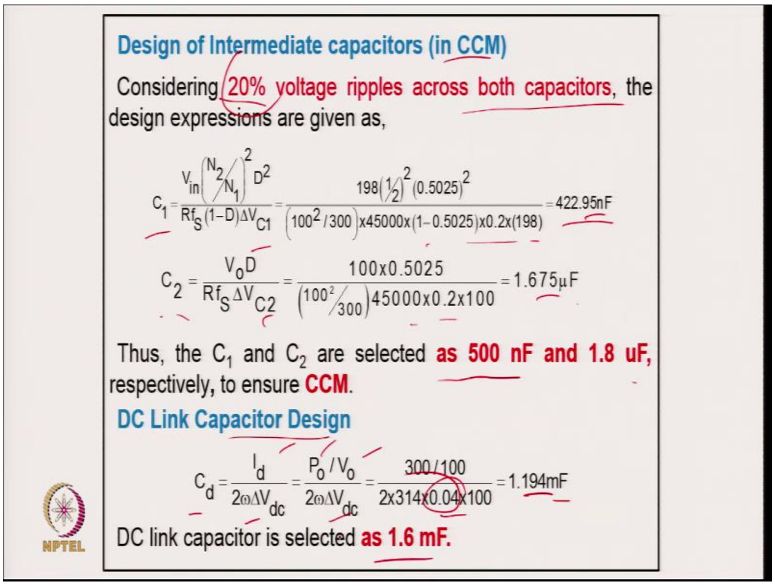
(Refer Slide Time: 57:08)



(Refer Slide Time: 58:57)

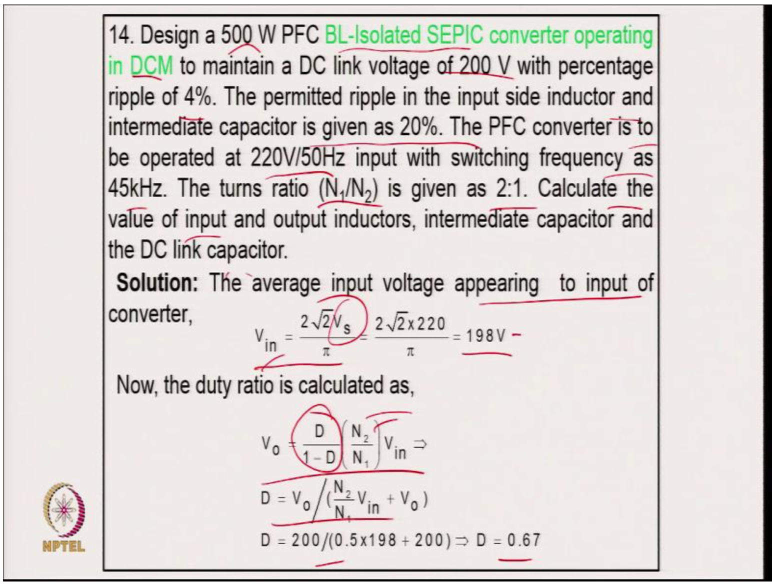


(Refer Slide Time: 60:12)



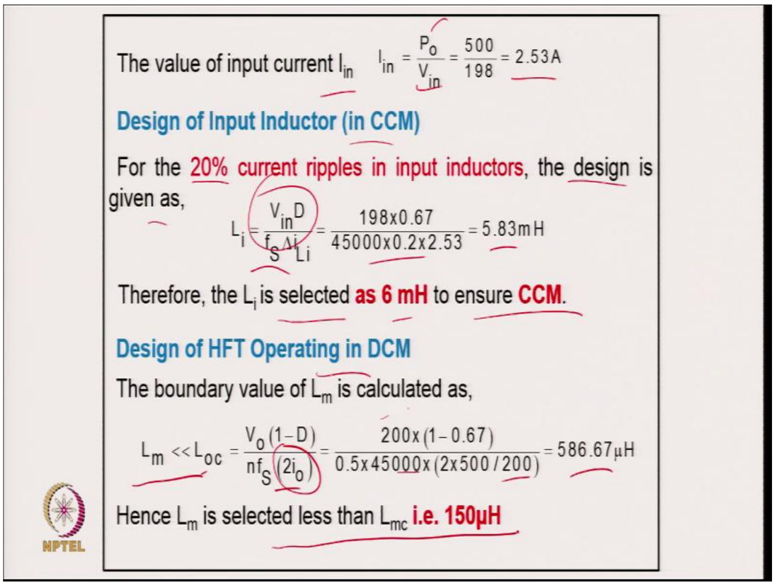
The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 61:31)

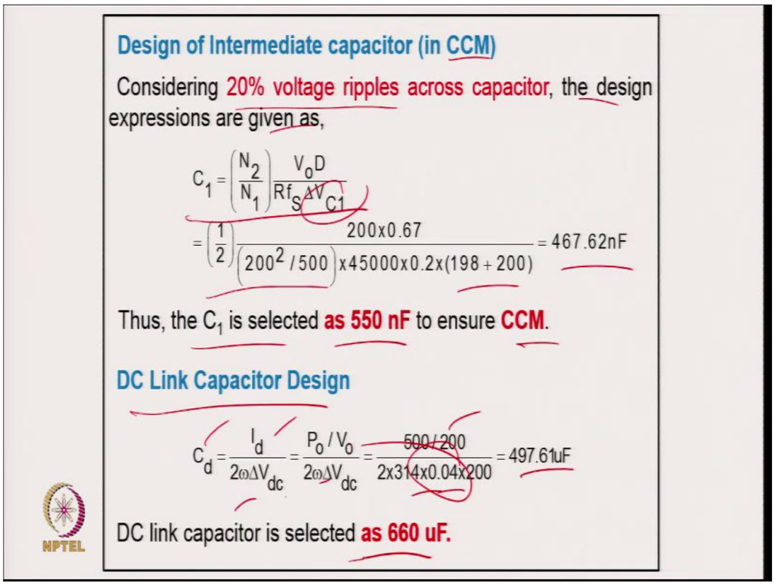


Now, coming to the 14th example. Design a 500 W power factor corrected (PFC) bridgeless isolated SEPIC converter operating in discontinuous mode to maintain the DC link voltage of 200 V with the percentage ripple of 4%. The permitted ripple in the input side inductor and intermediate capacitor is given 20% The PFC converter is operated with the supply of 220 V/50 Hz, and the switching frequency of 45 kHz. The turns ratio is selected typically as 2:1. Calculate the value of input and output inductor, and intermediate capacitor and the DC link capacitor.

(Refer Slide Time: 62:41)

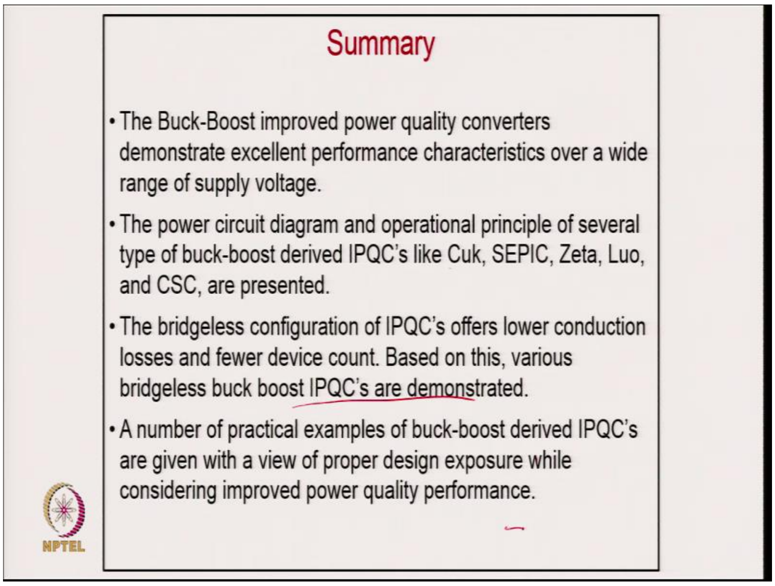


(Refer Slide Time: 63:41)



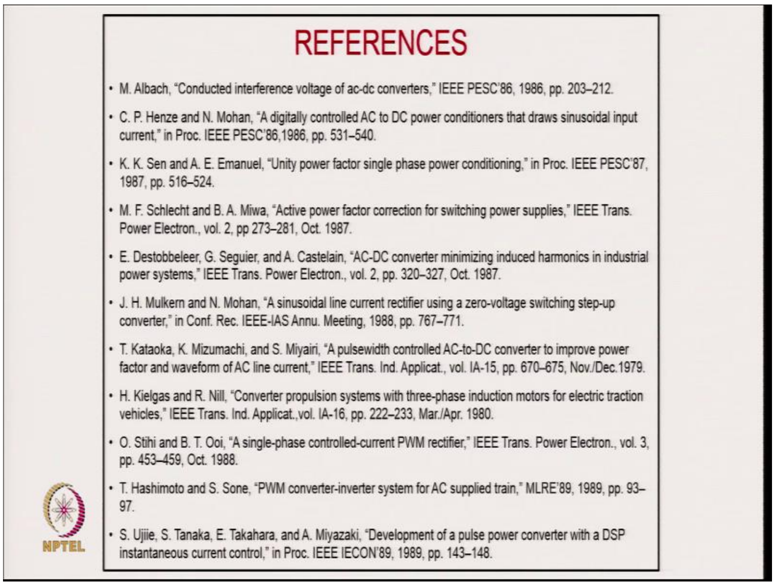
(Refer Slide Time: 64:35)

The solution of this problem is given in the abovemention slides.

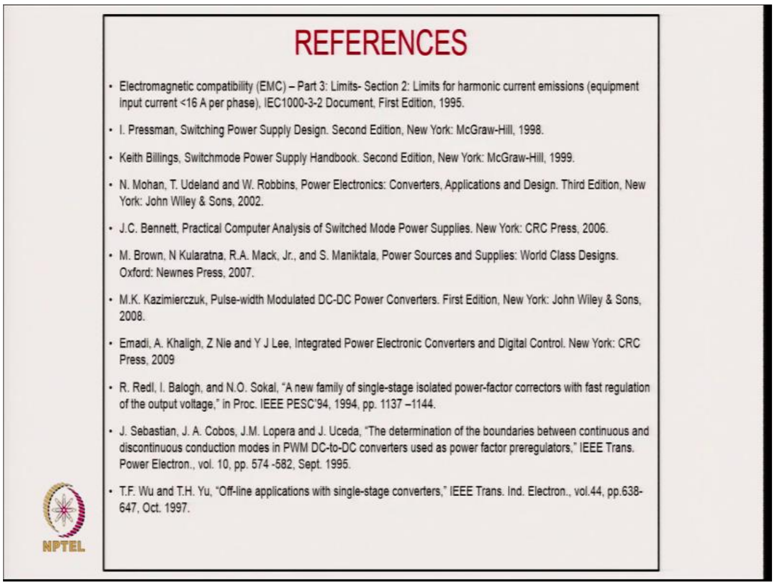


With this we would like to summarize. The buck-boost improve power quality converters demonstrate excellent performance characteristic over a wide range of supply voltage. The power circuit diagrams and operational principle of several type of buck-boost derive improve power quality converter like Cuk, SEPIC, Zeta, Luo, and canonical switching converter are presented. Further, various bridgeless buck-boost converters are also demonstrated. A number of practical examples of buck-boost derived improved power quality converters are given with the view of proper design exposure while considering the improved power quality performance at the grid.

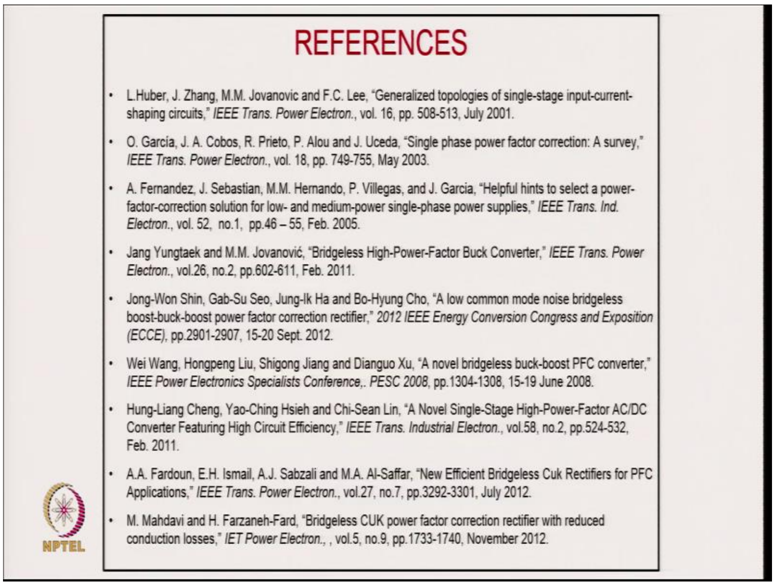
(Refer Slide Time: 65:26)



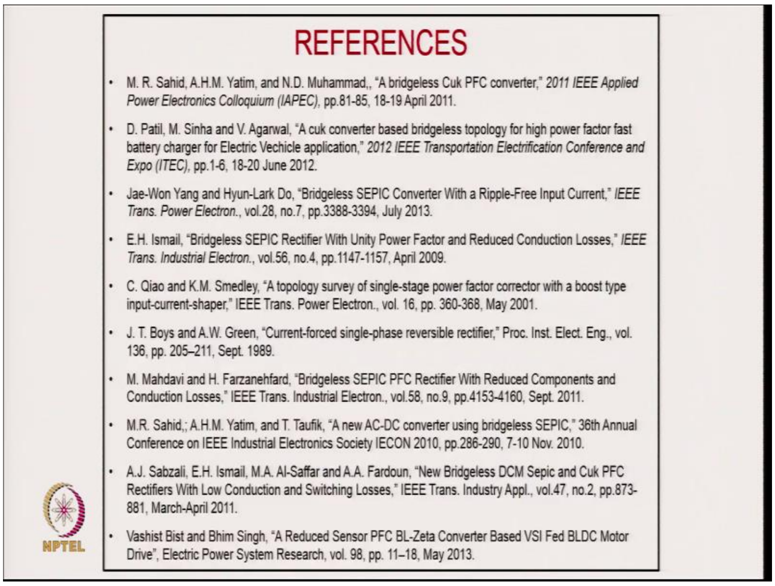
(Refer Slide Time: 65:30)



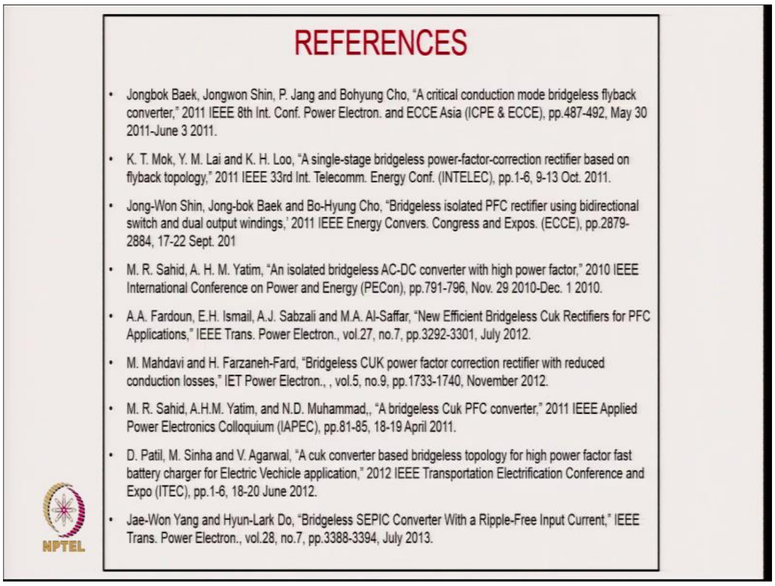
(Refer Slide Time: 65:31)



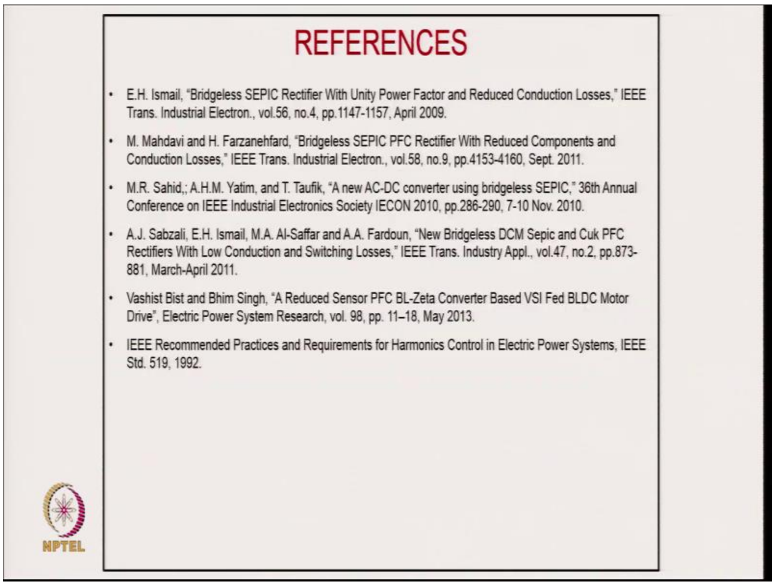
(Refer Slide Time: 65:32)



(Refer Slide Time: 65:32)



(Refer Slide Time: 65:33)



And these are the references which we have taken into account.

Thank you.