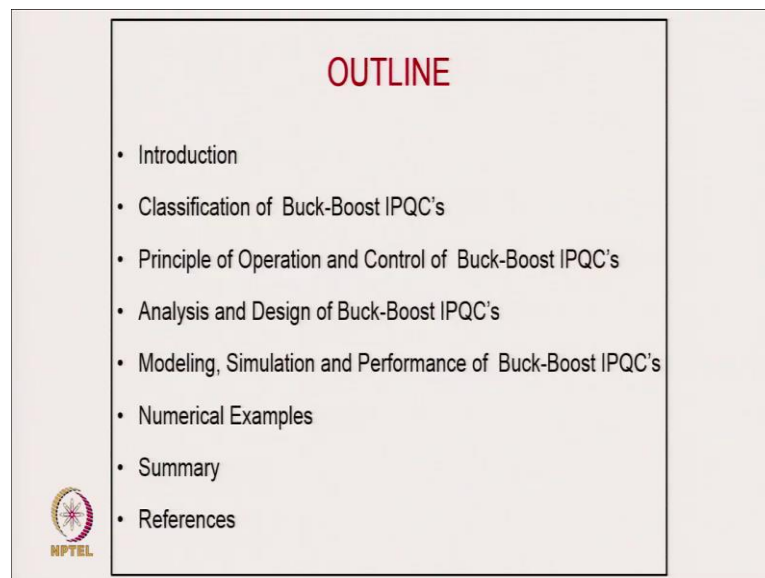


Power Quality
Prof. Bhim Singh
Department of Electrical Engineering
Indian Institute of Technology, Delhi

Module - 03
Chapter - 13
Lecture - 33
Improved Power Quality Converters - AC-DC Buck-Boost Converters


Welcome to the course on Power Quality. Today, we will cover Improved Power Quality Converters: AC DC Buck Boost Converter.

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These will be the outlines of this lecture.


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OBJECTIVES

- Requirements and Applications
- Configurations of Buck-Boost IPQC's
- Control of Buck-Boost IPQC's
- Analysis and Design of Buck-Boost IPQC's
- Method of Modeling and Control of Buck-Boost IPQC's

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Introduction

- **Buck-Boost IPQC's**
 - ✓ Wide input and output voltage range operating capability
 - ✓ High power factor at supply side
 - ✓ Natural protection against inrush current
 - ✓ High performance characteristics during startup and overload condition.
 - ✓ Less Electromagnetic Interference (EMI)
 - ✓ Easy implementation of transformer isolation
 - ✓ Better input/output current ripple characteristics
 - ✓ Efficient operation
 - ✓ Wide range of applications from few watts (W) to kW

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Applications

Electric Vehicle Battery Chargers



Four Wheelers



Three Wheelers




Two Wheelers




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Applications


Electric Drives Systems




PMSM Drives



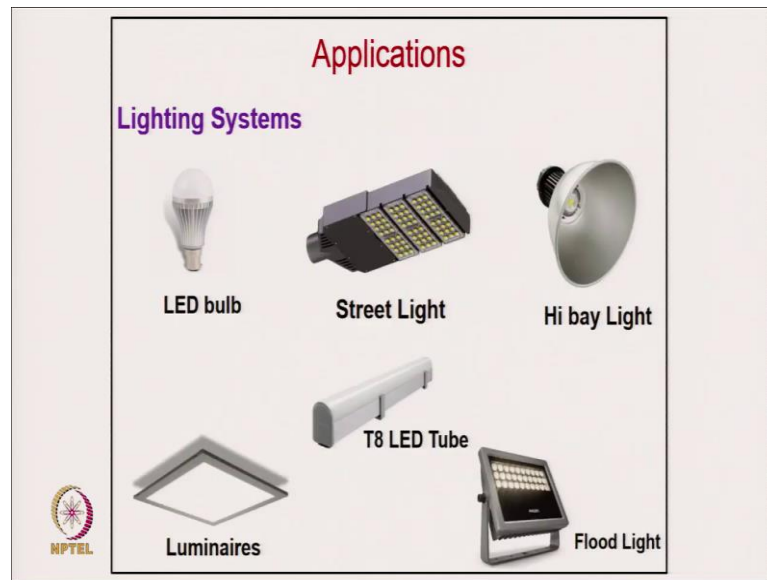
BLDC Machine Drive



SRM Drive



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Applications



Home Inverter



Uninterruptible Power Supply (UPS)



9

This slide, titled "Applications", displays two types of power conversion equipment. On the left is a grey "Home Inverter" with a control panel on the front. On the right is an "Uninterruptible Power Supply (UPS)" with its top cover removed, revealing internal electronic components and wiring. The NPTEL logo is in the bottom left corner, and the number 9 is in the bottom right corner.

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Applications



Computer Power Supply



Welding Machine



10

This slide, titled "Applications", displays two types of power conversion equipment. On the left is a "Computer Power Supply" with its metal casing open, showing internal components and a cooling fan. On the right is a blue "Welding Machine" with its power cables and electrode holder. The NPTEL logo is in the bottom left corner, and the number 10 is in the bottom right corner.

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Applications

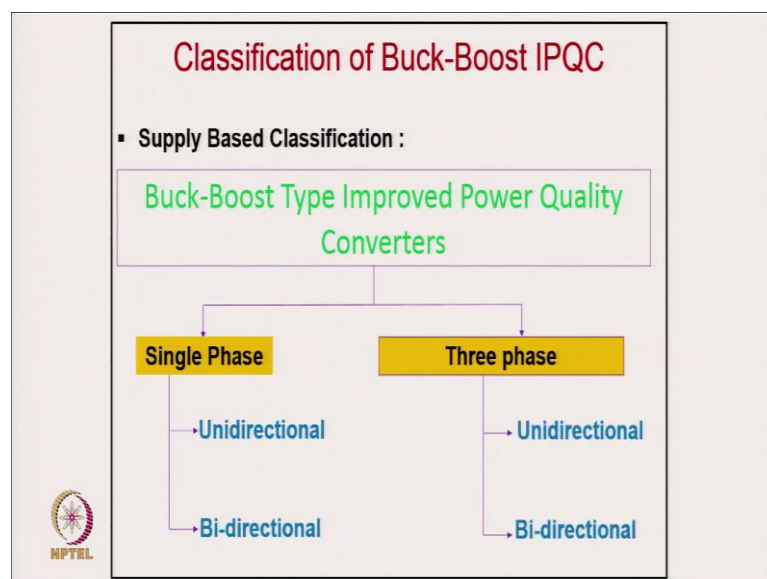
- Wireless Power Transfer
- More Electric Aircraft
- Traction Systems
- Home Appliances like Air Conditioners, LCD Display, Washing machines etc.
- High Voltage DC Transmission

Many more....

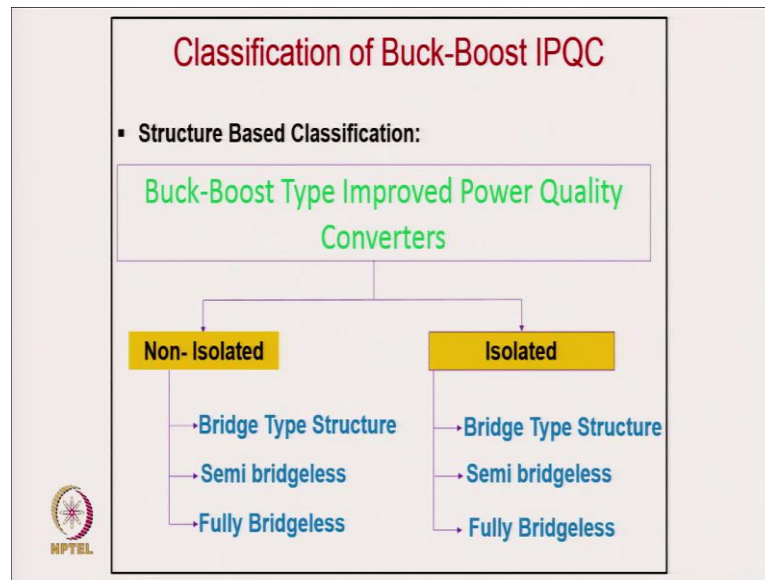


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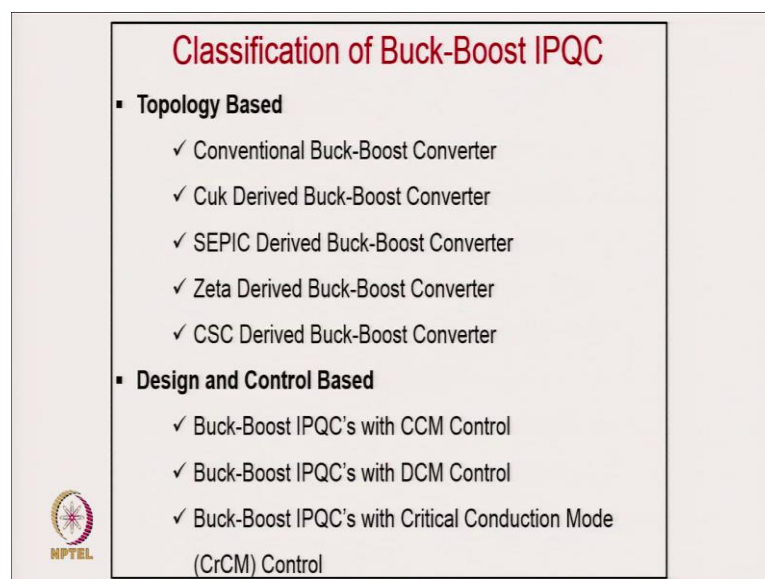
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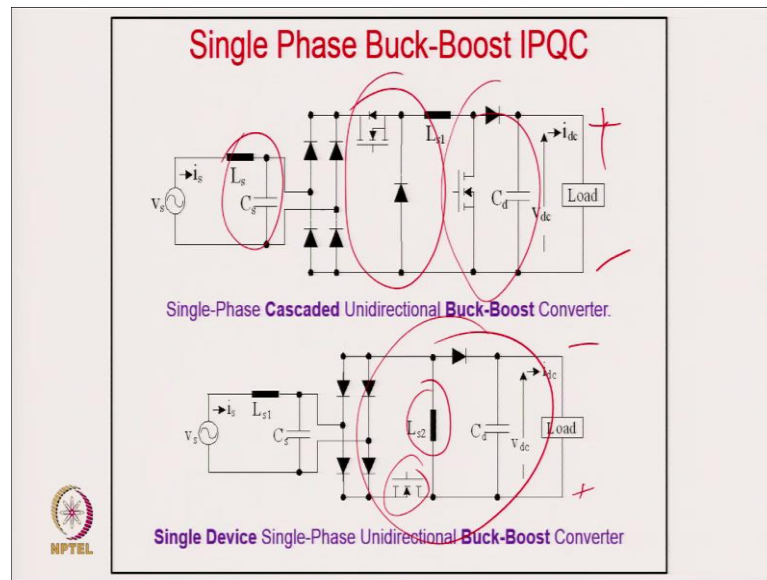


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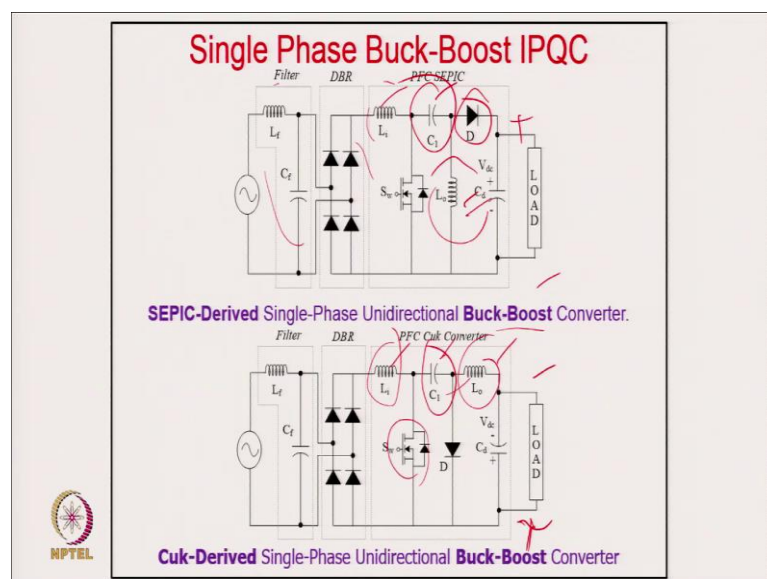


These are the classifications of buck-boost type improved power quality converters.

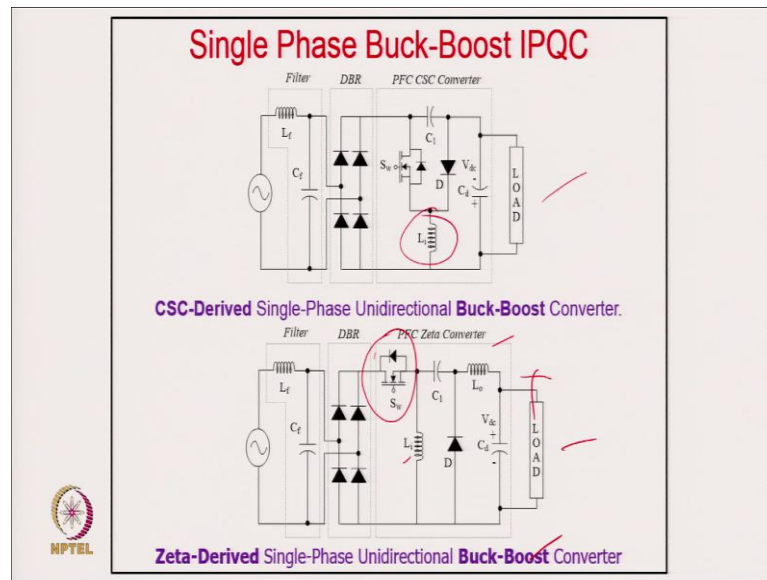
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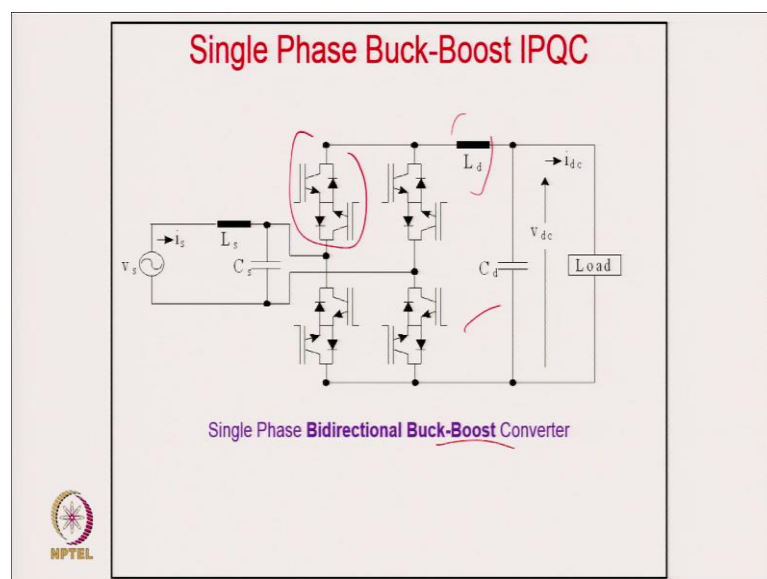
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Coming to like analysis of these single phase buck boost converters.

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Step-Down/Step-Up (Buck-Boost) Converter

- The output voltage can be higher or lower than the input voltage.
- Used in regulated dc power supplies where a negative polarity output may be desired with respect to the common terminal of the input voltage.
- The output to input voltage conversion ratio

$$\frac{V_0}{V_d} = D \frac{1}{1-D}$$

- This allows V_0 to be higher or lower than V_d

Filter DBR PFC Buck-Boost Converter

NPTEL

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Buck-Boost Converter: Continuous Current Conduction Mode

- **When the switch is ON:**
Diode is reversed biased output circuit is thus isolated inductor is charged

$$\frac{di_{L1}}{dt} = \frac{V_d}{L_1}$$
- **When the switch is OFF:**
The output stage received energy from the inductor

$$\frac{di_{L1}}{dt} = -\frac{V_{dc}}{L_1}$$

PFC Buck-Boost Converter

PFC Buck-Boost Converter

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Buck-Boost Converter: Continuous Current Conduction Mode

- Inductor current i_L flows continuously
- Average inductor voltage over a time period must be zero

$$V_d D T_s + (-V_o)(1-D)T_s = 0$$

$$\therefore \frac{V_o}{V_d} = \frac{D}{1-D}$$

Assuming a lossless circuit


$$V_d I_d = V_o I_o$$

and

$$\frac{I_o}{I_d} = \frac{(1-D)}{D}$$

- Depending on the duty ratio, the output voltage can be either higher or lower than the input

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- Considering $\xi\%$ current ripples the **minimum inductor (L_{\min})** for continuous current Conduction can be calculated as
$$L_{\min} = \frac{D \cdot V_d}{\xi \cdot I_m \cdot f_s}$$

Where, D is the ON duty ratio of the switch, and f_s is the switching frequency of the converter.

- Considering the slow varying voltage ripples at the output side, the **DC link capacitor** is selected as,
$$C_d = \frac{I_{dc}}{2\omega\Delta V_{dc}} = \frac{P_o/V_{dc}}{2\omega\delta V_{dc}}$$

Where, δ is the voltage ripples across DC link capacitor (C_d).

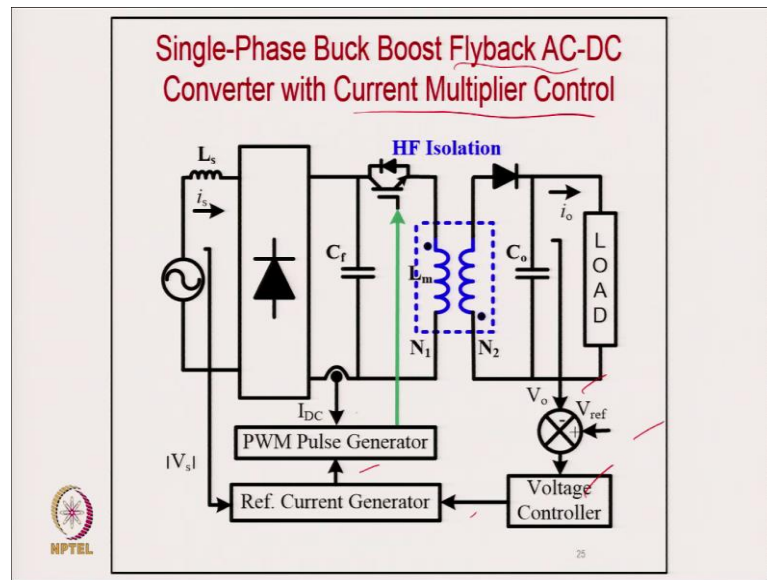
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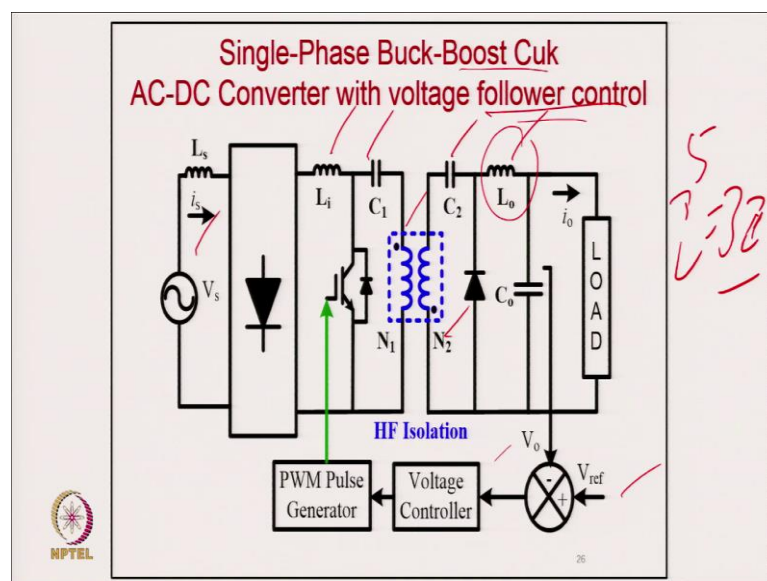
**Single Phase Buck-Boost
AC-DC Converters with High Frequency
Transformer Isolation**

Coming to now the single phase buck boost AC DC converters with high frequency transformer isolation.

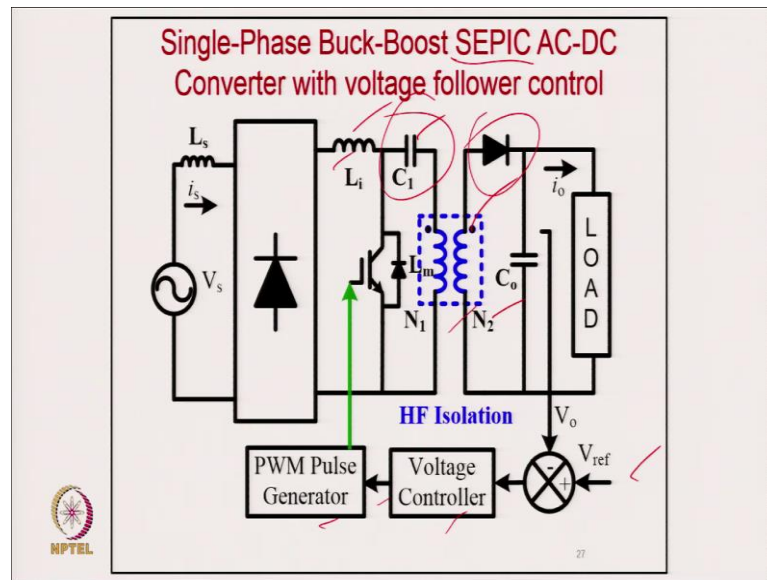
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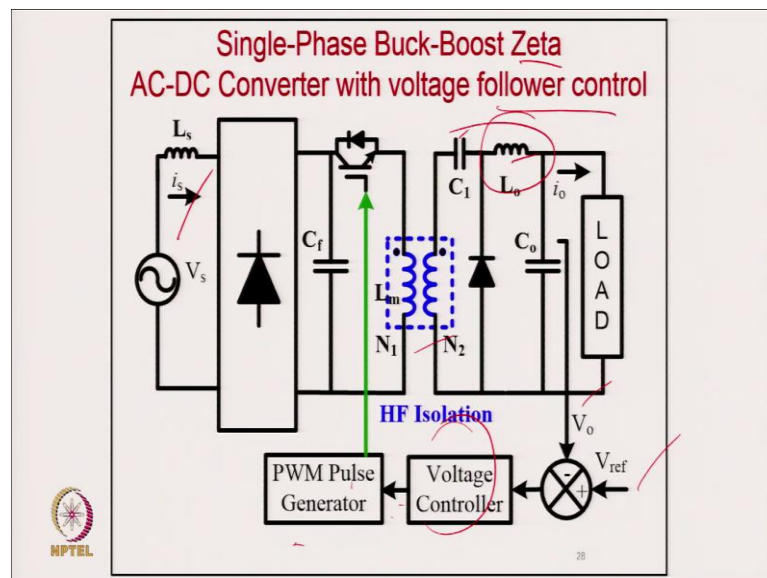
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Design Equations of Isolated Buck-Boost PFC Topologies in CCM and DCM

Flyback Converter	$V_o = V_{in} \{D / (1-D)\} (N_2/N_1)$
	$L_m = V_{in} D / (f_s \Delta i_{Lm})$ (CCM)
	$L_{m(critical)} = \{V_{in}(N_2/N_1) - V_o\} DR / 2f_s V_o$ (DCM)
Cuk Converter	$V_o = D (N_2/N_1) V_{in} / (1-D)$
	$L_m = V_{in} D / (f_s \Delta i_{Lm})$ (CCM)
	$L_n = V_o (1-D) / (f_s \Delta i_{Ln})$
	$C_1 = V_{in} (N_2/N_1)^2 D^2 / (R_f (1-D) \Delta V_{C1})$
	$C_2 = V_o D / (R_f \Delta V_{C2})$
	$L_{m(critical)} = R_f (1-D)^2 / \{2Df_s (N_2/N_1)^2\}$ (DCM)
SEPIC Converter	$V_o = V_{in} (N_2/N_1) D / (1-D)$
	$L_m = V_{in} D / (f_s \Delta i_{Lm})$ (CCM)
	$L_n = V_o (1-D) / (n f_s \Delta i_{Ln})$
	$C_1 = (N_2/N_1) V_o D / (R_f \Delta V_{C1})$
	$L_{m(critical)} = R_f (1-D)^2 / \{2Df_s (N_2/N_1)^2\}$ (DCM)
Zeta Converter	$V_o = (N_2/N_1) V_{in} D / (1-D)$
	$L_m = V_{in} D / (f_s \Delta i_{Lm})$
	$L_n = V_o (1-D) / (f_s \Delta i_{Ln})$ (CCM)
	$C_1 = V_o D / (R_f \Delta V_{C1})$
	$L_{m(critical)} = R_f (1-D)^2 / \{2Df_s (N_2/N_1)^2\}$ (DCM)
DC Link Capacitor for all Converters	$C_o = I_{avg} / (2\omega \Delta V_o)$

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Power Quality Parameters of Isolated Buck-Boost PFC Topologies in CCM (at 48 V DC 100 W Load)

S.N.	PFC Converter Topology	THD (% of I_a)	DF	DPF	PF	CF	ΔV_o (V)	Design values of components and control parameters
1	Flyback	3.66	0.999	0.999	0.998	1.53	0.15	$C_1=5nF, L_m=37mH, C_2=24mF, K_p=0.2985, K=5.985$
2	Cuk	4.52	0.999	1.000	0.999	1.56	0.15	$L=27mH, C_1=87nF, L_n=0.37mH, C_2=8.7nF, C_3=24mF, K_p=0.3985, K=3.985$
3	SEPIC	4.78	0.999	1.000	0.999	1.54	0.15	$L=16mH, C_1=87nF, C_2=24mF, K_p=0.185, K=1.85$
4	Zeta	3.48	0.999	1.000	0.999	1.47	0.15	$C_1=9nF, L_m=3.3mH, C_2=174nF, L_n=1.64mH, C_3=24mF, K_p=0.485, K=4.85$

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Comparison of Isolated Buck-Boost PFC Topologies with in CCM
($V_{o \text{ base}}=48\text{V}$, $I_{o \text{ base}}=2.08\text{A}$)


S. N.	PFC Converter Topology	Switch Current Rating (PU)			Switch Voltage Rating (V)		Power Density	Cost	Transient Response of V_o	
		Av	RMS	Peak	Peak	Selected			Over shoot (%)	Under shoot (%)
1	Flyback	0.2	0.43	1.27	400	600	low	low	2.81	2.81
2	Cuk	0.19	0.49	1.44	400	600	medium	medium	2.20	2.50
3	SEPIC	0.19	0.43	1.28	400	600	medium	medium	2.60	2.50
4	Zeta	0.19	0.43	1.37	400	600	medium	medium	1.95	2.02



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Power Quality Parameters of Isolated Buck-Boost PFC Topologies in DCM
(at 48 V DC 100 W Load)

S.N.	PFC Converter Topology	THD (% of I_o)	DF	DPF	PF	CF	ΔV_o (V)	Design values of components and control parameters
1	Flyback	5.04	0.999	0.995	0.994	1.46	0.15	$L_m=37\text{mF}$, $C_3=3.4\text{nF}$, $C_2=24\text{mF}$, $K_2=0.4985$, $K_3=5.985$
2	Cuk	4.56	0.999	0.997	0.996	1.42	0.15	$L_1=5.2\text{mH}$, $C_1=0.22\mu\text{F}$, $L_2=15\mu\text{H}$, $C_2=22\mu\text{F}$, $C_3=24\text{mF}$, $K_2=0.2985$, $K_3=5.861$
3	SEPIC	4.91	0.999	0.998	0.997	1.47	0.15	$L_1=2.1\text{mH}$, $C_1=0.22\mu\text{F}$, $L_2=120\mu\text{H}$, $C_2=24\text{mF}$, $K_2=0.125$, $K_3=2.251$
4	Zeta	4.81	0.999	0.997	0.996	1.43	0.15	$C_1=220\text{nF}$, $C_2=10\mu\text{F}$, $L_1=12\mu\text{H}$, $C_3=24\text{mF}$, $K_2=0.1985$, $K_3=2.851$




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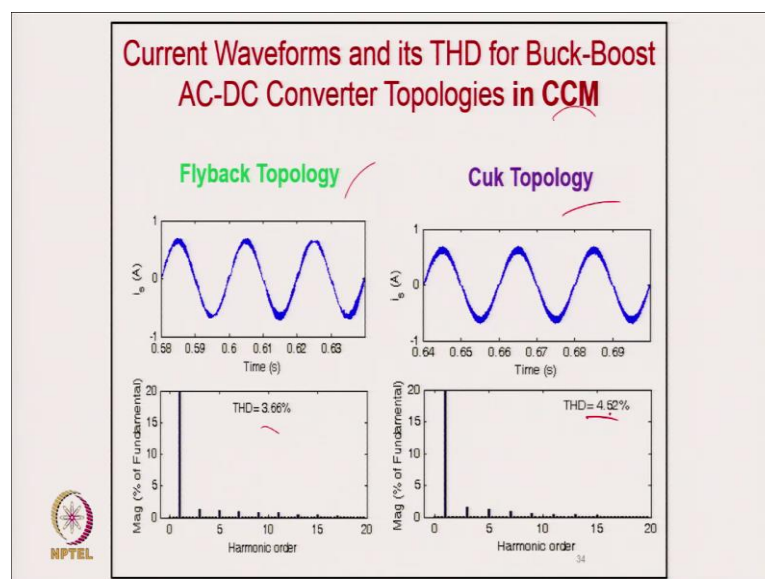
Comparison of Isolated Buck-Boost PFC Topologies with in DCM

($V_{o \text{ base}}=48V$, $I_{o \text{ base}}=2.08A$)

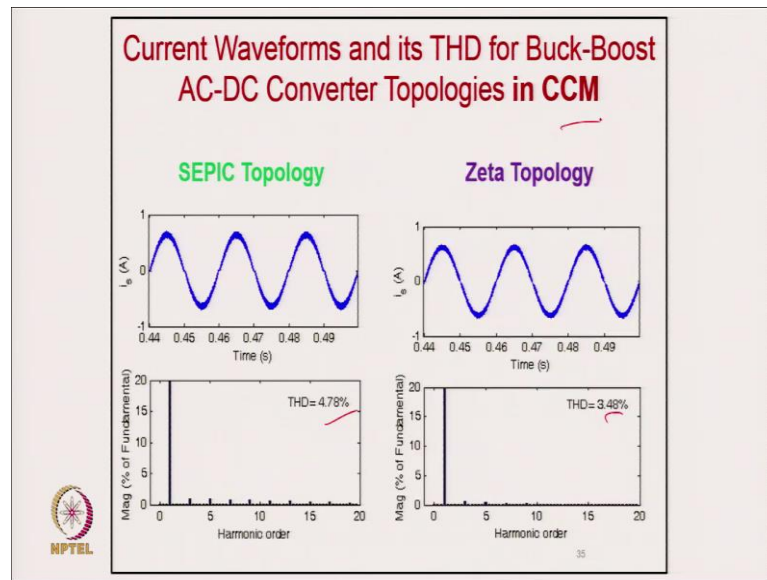
S. N.	PFC Converter Topology	Switch Current Rating (PU)			Switch Voltage Rating (V)		Power Density	Cost	Transient Response of V_o	
		Av	RMS	Peak	Peak	Selected			Over shoot (%)	Under shoot (%)
1	Flyback	0.22	0.48	1.42	400	600	low	low	2.05	1.87
2	Cuk	0.19	0.51	1.54	400	600	low	low	2.19	2.5
3	SEPIC	0.21	0.58	1.61	400	600	low	low	1.29	1.25
4	Zeta	0.21	0.48	1.44	400	600	low	low	3.54	4.79



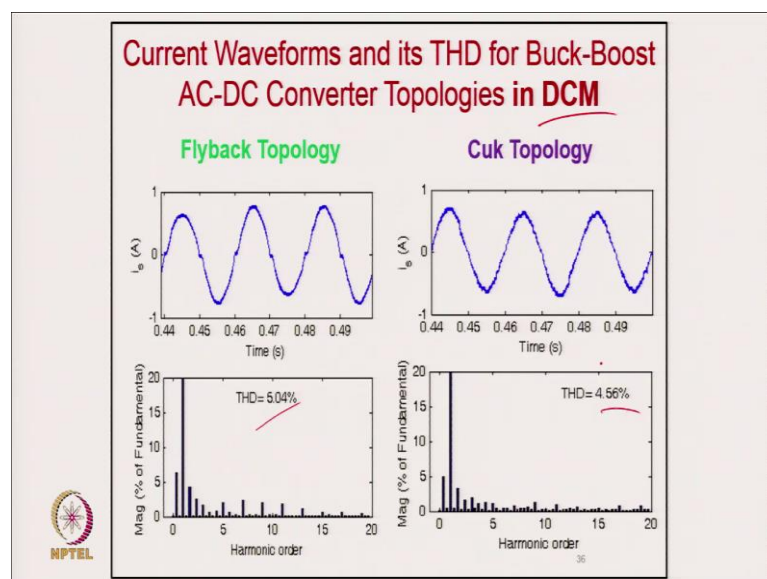
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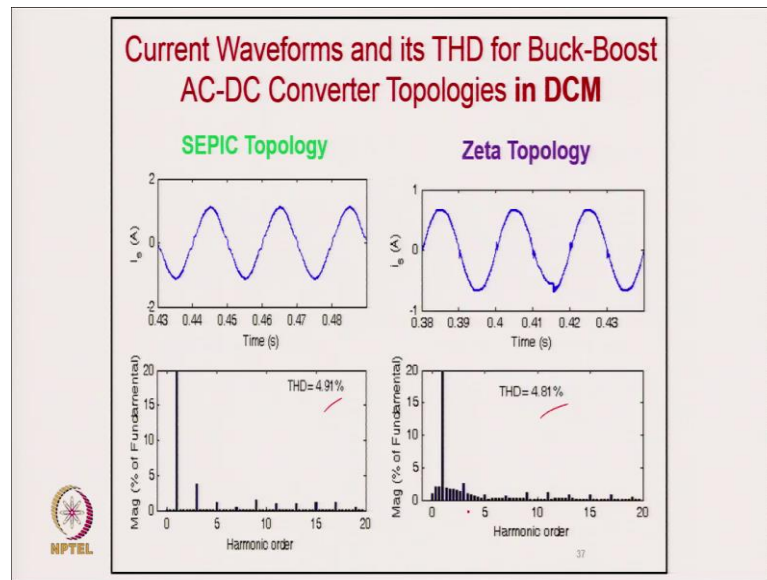
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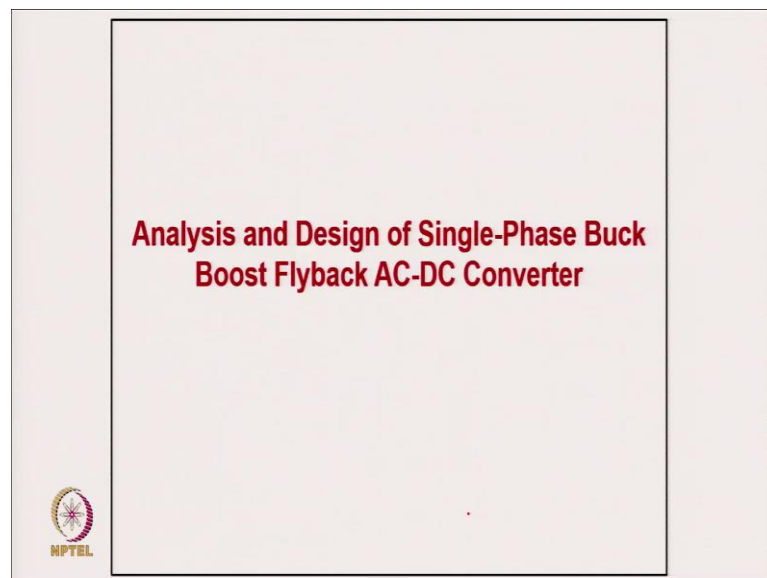
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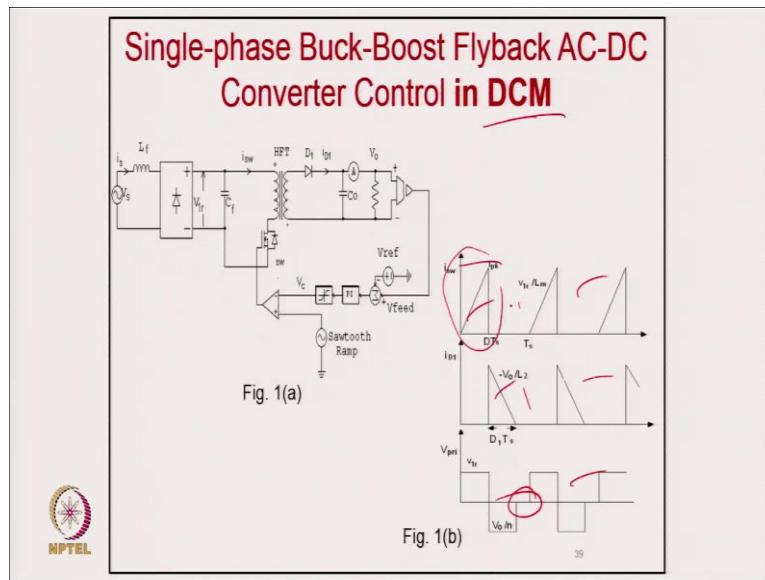
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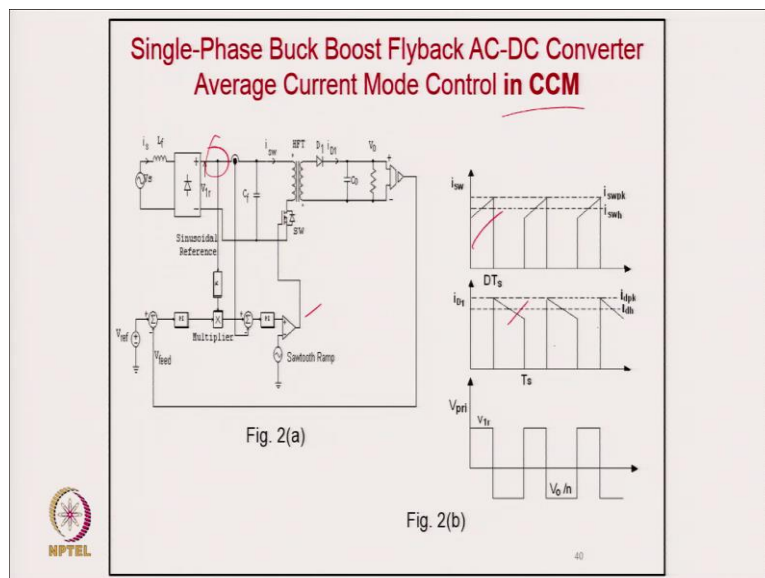
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Single-Phase Buck Boost Flyback AC-DC Converter in DCM

The average input current over a switching cycle is given as:


$$i_1 = \frac{1}{2} I_{pk} D \quad (1)$$

Where I_{pk} is the peak of input current (that's switch current) and D is the duty ratio. From Fig. 1b I_{pk} is given as:

$$I_{pk} = \frac{DT_s}{L_m} v_{1r} \quad (2)$$

Where v_{1r} is rectified input voltage and L_m is transformer magnetizing inductance referred to primary.

From (1) and (2), the input current is as: $i_1 = \frac{D^2 T_s}{2L_m} v_{1r} \quad (3)$

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Equation (3) presents nicely PFC operation in DCM. It is clear that if duty cycle and switching frequency is kept constant, then input current is a linear function of input voltage. Eqn. (3) can be written as:

$$i_1 = I_1 |\sin \omega t| \quad (4)$$


where,

$$v_{1r} = V_1 |\sin \omega t| \quad (5)$$
$$I_1 = \frac{V_1 D^2 T_s}{2L_m} \quad (6)$$

The transfer function of the flyback converter in DCM is given as:

$$V_o = \frac{D v_{1r}}{D_2 n} \quad (7)$$

Where n is the turn ratio. From Fig. 1b, for DCM operation, the condition is:

$$D + D_2 < 1 \quad (8)$$
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From Eqns. (7) and (8), for the desired maximum duty ratio at minimum input voltage, turn ratio can be obtained by satisfying following inequality as:


$$n > \frac{D}{(1-D)} \frac{V_i}{V_o} \quad (9)$$

In order to ensure DCM of operation at maximum load, following condition must be satisfied

$$L_m < \frac{R_{Lmin}}{4f_s \left(\frac{1}{n} + \frac{V_o}{V_{i,mp}} \right)^2} \quad (10)$$

Where $V_{i,mp}$ is the peak value of minimum input voltage. R_{Lmin} is the minimum value of load resistance and f_s is the switching frequency.

Output capacitor is selected on the basis of maximum peak-to-peak ripple in output voltage (r_v) as:

$$C_o > \frac{V_o}{r_v \omega R_L} \quad (11)$$


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Stresses on semiconductor devices in DCM can be given by following equations,

Peak current through switch is given as:

$$I_{s, \text{pk}} = \frac{V_i D T_s}{L_m} \quad (12)$$


Peak voltage across switch is given as:

$$V_{s, \text{pk}} = V_i + n V_o \quad (13)$$

Similarly, peak current through diode is as:

$$I_{d, \text{pk}} = \frac{n^2 V_i D T_s}{L_m} \quad (14)$$

and peak voltage across the diode can be given as:

$$V_{d, \text{pk}} = \frac{V_i}{n} + V_o \quad (15)$$


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Single-Phase Buck Boost Flyback AC-DC Converter in CCM


For CCM operation, the transfer function is given as:

$$V_o = \frac{D V_{ir}}{(1-D)n} \quad (16)$$

Thus in a similar manner as in DCM, for desirable maximum duty ratio, the turn ratio is determined. However, magnetizing inductance of the transformer is defined by satisfying the following inequality:

$$L_m > \frac{R_{l,max}}{4f_s \left(\frac{V_o}{V_{i,min}}\right)^2} \quad (17)$$

Referring Fig. 2b, switch current at half of the ripple is given as:

$$I_{sw} = \frac{P_{max}}{V_{i,min} \eta D_{max}} \quad (18)$$


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From Fig 2b, switch peak current for ripple ΔI_{sw} is given as:

$$I_{swpk} = I_{sw} + \frac{\Delta I_{sw}}{2} \quad (19)$$

where, $\Delta I_{sw} = \frac{V_{i,min} D_{max} T_s}{L_m}$ (20)

Switch RMS current is given as:

$$I_{swRMS} = \sqrt{D_{max} [I_{swpk}^2 - \Delta I_{sw} I_{swpk}] + \frac{1}{3} \Delta I_{sw}^2} \quad (21)$$

Similarly diode current at half of the ripple is given as:


$$I_{di} = \frac{I_{o,max}}{(1-D_{max})} \quad (22)$$

From Fig 2b, diode peak current for ripple is given as:

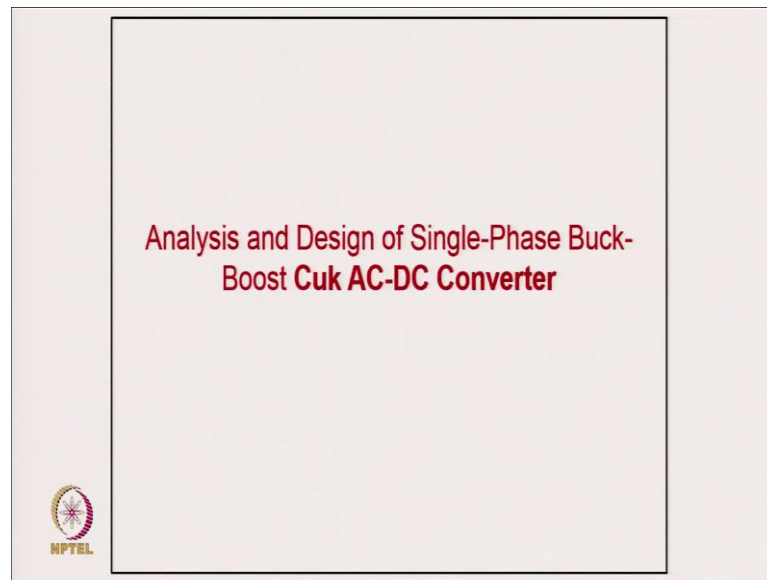
$$I_{di,pk} = I_{di} + \frac{\Delta I_d}{2} \quad (23)$$

Where, $\Delta I_d = \frac{V_o (1-D_{max}) T_s}{L_2}$ (24)

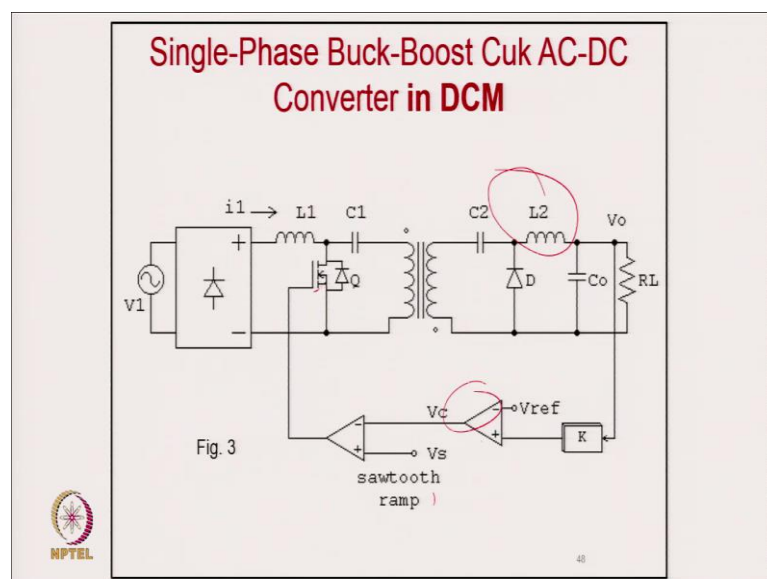
Diode RMS Current is given as

$$I_{diRMS} = \sqrt{(1-D_{max}) [I_{di,pk}^2 - \Delta I_d I_{di,pk}] + \frac{1}{3} \Delta I_d^2} \quad (25)$$


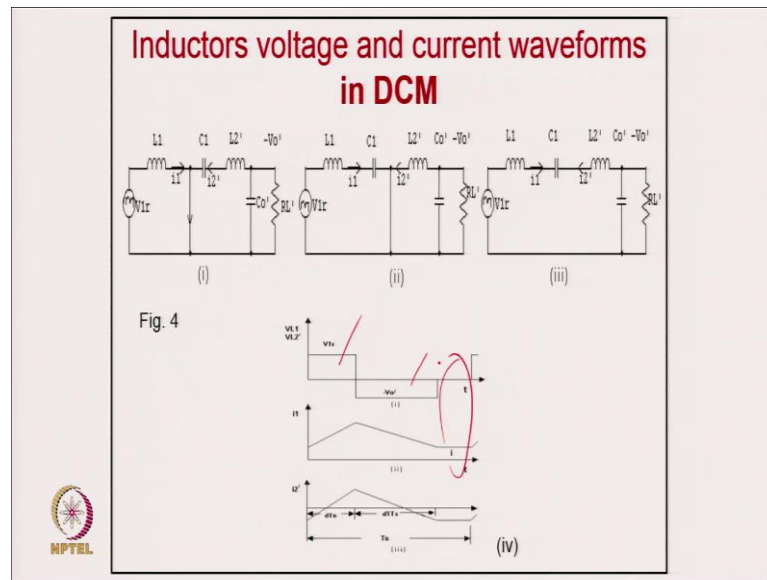
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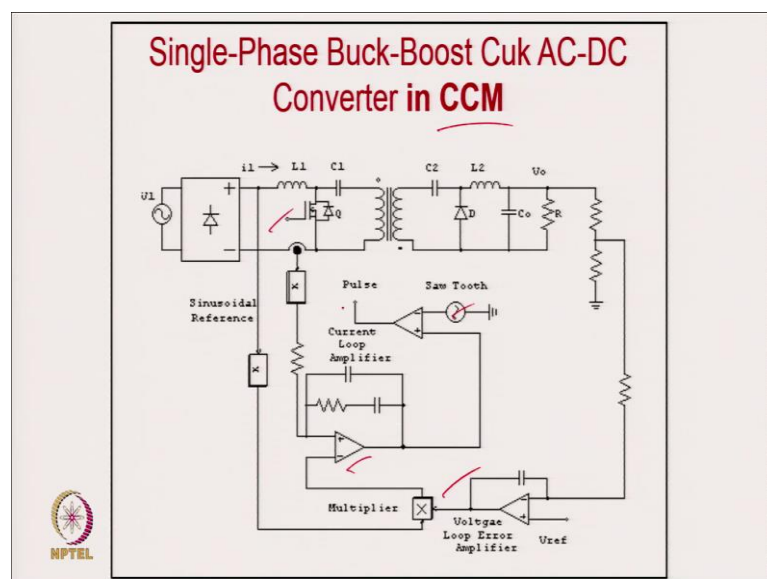
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• **First stage of Operation**

When switch is on, two inductor currents increase linearly with the voltage across them equal to input voltage. The equations of input and output inductor currents for the interval (referring to Fig. 4(i)) are given by:

$$i_1 = i + \frac{V_{Ir}}{L_1} t \quad (3)$$


$$i_2' = -i + \frac{V_{Ir}}{L_2'} t \quad (4)$$

where i is the minimum input inductor current.

• **Second Stage of Operation**

When switch is off, inductor currents decrease linearly with voltage across them equal to output voltage. Referring to Fig. 4(ii) and Fig. 4(iv), inductor currents are given by:

$$i_1 = -\frac{V_o'}{L_1} t + \frac{V_{Ir}}{L_1} dT_s + i \quad (5)$$

$$i_2' = -\frac{V_o'}{L_2'} t + \frac{V_{Ir}}{L_2'} dT_s - i \quad (6)$$


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• **Third stage of Operation**

This is the stage when the diode current is zero.

Averaged input and output inductor currents over a switching period can be given by:


$$i_1 = \frac{V_{Ir}}{2L_1} dT_s (d + d_1) + i \quad (7)$$

$$i_2' = \frac{V_{Ir}}{2L_2'} dT_s (d + d_1) - i \quad (8)$$

Sum of the input and output inductor currents is given by:

$$i_1 + i_2' = \frac{1}{2} \frac{V_{Ir}}{L_{eq}} dT_s \left(1 + \frac{d_1}{d}\right) d \quad (9)$$

where,

$$L_{eq} = \frac{L_1 L_2'}{L_1 + L_2'} \quad (10)$$


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By substituting the expression in eqn. (2) in to eqn. (9), we get:

$$i_l \left(1 + \frac{d_1}{d}\right) = \frac{1}{2} \frac{v_{1r}}{L_{eq}} d^2 T_s \left(1 + \frac{d_1}{d}\right) d \quad (11)$$

After simplification it gives:


$$i_l = \frac{v_{1r} d^2 T_s}{2L_{eq}} \quad (12)$$

It can be written as:

$$i_l = I_1 |\sin \omega t| \quad (13)$$

where,

$$v_{1r} = V_1 |\sin \omega t| \quad (14)$$

$$I_1 = \frac{V_1 d^2 T_s}{2L_{eq}} \quad (15)$$


(Refer Slide Time: 33:03)

Average and peak currents in the semiconductors and input inductor

Average current (i_{swav}) and peak current (i_{swpk}) of the MOSFET switch over a switching cycle are as:


$$i_{swav} = \frac{v_{1r}}{L_{eq}} \left(\frac{d^2 T_s}{2} \right) + (I_{1max} + I_{2max}') \cdot d \quad (16)$$

$$i_{swpk} = (I_{1max} + I_{2max}') \quad (17)$$

Where I_{1max} and I_{2max}' are the maximum value of input inductor current and output inductor current (referred to primary) respectively.

Average current (i_{dav}'), and peak current (i_{dpk}') of the diode (all referred to primary) are as:

$$i_{dav}' = \frac{v_o}{L_{eq}} \left(\frac{d^2 T_s}{2} \right) + (I_{1max} + I_{2max}') \cdot (1-d) \quad (18)$$


$$i_{dpk}' = (I_{1max} + I_{2max}') \quad (19)$$


(Refer Slide Time: 33:22)

Peak voltage across switch (V_{swpk}) and diode (V_{dpk}) (referred to primary) is given as:

$$V_{swpk} = V_{dpk} = V_{inmax} + V_o' \quad (20)$$

The average current (i_{L1av}) and RMS current (i_{L1rms}) of input inductor are as:

$$i_{L1av} = \frac{2I_{1max}}{\pi} \quad (21)$$
$$i_{L1rms} = \frac{I_{1max}}{\sqrt{2}} \quad (22)$$


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(Refer Slide Time: 33:36)

Single-Phase Cuk AC-DC Converter Design Description in DCM and CCM

Step 1: Conversion ratio

Defining the dc voltage conversion ratio (M) as,

$$M = \frac{V_o}{V_{1r}} \quad (23)$$

where,

$$v_{1r} = V_1 |\sin \omega t| \quad (24)$$


For $\omega t = 90^\circ$, conversion ratio is obtained as the first step of the design. Here V_1 is the peak value of input voltage.

Step 2: Condition for operation in DCM and CCM

Design must ensure the DCM operation, for which following inequality must hold good:

$$K_e < \frac{1}{2(M+n)^2} \quad (25)$$

Where K_e is the conduction parameter and n is the transformer primary to secondary turn ratio.



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(Refer Slide Time: 34:11)

For CCM, following condition must be satisfied to ensure the continuous conduction mode of operation:

$$K_e > \frac{1}{2(M+n)^2} \quad (26)$$

K_e is calculated for minimum value of M which occurs at minimum output voltage and maximum input voltage in CCM for given range of specification.


Step 3: Equivalent inductance (L_{eq}) which is the parallel combination of L_1 and L_2' , is given as:

$$L_{eq} = \frac{K_e R_L \Gamma_s}{2} \quad (27)$$

Where R_L is the load resistance.

Step 4: Duty Ratio

The duty ratio for the given power (load resistance) in DCM is obtained by:

$$d = \sqrt{2M} \sqrt{K_e} \quad (28)$$


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Step 5: L_1 and L_2' Design


L_1 can be obtained by considering the specified maximum current ripple for DCM as:

$$L_1 = \frac{2L_{eq}}{d r_i} \quad (29)$$

Where r_i is p.u. ripple current.

L_2' can be obtained using expressions for L_1 and L_{eq} in eqns. (29) and (10) respectively.

Similarly, for CCM L_1 and L_2' can be obtained by specified maximum current ripple allowed and eqn. (10).



60

(Refer Slide Time: 34:56)

Step 6: Design of energy transfer capacitor C_1
It has great influence on input current waveform. To avoid input current oscillations at every line half cycle, it is given by:


$$C_1 = \frac{1}{\omega_r^2(L_1 + L_2')} \quad (30)$$

where, $\omega_L < \omega_r < \omega_s$
Resonant frequency (ω_r) should lie between line frequency (ω_L) and switching frequency (ω_s).

Step 7: Output Capacitor
Output capacitor is chosen according to specified ripple allowed in the output voltage. It can be achieved by following formula:

$$C_o = \frac{1}{\omega_L r_v R_{Lmin}} \quad (31)$$


Where r_v is the pu ripple in the output voltage and R_{Lmin} is the minimum load resistance.



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(Refer Slide Time: 35:35)

Modelling and Simulation of Single-Phase Buck Boost Flyback AC-DC Converter




(Refer Slide Time: 35:43)

Specifications

Input Voltage (V_1) – 220 V/50Hz, Single-Phase Supply
Output Voltage (V_o) – 110 V, P_o – 1000 W
Output voltage-ripple less than 2%
Switching frequency f_s – 50 kHz

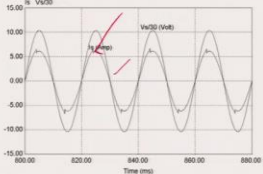
Design parameters for DCM
Transformer turn ratio (n) 1.5:1,
Magnetizing inductance $L_m = 50 \mu\text{H}$, $L_r = 1 \text{ mH}$, $C_r = 800 \text{ nF}$, and $C_o = 15 \text{ mF}$.



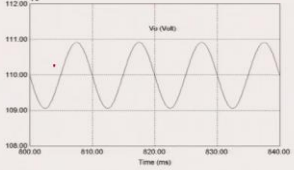
63

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Single-Phase Buck Boost Flyback AC-DC Converter (in DCM)



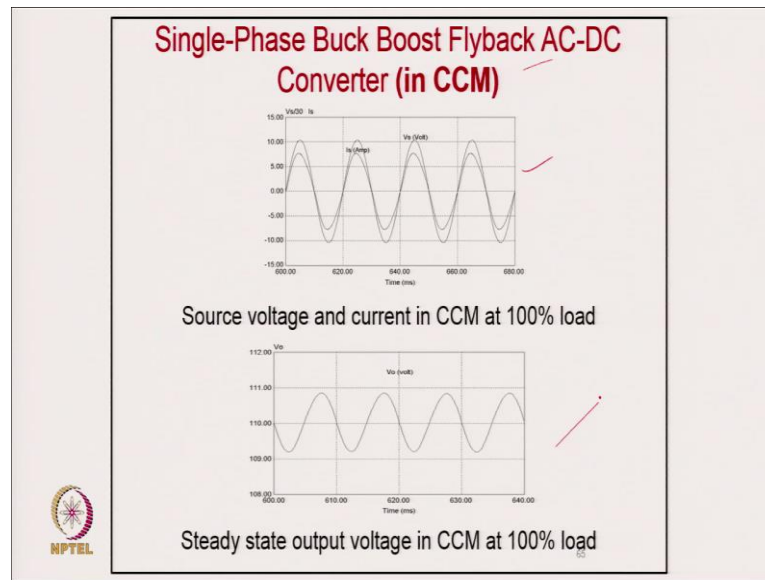
Source voltage and current in DCM at 100% load



Steady state output voltage in DCM at 100% load




(Refer Slide Time: 36:33)



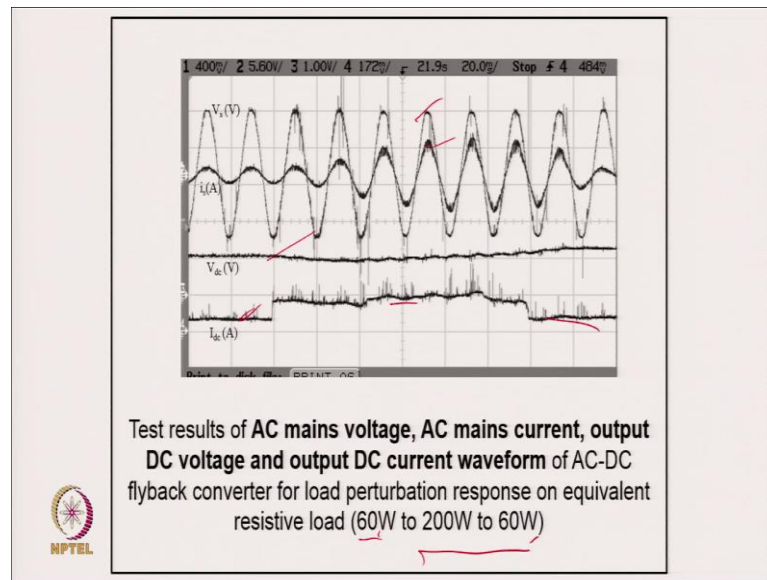
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Comparisons of Buck Boost Flyback AC-DC Converter Operation in DCM and CCM

Quantity	DCM Operation		CCM Operation		
	10% Load	100% Load	10% Load	100% Load	
Input Current THD	12%	5.1%	11%	4.4%	
PF	0.981	0.997	0.989	0.998	
Output Ripple	0.55%	1.73%	0.52%	1.45%	
Normalized Current of Switch (pu)	Peak	25.1	6.73	2.60	
	Average	0.93	0.71	0.54	0.67
	RMS	2.87	1.62	1.35	1.14
Normalized Current of Diode (pu)	Peak	14.5	9.76	10.13	3.95
	Average	1.13	1.48	1.29	1.16
	RMS	5.27	2.86	2.57	1.90
Control Technique	Voltage Mode Control		Average Current Control		
Size of Converter	Small		Large		
Circuit Simplicity	Simple		Complex		



(Refer Slide Time: 37:41)



(Refer Slide Time: 38:05)

Modelling, Simulation and Performance of Single-Phase Cuk AC-DC Converter

NPTEL

Now, coming to the Cuk converter modelling and simulation performance.

(Refer Slide Time: 38:11)

Specifications

Input Voltage (V_1) – ~~160~~ 270 V_{RMS}, 50Hz, Single-Phase AC Supply


Output Voltage (V_o) – ~~98~~ 132 V adjustable with nominal value of ,

Output voltage-ripple less than ~~2%~~

Switching frequency (f_s) – 50 kHz

Design parameters for DCM mode:

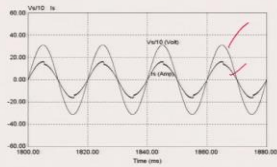
Transformer turn ratio (n) 1:1,
 L_1 – 1500 μ H, L_2 – 4.3 μ H, C_1 – 2.5 μ F, C_2 – 10 μ F,
and C_o – 30 mF



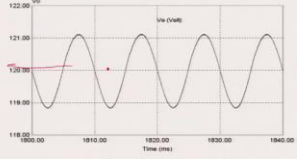
69

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Single-Phase Buck-Boost Cuk AC-DC Converter



Source voltage and current in DCM at 100% load

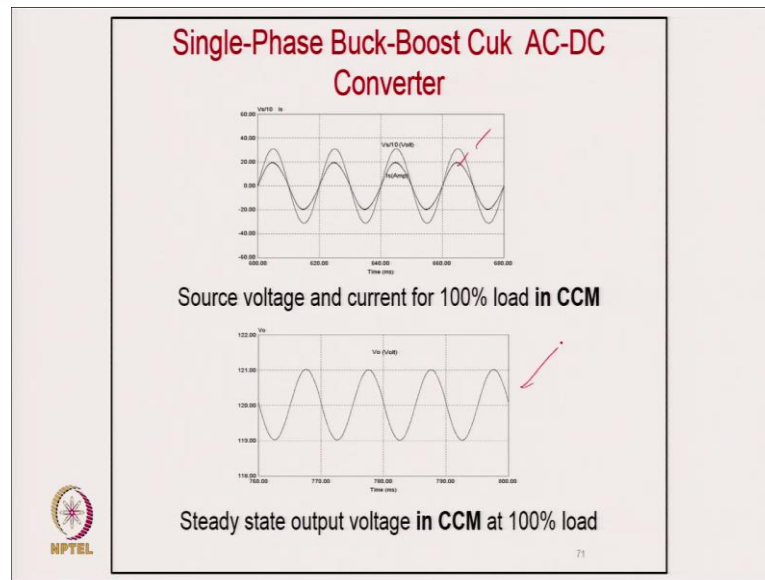


Steady state output voltage in DCM at 100% load



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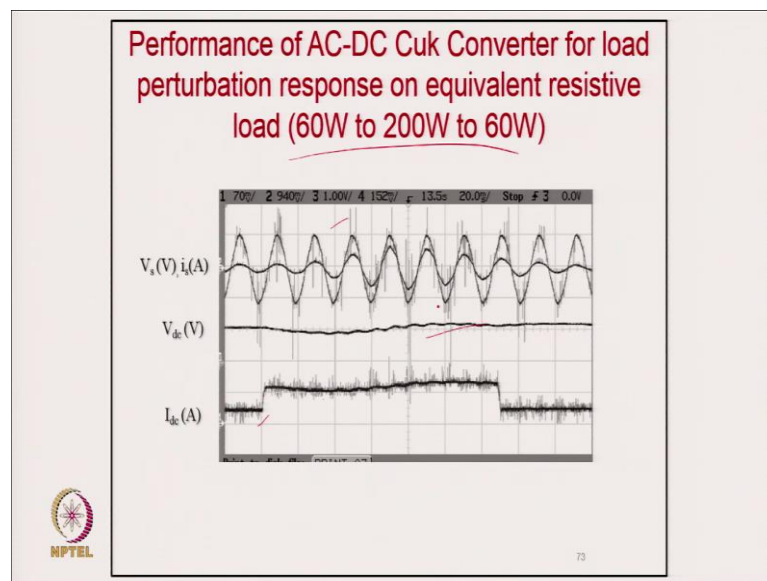


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Comparisons of Cuk Converter Operation in DCM and CCM at Full Load

Quantity	DCM Operation	CCM Operation
Input Current THD	5.5%	3.8%
PF	0.998 to 1.0	0.9975 to 1.0
Ripple Factor	1.83%	1.67%
Peak Current Through Device	170A	60A
Control Technique	Voltage Mode Control	Average Current Control
Size of Converter	Small	Large
Circuit Simplicity	Simple	Complex

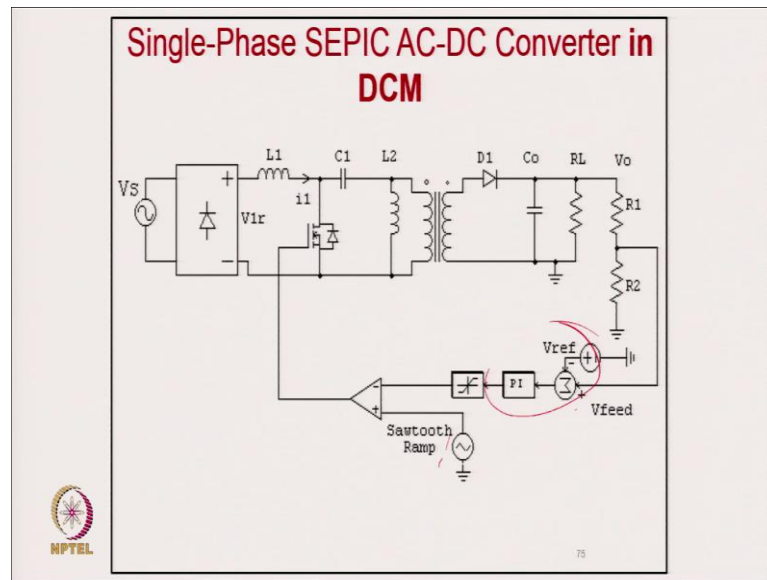
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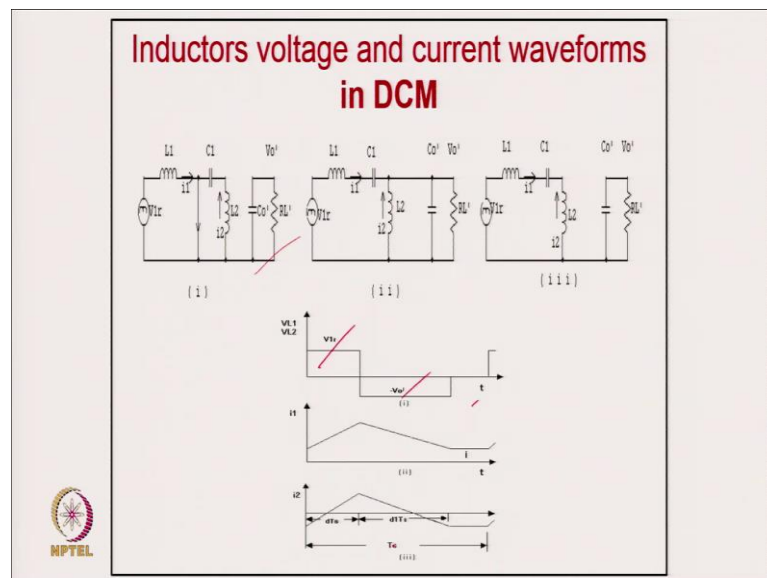
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Modelling, Simulation and Performance of Single-Phase SEPIC AC-DC Converter

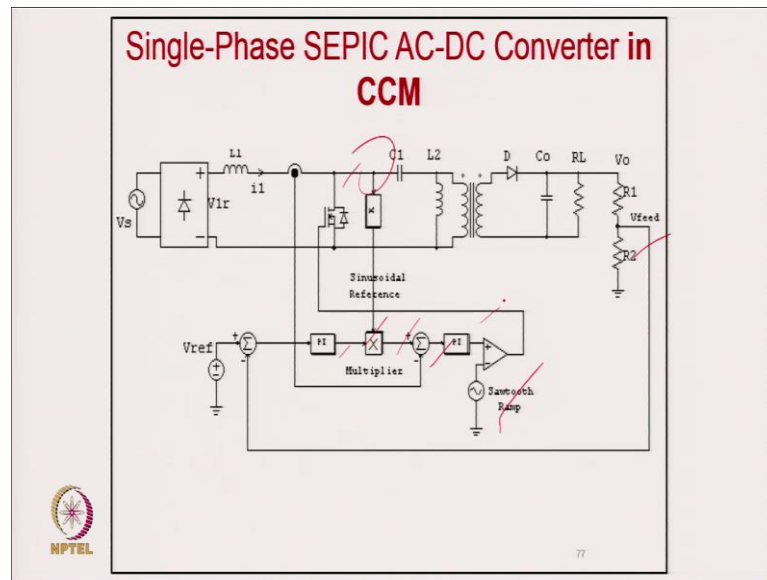
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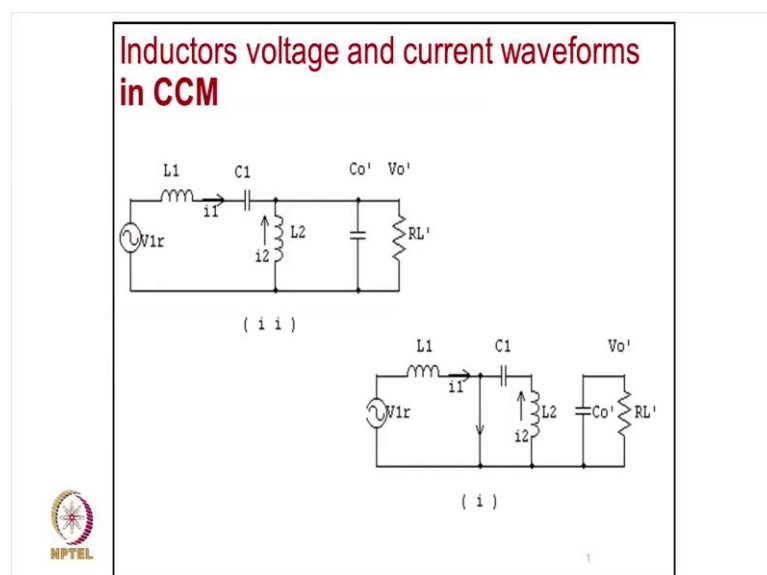
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Specifications

Input Voltage (V_1) – 230 V_{RMS} , 50Hz, Single-Phase AC Supply

Output Voltage (V_o) – 110 V, P_o – 1.5 kW


Output voltage-ripple less than 2%

Switching frequency (f_s) – 50 kHz

Design parameters for DCM mode:

Transformer turn ratio (n), 1:1,
 L_1 – 1200 μ H, L_2 – 8.1 μ H, C_1 – 1 μ F, and C_o – 30 mF.

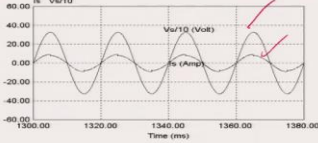
PI controller parameters: gain = 0.308, time constant – 0.03



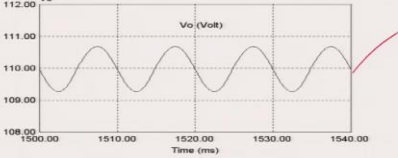
79

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Performance of Single-Phase SEPIC AC-DC Converter in DCM



Source voltage and current in DCM at 100% load

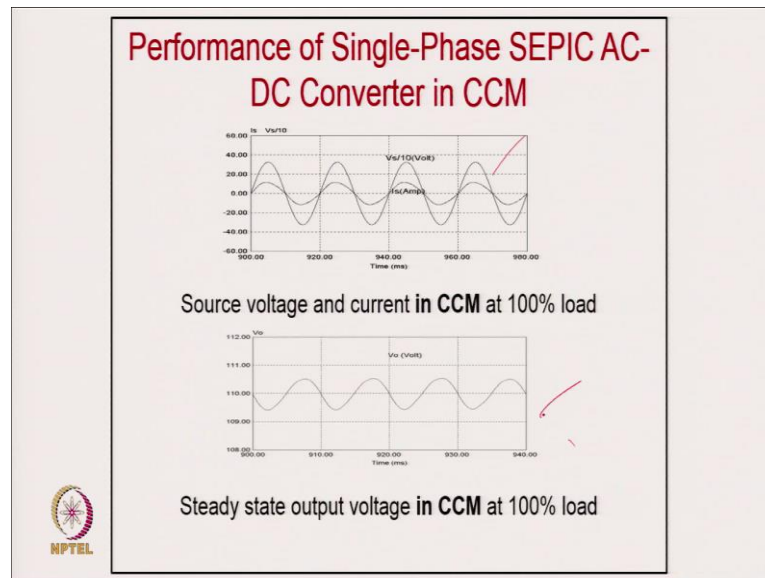


Steady state output voltage in DCM at 100% load



80

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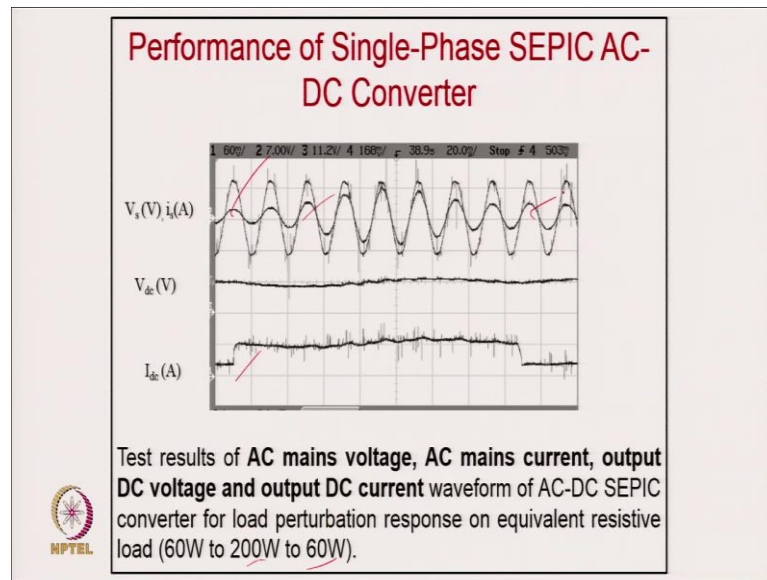


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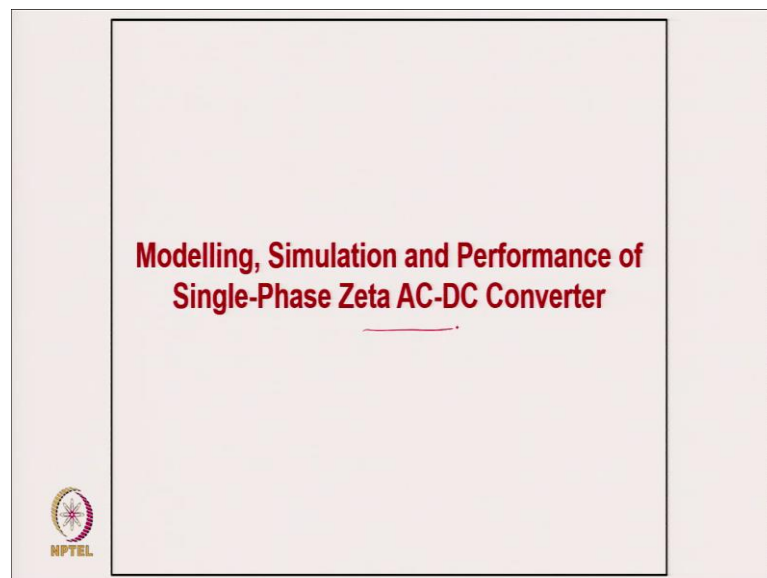
Comparisons of SEPIC Converter Operation in DCM and CCM

Quantity	DCM Operation		CCM Operation	
	10% Load	100% Load	10% Load	100% Load
Input Current THD	10%	6%	3.8%	8.5%
PF	0.994	0.997	0.998	0.995
Output Ripple	0.22%	1.27%	1.1%	0.1%
Normalized Current of Switch	Peak	14.50pu	9.84pu	3.14pu
	Average	0.76pu	0.77pu	0.71pu
	RMS	4.60pu	2.18pu	1.50pu
Normalized Current of Diode	Peak	15.2pu	10.94pu	3.17pu
	Average	1.47pu	1.27pu	0.93pu
	RMS	7.22pu	3.34pu	1.68pu
Control Technique	Voltage Mode Control		Average Current Control	
Size of Converter	Small		Large	
Circuit Simplicity	Simple		Complex	

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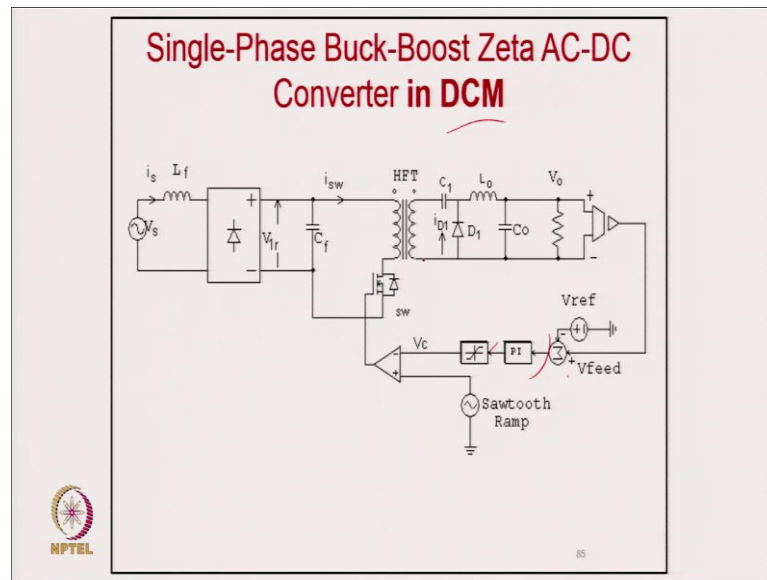


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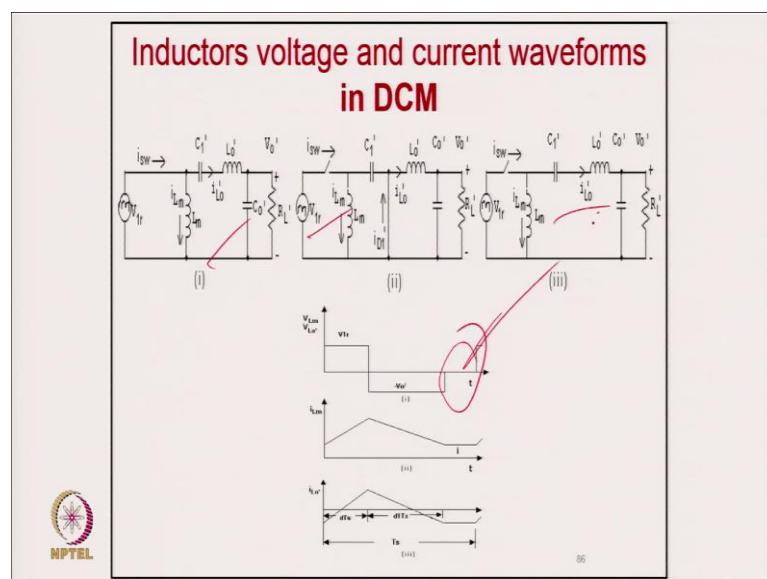


Now coming to the modelling and simulation performance of single phase zeta AC DC converter.

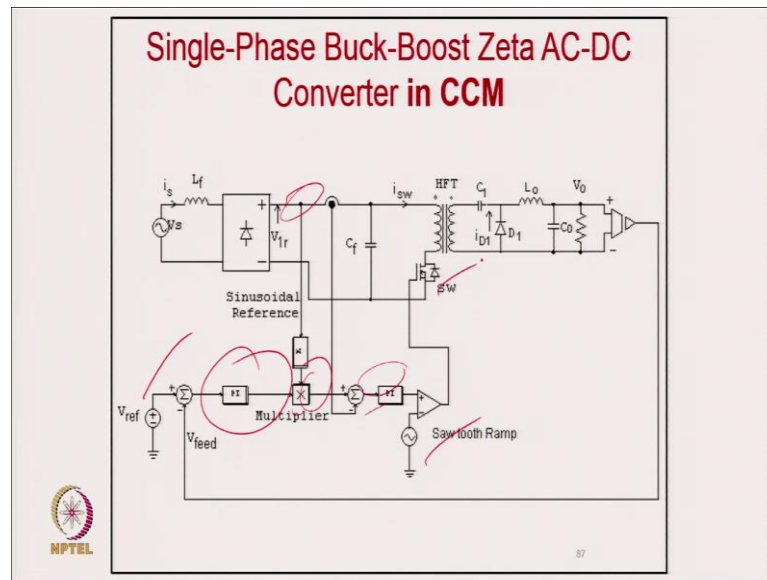
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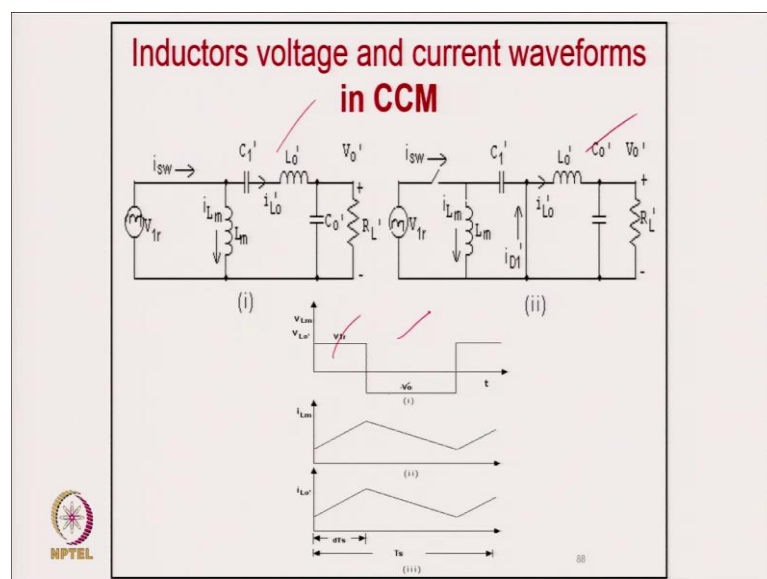
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Specifications

Input Voltage (V_1) – 220 V_{RMS}, 50Hz, Single-Phase AC Supply


Output Voltage (V_0) – 48 V, P_0 – 1 kW

Output voltage-ripple less than 2%

Switching frequency (f_s) – 50 kHz

Transformer turn ratio (n) 5:1,

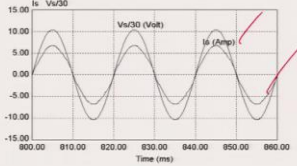
Magnetizing Inductance L_1 – 100 μ H, L_f – 3 mH, L_0 – 10 mH C_1 – 10 μ F, and C_f – 100 nF.



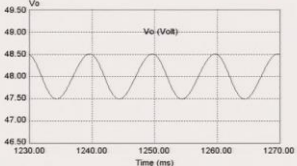
85

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Performance of Single-Phase Buck-Boost Zeta AC-DC Converter in DCM



Source voltage and current in DCM at 100% load

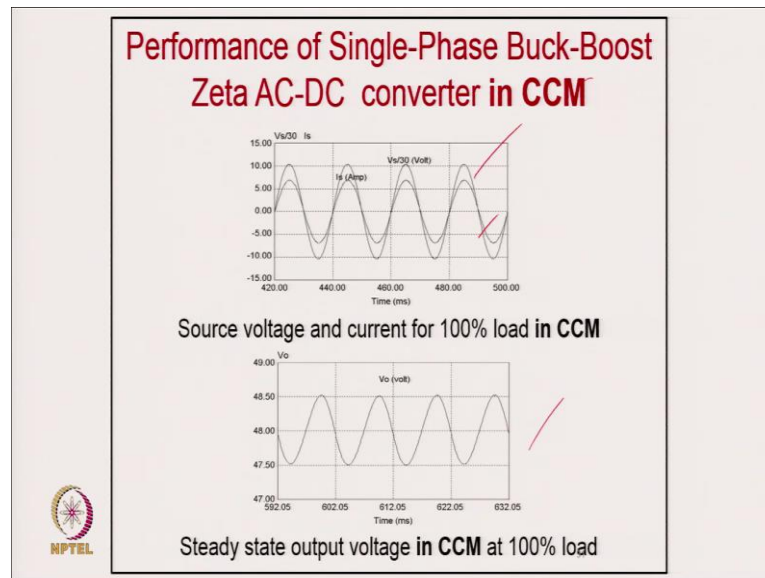


Steady state output voltage in DCM at 100% load

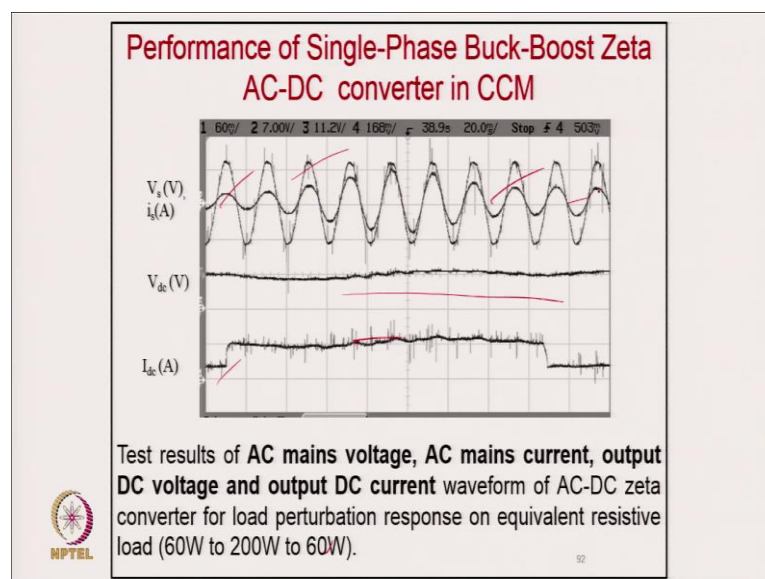


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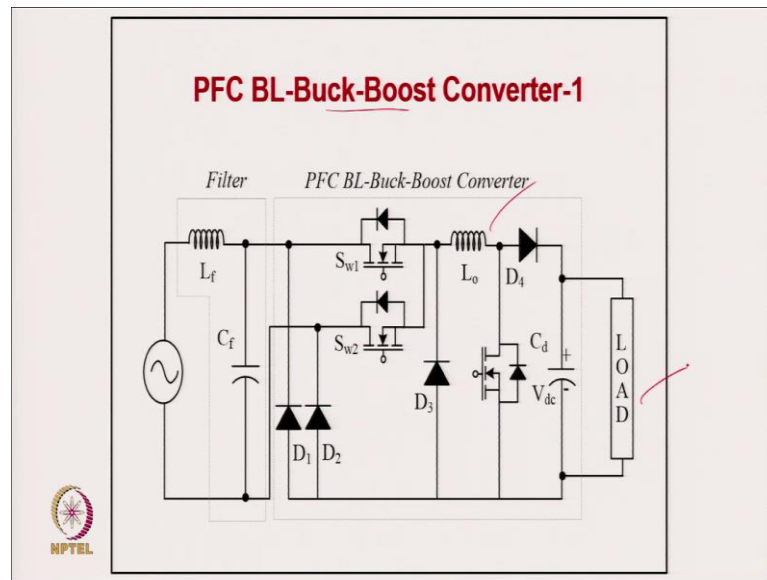
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Comparisons of Zeta Converter Operation in DCM and CCM					
Quantity		DCM Operation		CCM Operation	
		10% Load	100% Load	10% Load	100% Load
Input Current THD		11%	4.98%	9.2%	1.36%
PF		0.993	0.9975	0.994	0.998
Output Ripple		0.62%	1.99%	0.67%	1.98%
Normalized Current of Switch	Peak	9.21	4.15	2.92	1.75
	Average	0.92	1.01	0.45	0.62
	RMS	2.15	1.71	1.04	0.95
Normalized Current of Diode	Peak	36.90	20.01	14.6	8.73
	Average	4.52	3.02	3.24	3.17
	RMS	10.45	5.41	5.37	4.57
Control Technique		Voltage Mode Control		Average Current Control	
Size of Converter		Small		Large	
Circuit Simplicity		Simple		Complex	

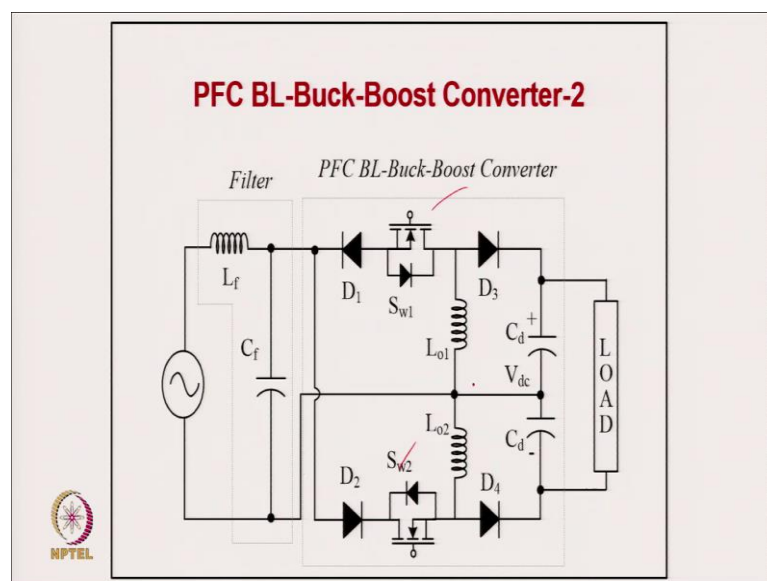
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Analysis, Design, Simulation and Performance of PFC Bridgeless Buck-Boost Converters

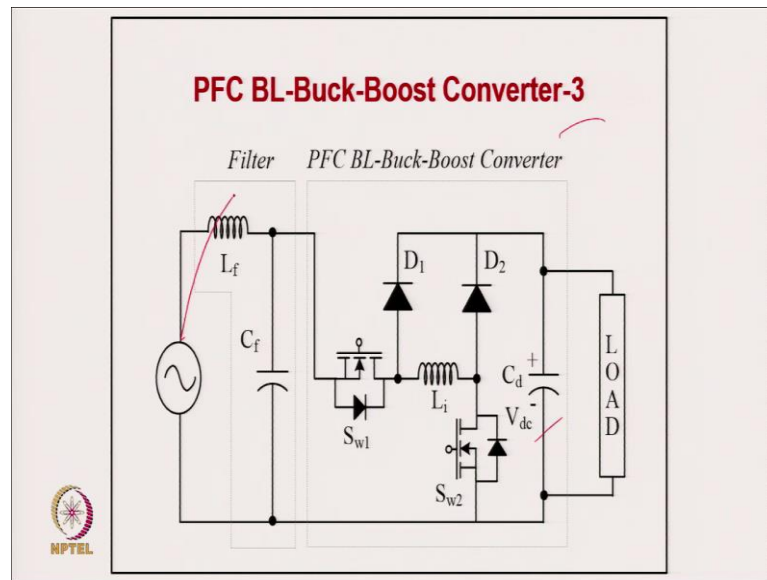
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Design of a PFC BL-Buck-Boost Converter

The average input voltage appearing to input of converter

$$V_{in} = \frac{2\sqrt{2}V_s}{\pi}$$

The voltage conversion ratio is given as,

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

Inductor Operating
in CCM

$$L_i = \frac{V_{in} D}{f_s \Delta I_{L_i}}$$

Inductor Operating in
DCM

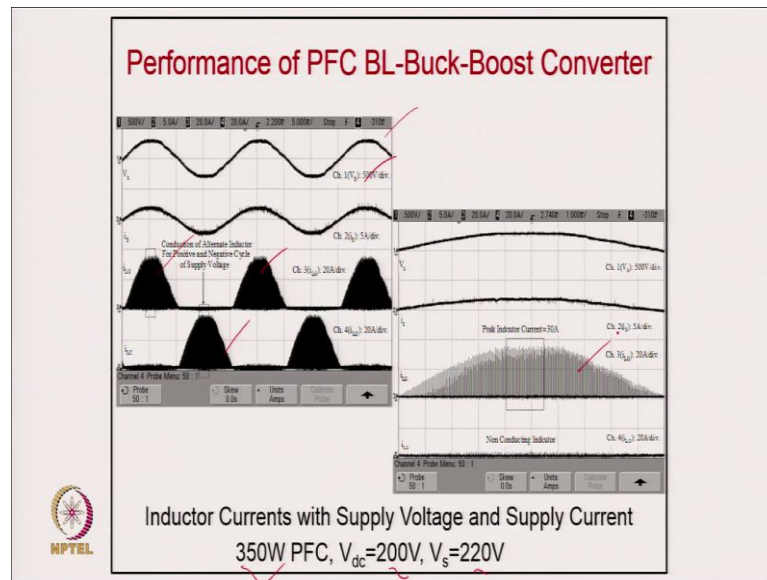
$$L_i \ll L_{ic} = \frac{R(1-D)^2}{2f_s}$$

DC Link Capacitor Design

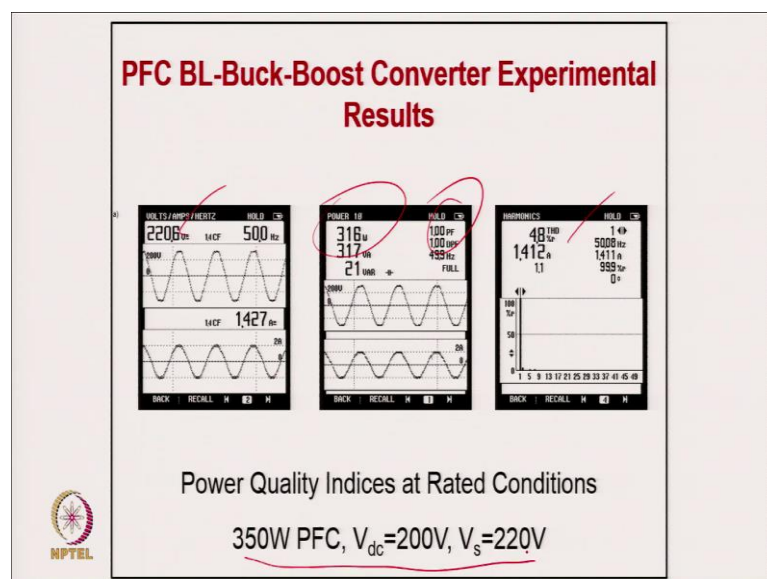
$$C_d = \frac{I_d}{2\omega \Delta V_{dc}}$$

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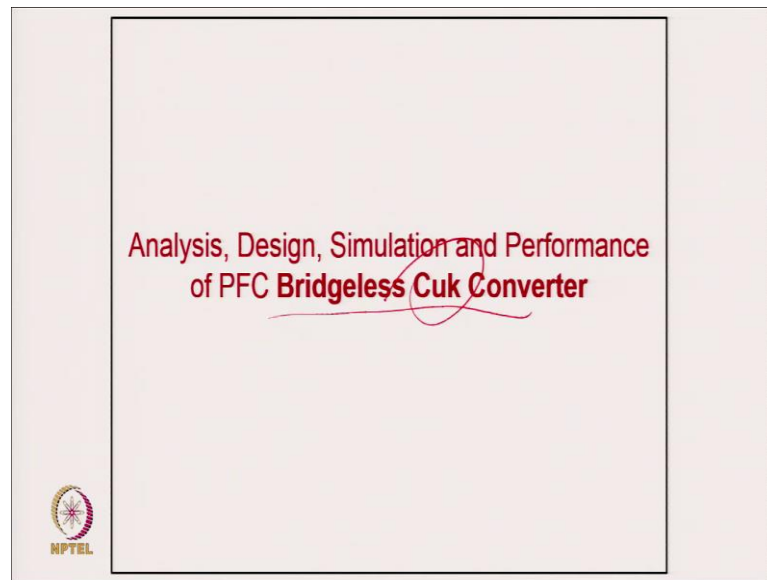
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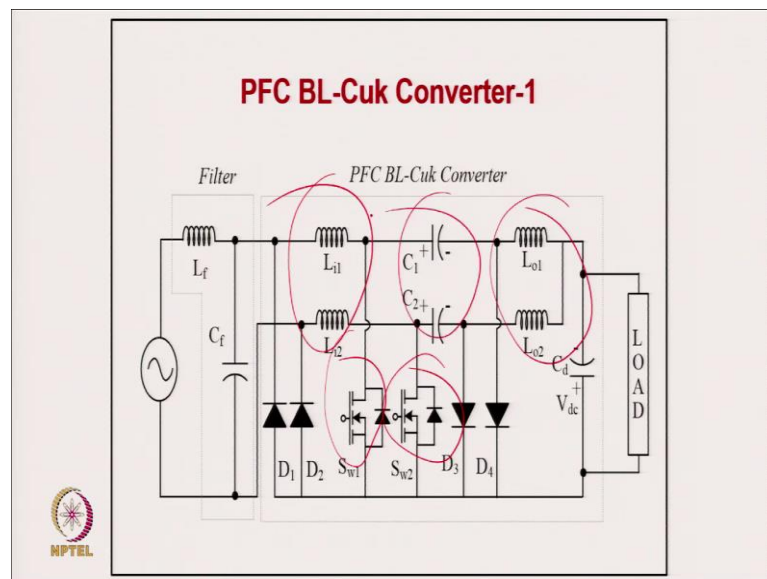


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Coming to the analysis, design, and simulation of PFC bridgeless Cuk converter.

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Design of a PFC BL-Cuk Converter

The voltage conversion ratio $V_o = \frac{D}{1-D} V_{in}$

Output Inductor Operating in CCM $L_{o1} = L_{o2} = \frac{V_o(1-D)}{f_s \Delta i_{L_o}}$


Input Inductor Operating in CCM $L_{i1} = L_{i2} = \frac{V_{in} D}{f_s \Delta i_{L_i}}$

Output Inductor Operating in DCM $L_{o1} = L_{o2} \ll L_{oc} = \frac{V_o(1-D)}{f_s (2i_o)}$

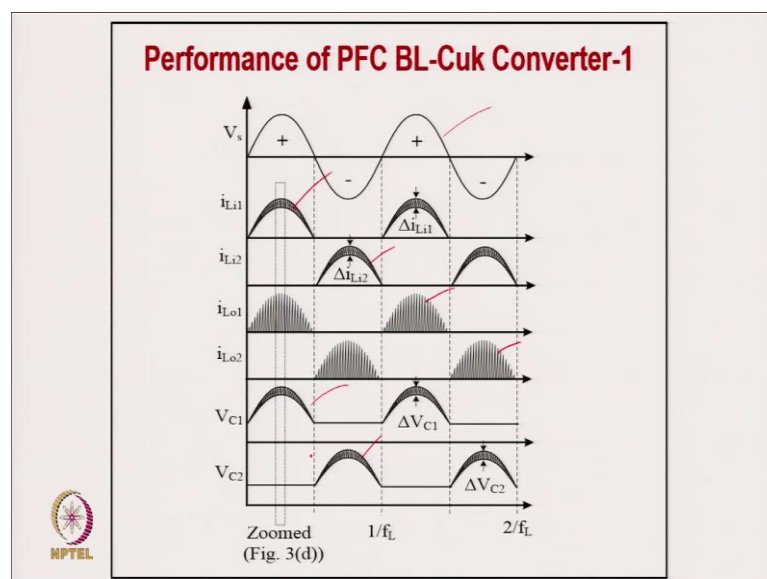
Input Inductor Operating in DCM $L_{i1} = L_{i2} \ll \frac{V_{in} D}{f_s (2i_{in})}$

Intermediate Capacitor $C_1 = C_2 = \frac{V_o D}{R f_s \Delta V_{C1}}$

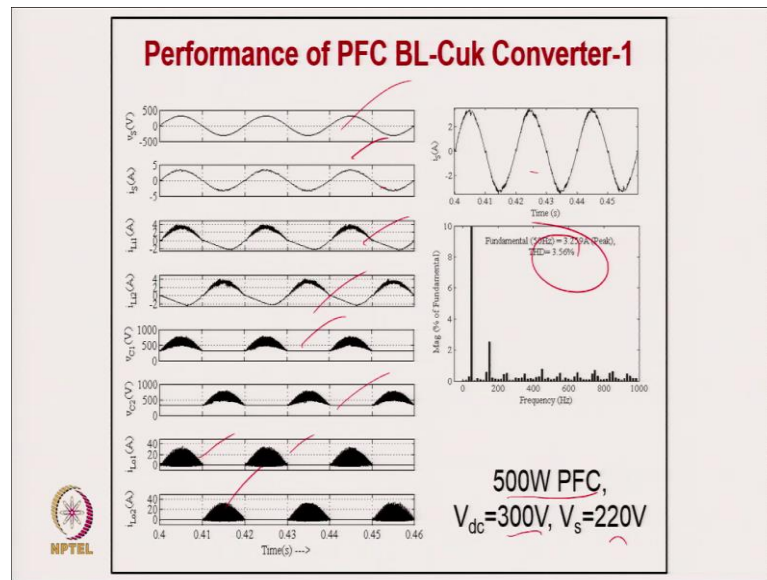
DC Link Capacitor Design $C_d = \frac{I_d}{2\omega \Delta V_{dc}}$



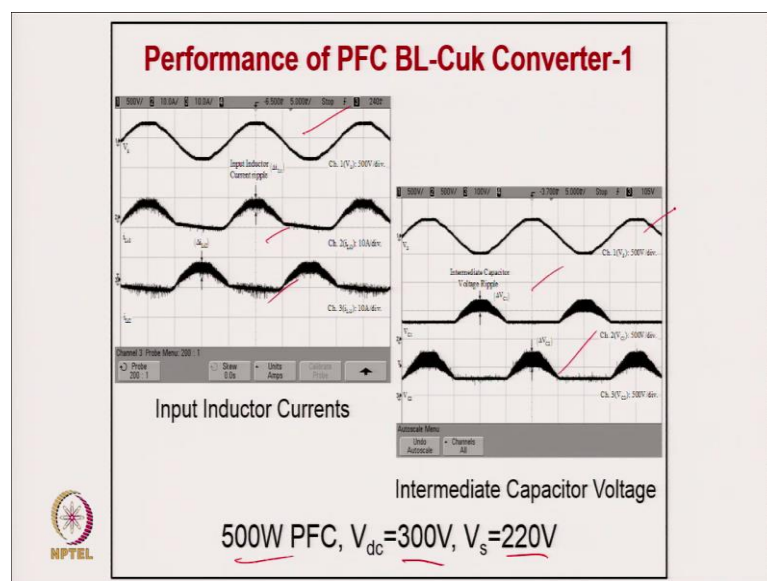
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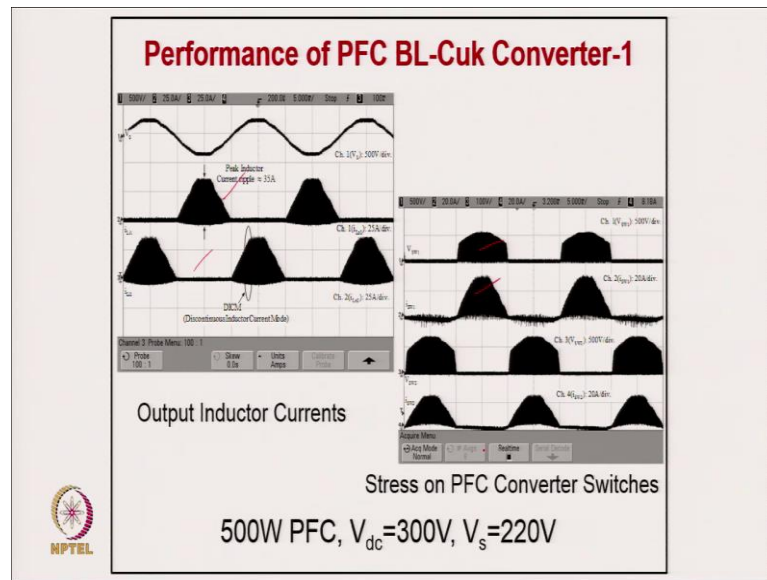
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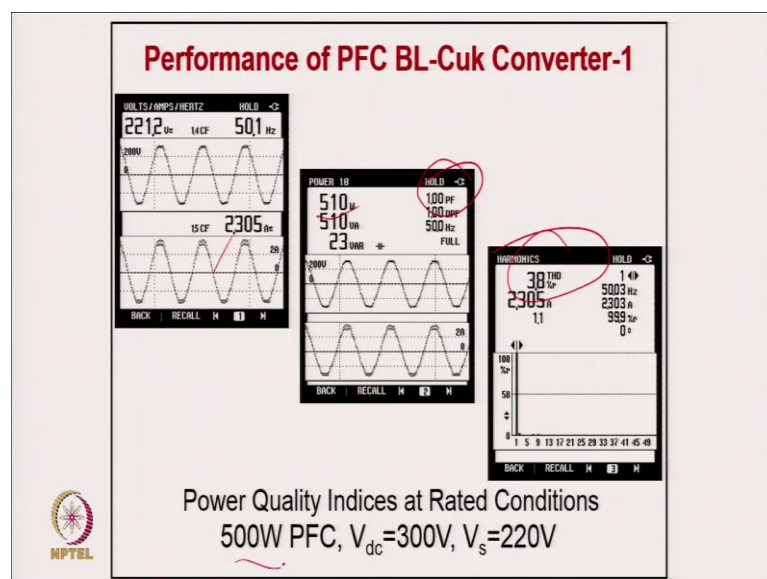
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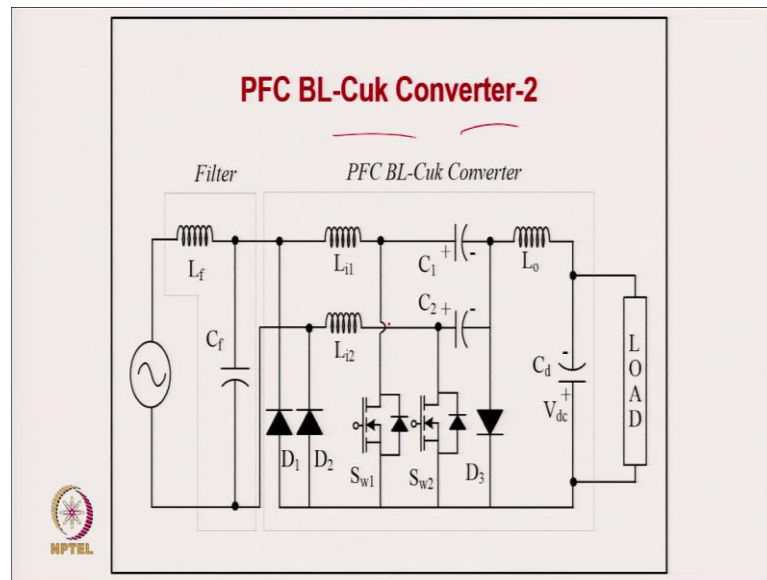
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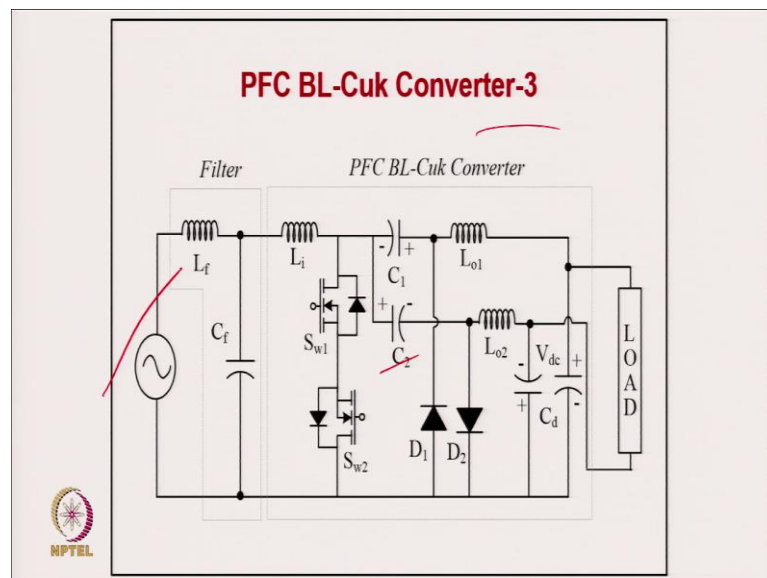
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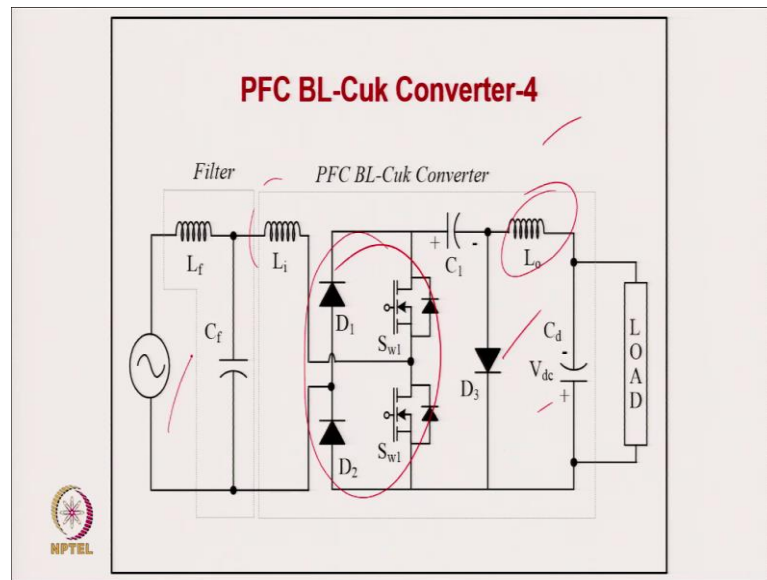
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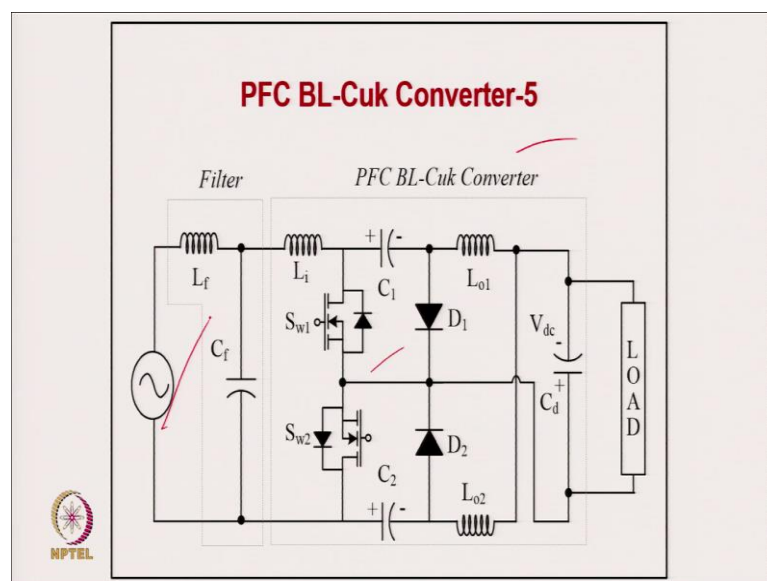
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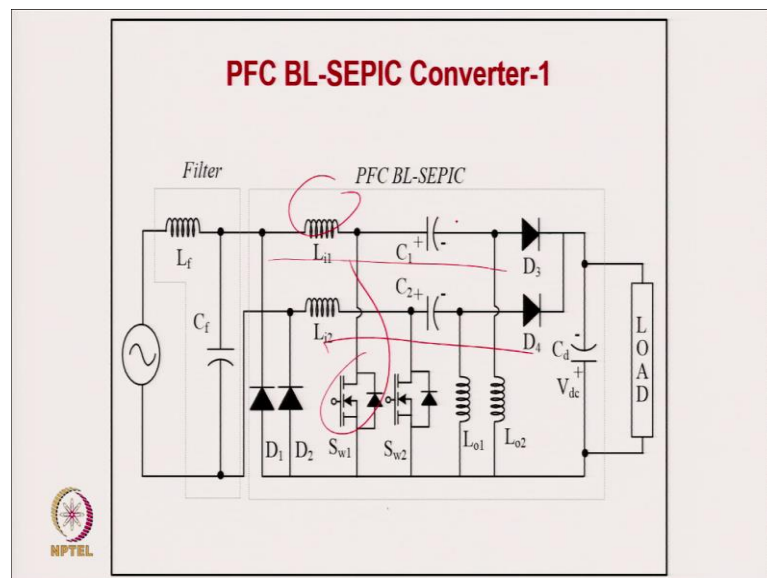
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Design of a PFC BL-SEPIC Converter

The voltage conversion ratio Output Inductor Operating in CCM

$$V_o = \frac{D}{1-D} V_{in} \qquad L_{o1} = L_{o2} = \frac{V_o(1-D)}{f_s \Delta i_{L_o}}$$


Input Inductor Operating in CCM Output Inductor Operating in DCM

$$L_{i1} = L_{i2} = \frac{V_{in} D}{f_s \Delta i_{L_i}} \qquad L_{o1} = L_{o2} \ll L_{oc} = \frac{V_o(1-D)}{f_s (2i_o)}$$

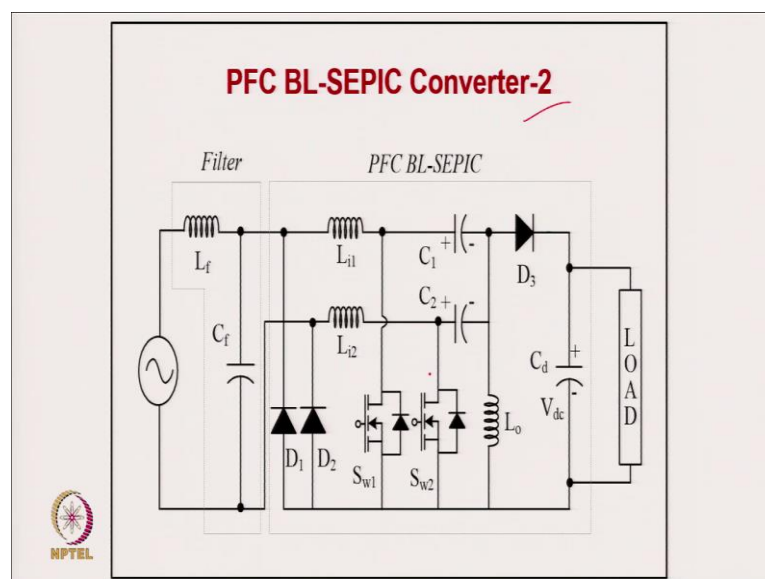
Input Inductor Operating in DCM Intermediate Capacitor

$$L_{i1} = L_{i2} \ll \frac{V_{in} D}{f_s (2i_m)} \qquad C_1 = C_2 = \frac{V_o D}{R f_s \Delta V_c}$$

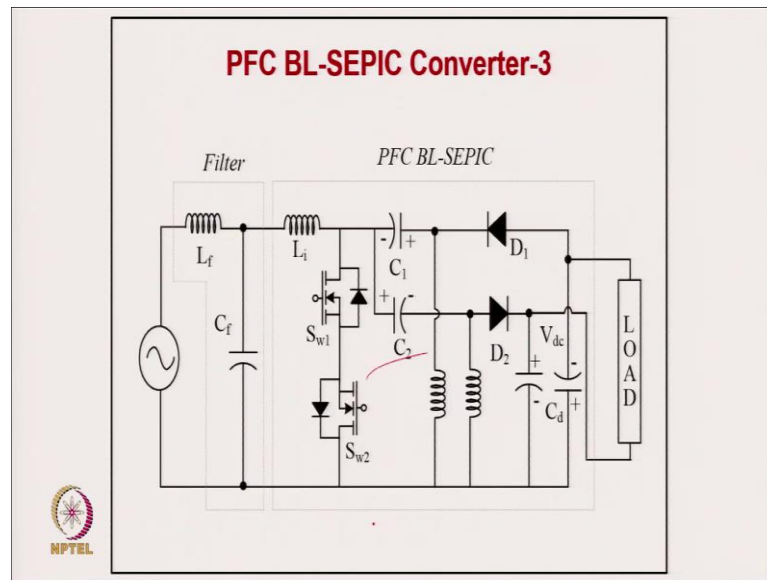
DC Link Capacitor Design $C_d = \frac{I_d}{2\omega \Delta V_{dc}}$



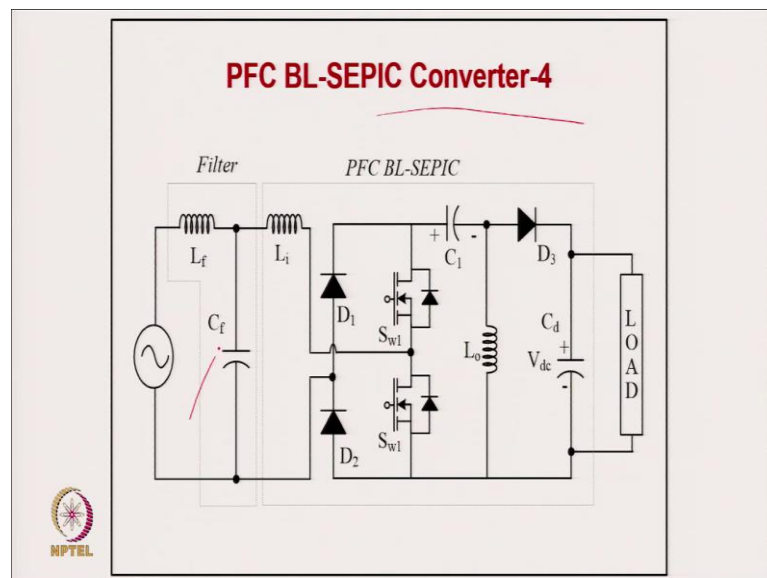
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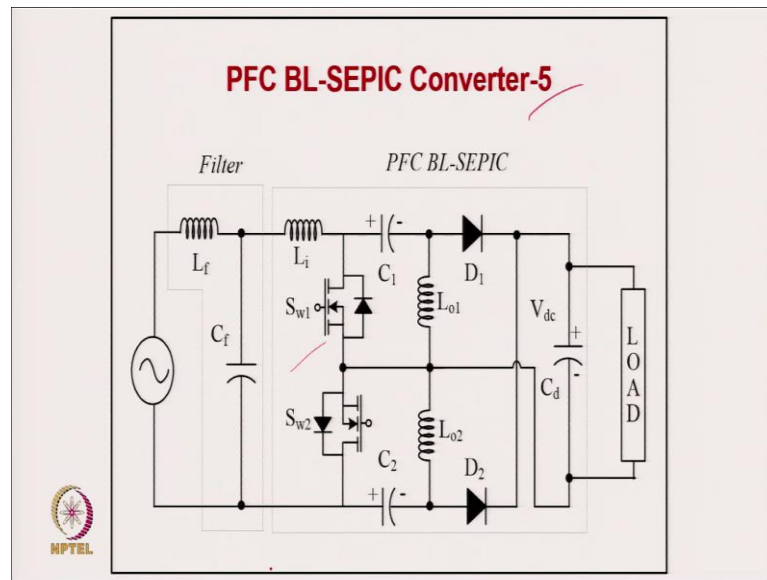
(Refer Slide Time: 51:23)



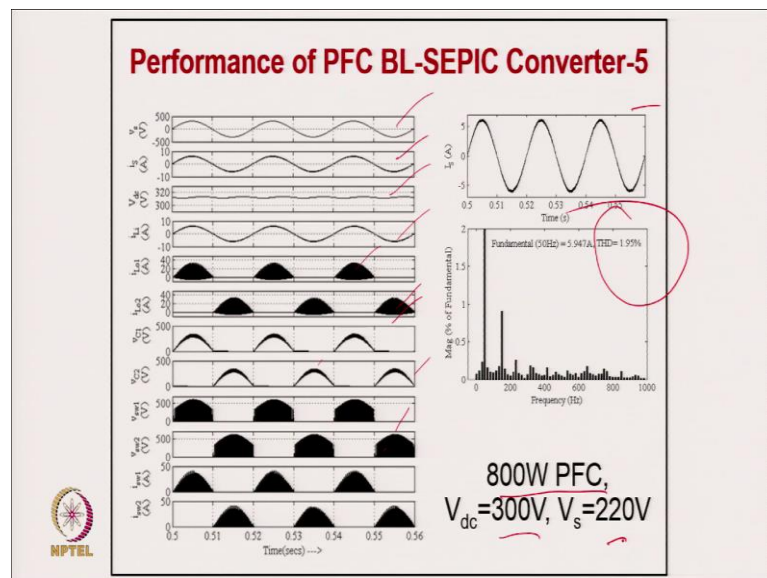
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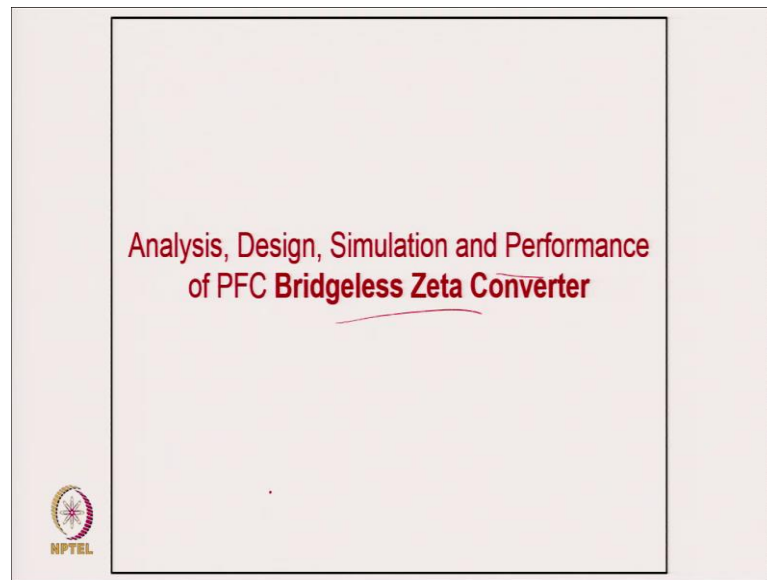
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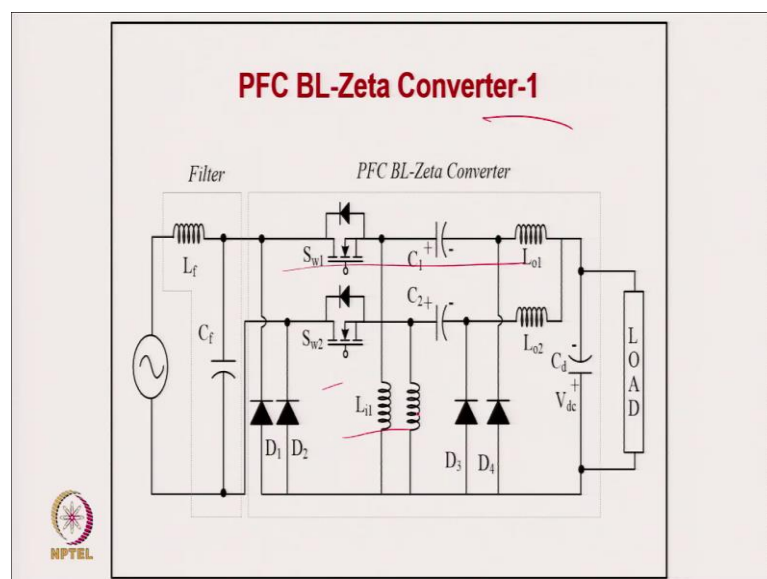
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Design of a PFC BL-Zeta Converter

The voltage conversion ratio, Output Inductor Operating in CCM

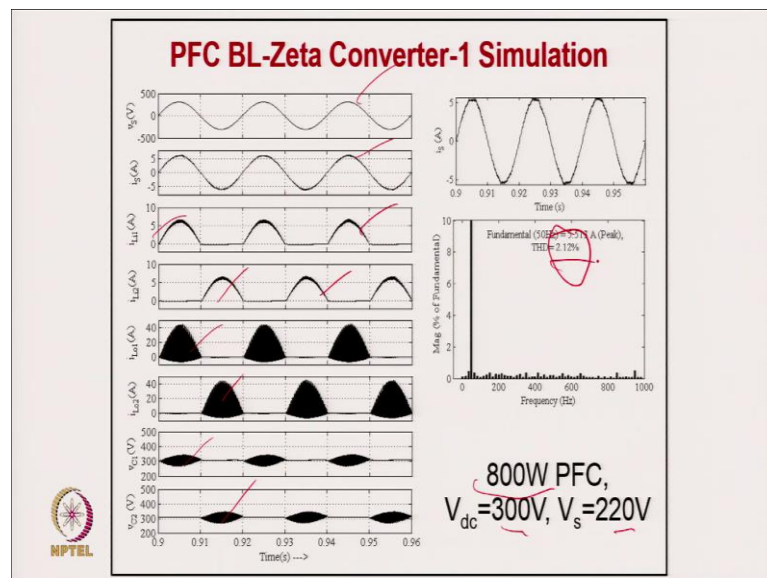
$$V_o = \frac{D}{1-D} V_{in} \quad L_{o1} = L_{o2} = \frac{V_o(1-D)}{f_s \Delta i_{L_o}}$$

<p>Input Inductor Operating in CCM</p> $L_{i1} = L_{i2} = \frac{V_{in} D}{f_s \Delta i_{L_i}}$	<p>Output Inductor Operating in DCM</p> $L_{o1} = L_{o2} \ll L_{oc} = \frac{V_o(1-D)}{f_s (2i_o)}$
<p>Input Inductor Operating in DCM</p> $L_{i1} = L_{i2} \ll \frac{V_{in} D}{f_s (2i_{in})}$	<p>Intermediate Capacitor</p> $C_1 = C_2 = \frac{V_o D}{R f_s \Delta V_c}$

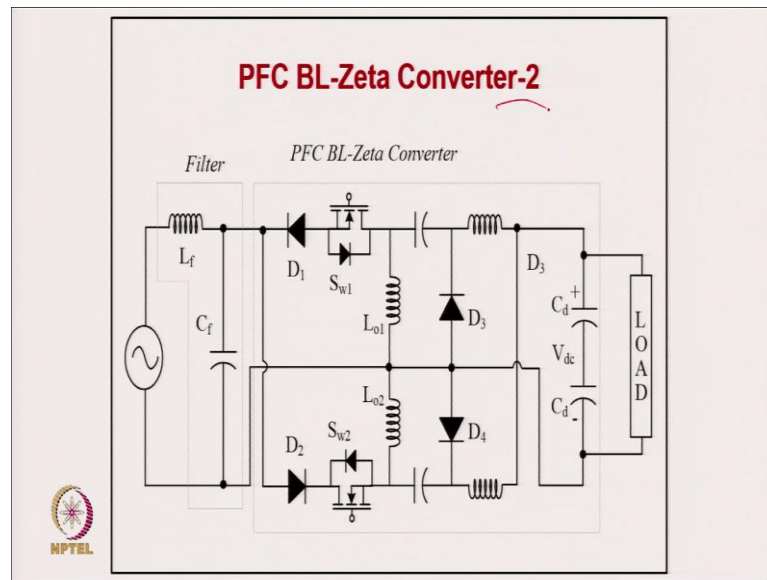
DC Link Capacitor Design $C_d = \frac{I_d}{2f_s \Delta V_{dc}}$



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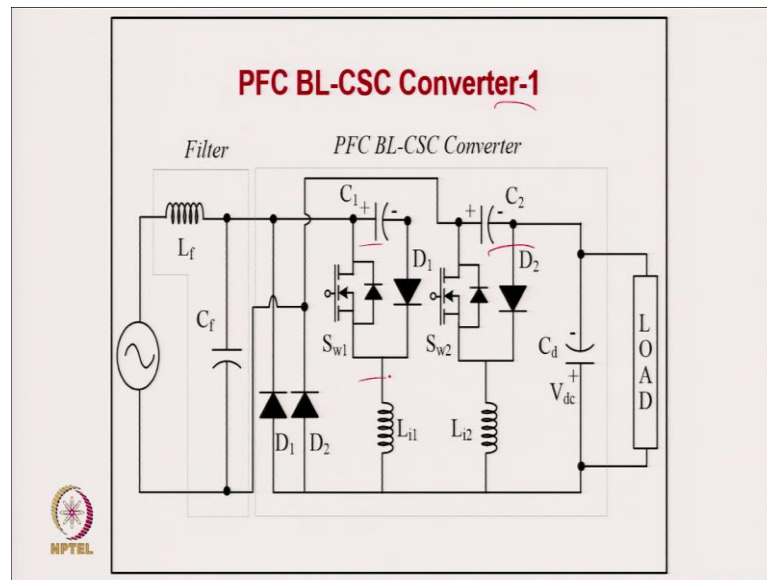


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**Analysis, Design, Simulation and Performance
of PFC Bridgeless CSC Converter**

NPTEL

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Design of a PFC BL-CSC Converter

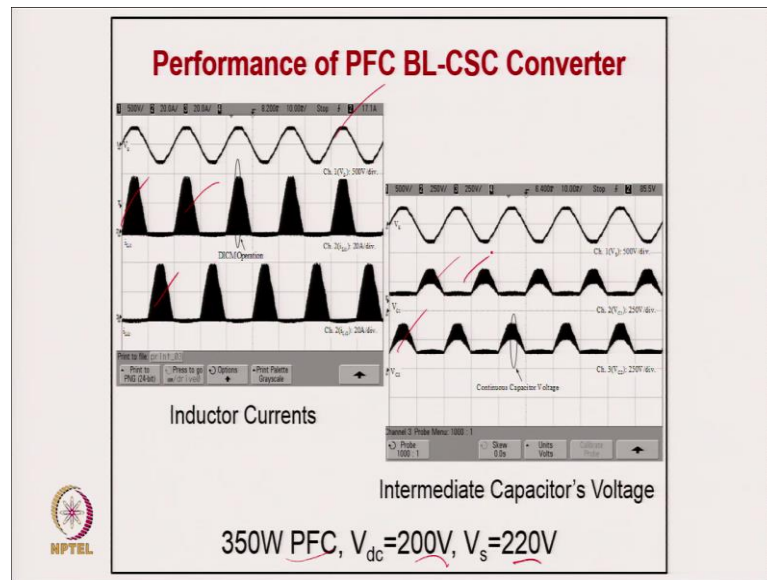
The voltage conversion ratio is given as,

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

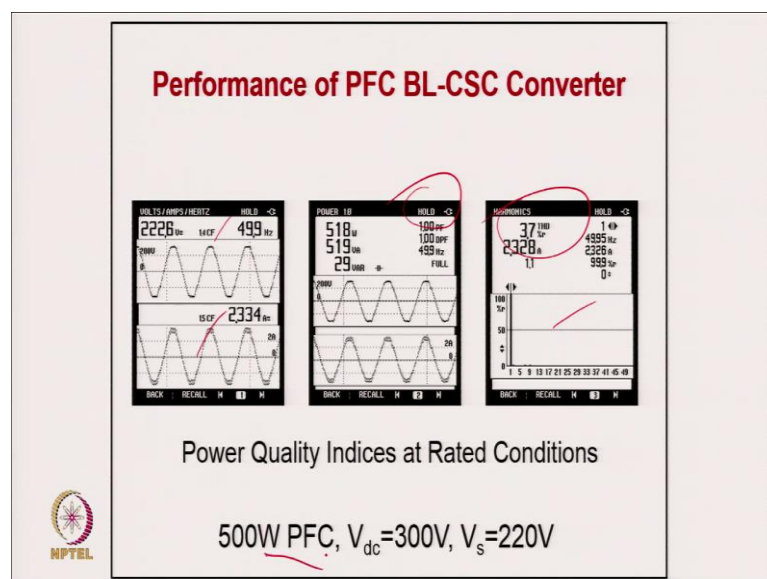
<p>Input Inductor Operating in CCM</p> $L_{i1} = L_{i2} = \frac{V_{in} D}{f_s \Delta I_{L_i}}$	<p>Intermediate Capacitor</p> $C_1 = C_2 = \frac{V_o D}{R f_s \Delta V_c}$
<p>Input Inductor Operating in DCM</p> $L_{i1} = L_{i2} \ll \frac{V_{in} D}{f_s (2I_{in})}$	<p>DC Link Capacitor Design</p> $C_d = \frac{I_d}{2 \phi \Delta V_{dc}}$

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Thank you.