Power Quality

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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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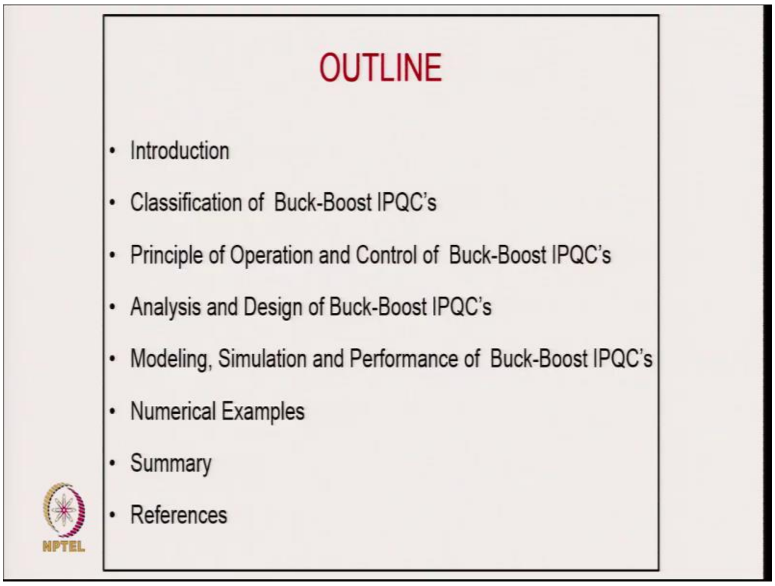

These will be the outlines of this lecture.

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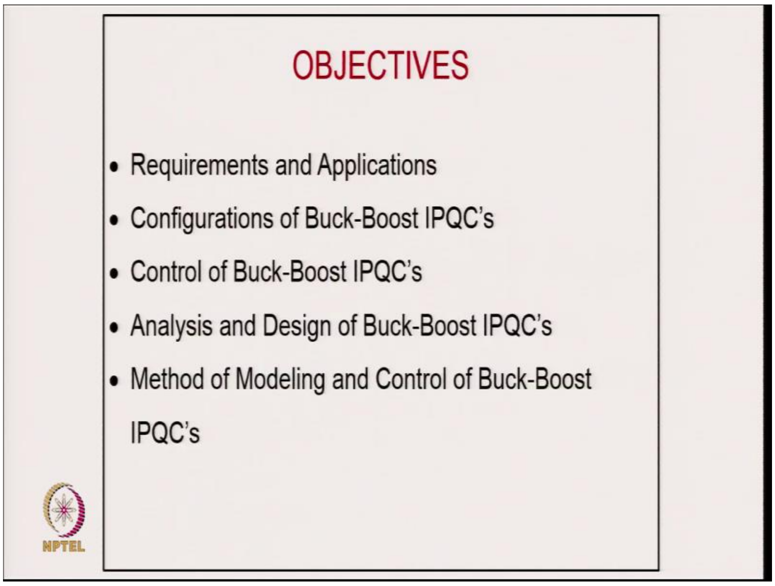

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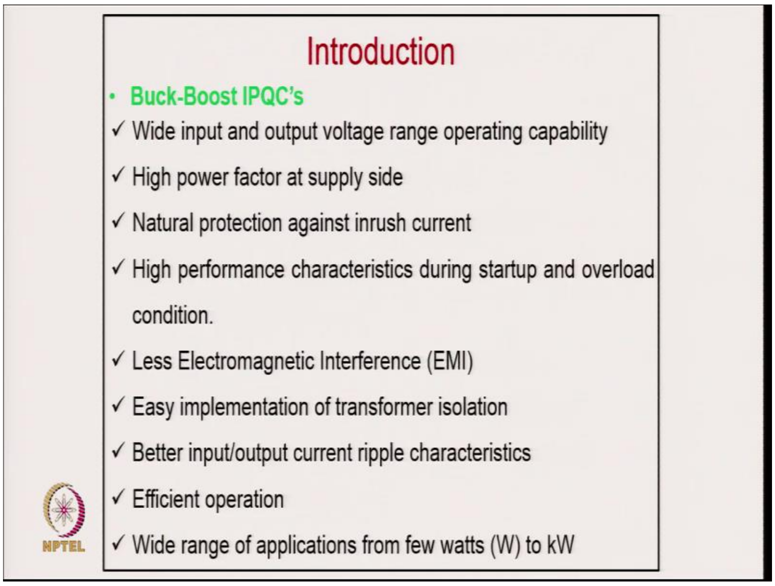

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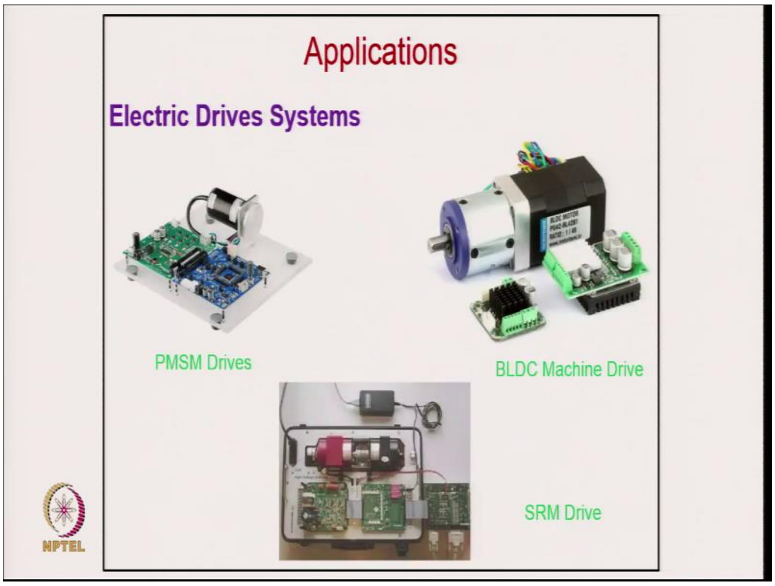

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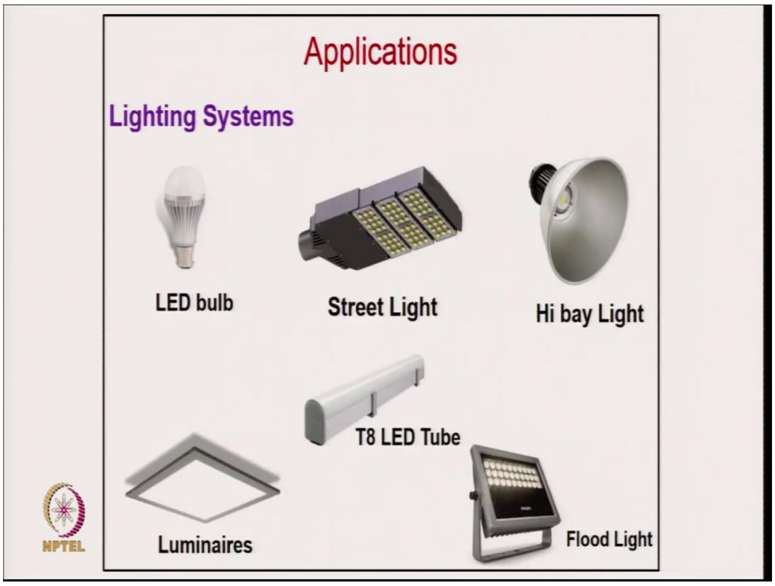

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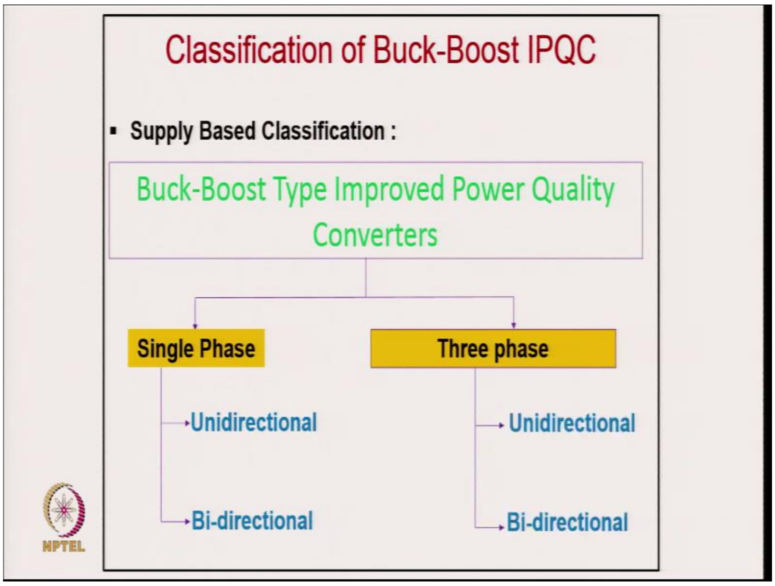

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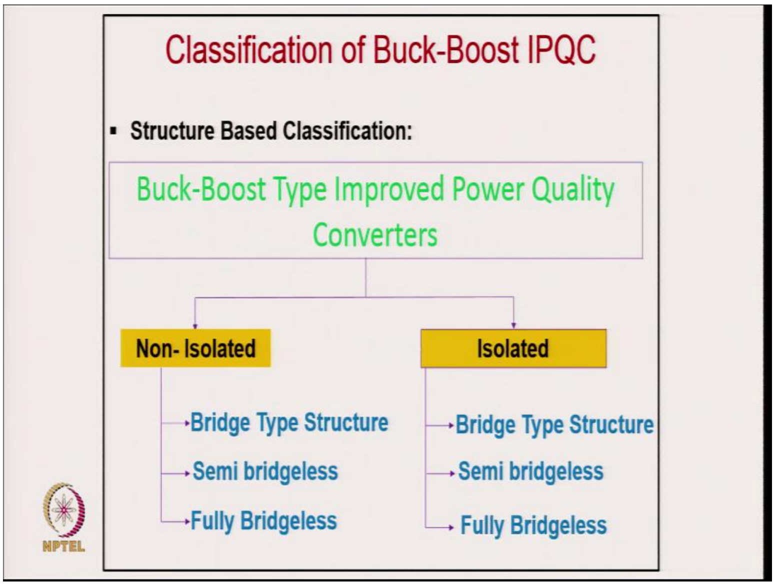

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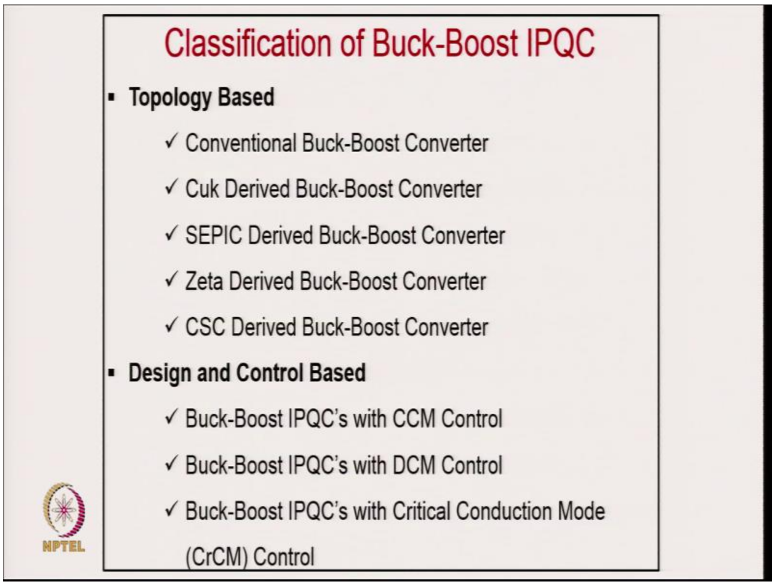

These are the classifications of buck-boost type improved power quality converters.

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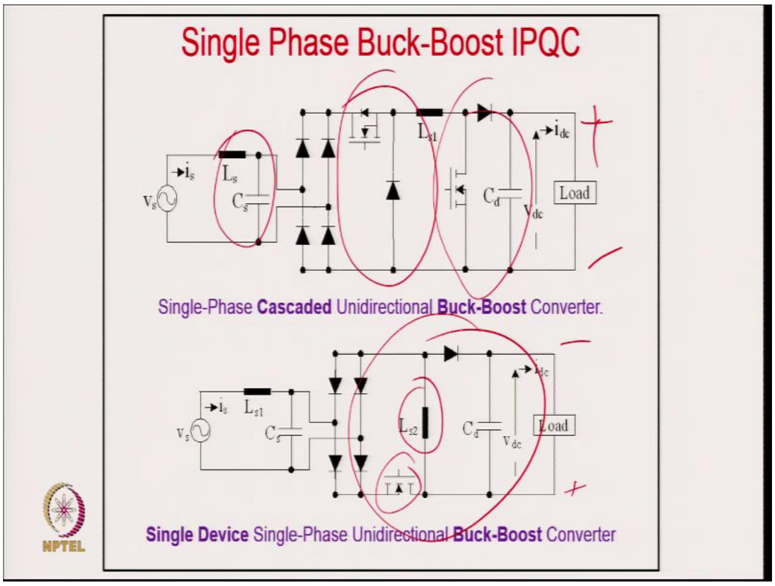

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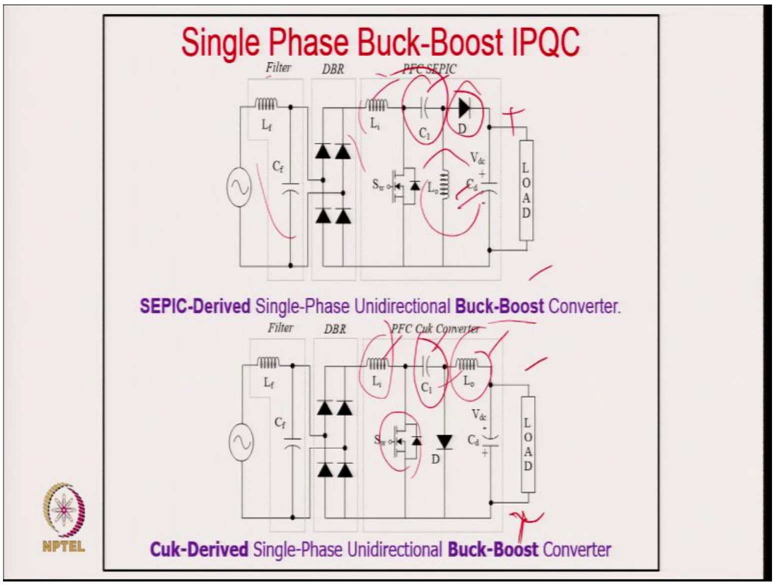

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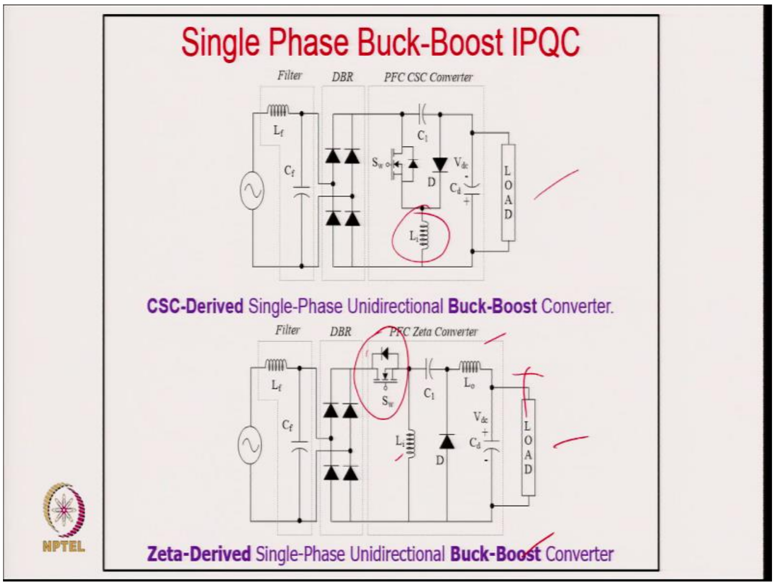

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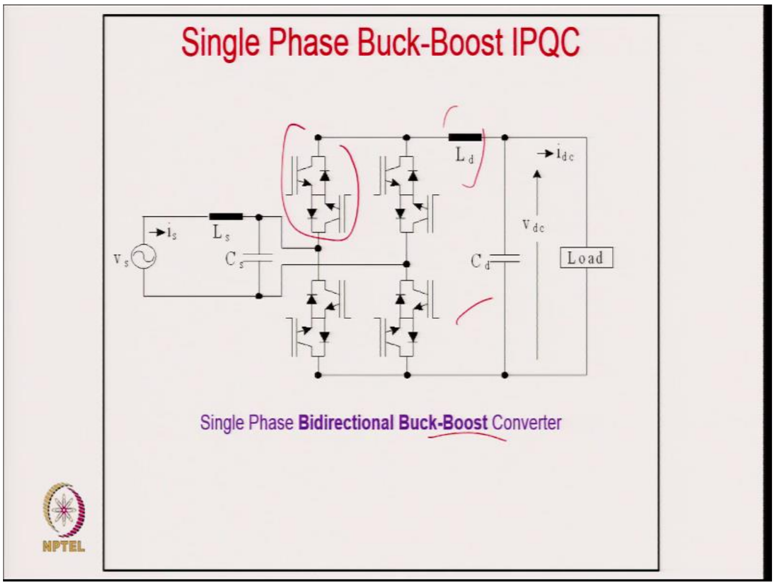

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Coming to like analysis of these single phase buck boost converters.

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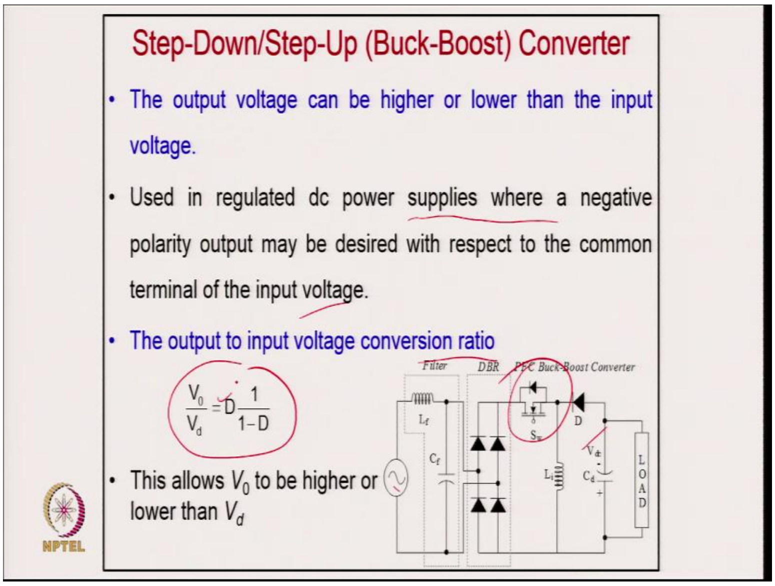

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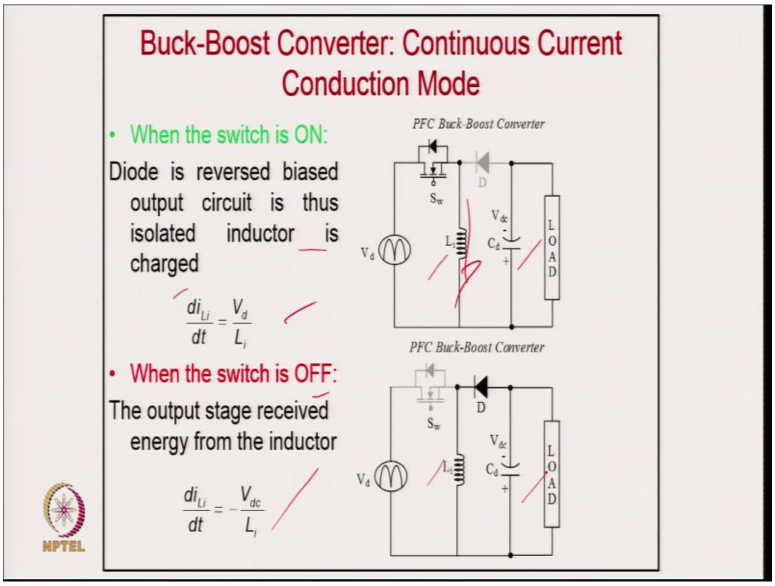

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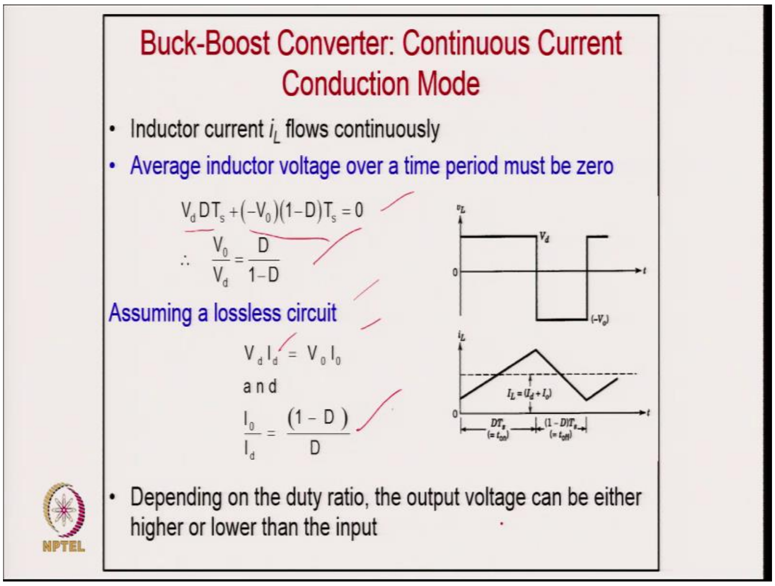

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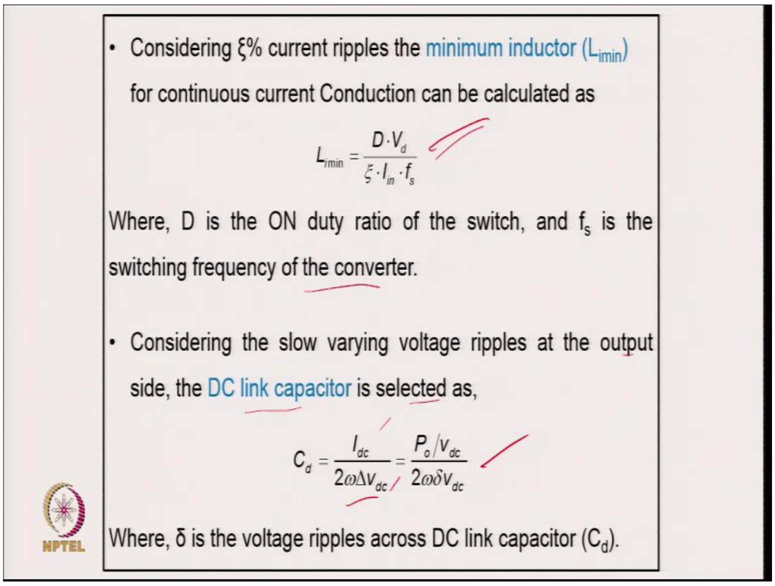

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Coming to now the single phase buck boost AC DC converters with high frequency transformer isolation.

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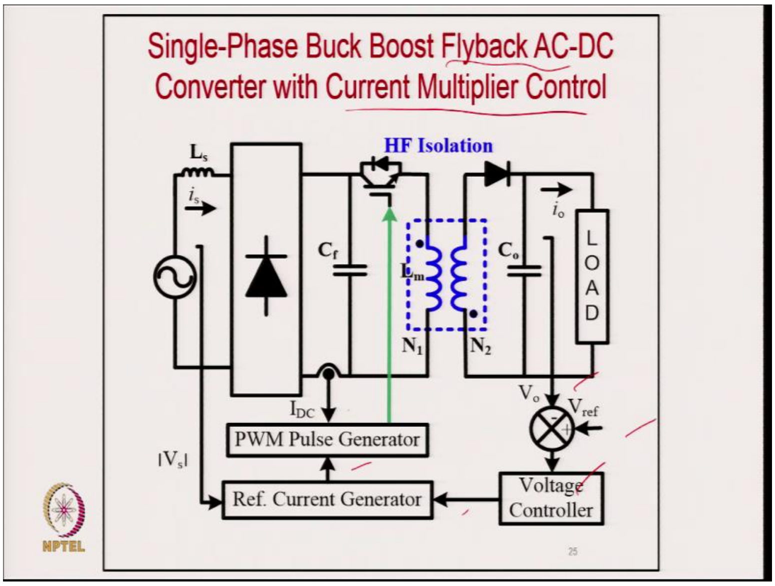

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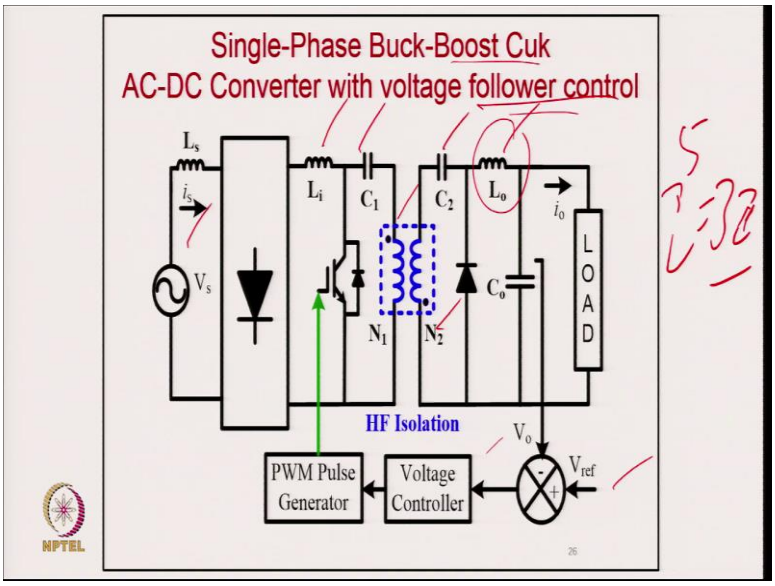

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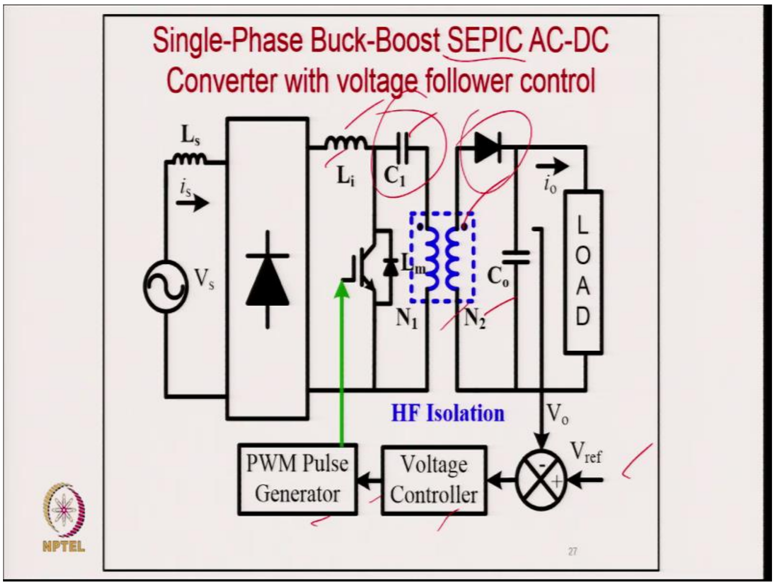

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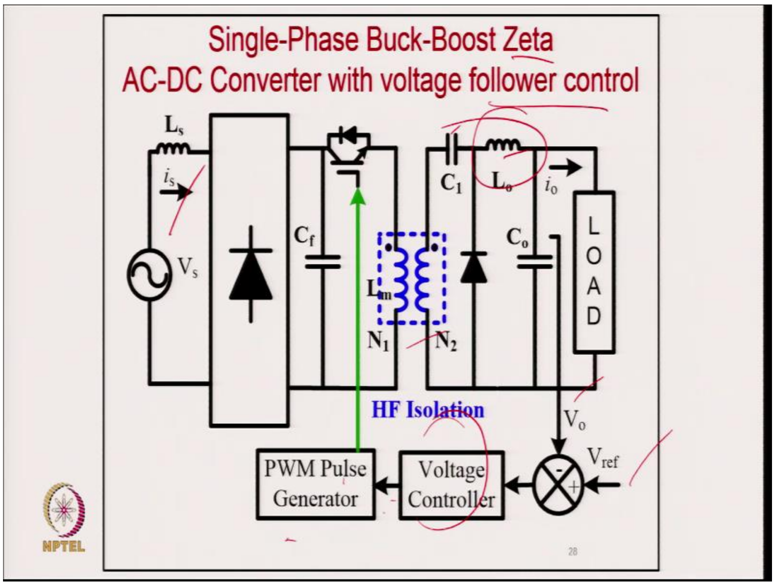

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Design Equations of Isolated Buck-Boost PFC Topologies in CCM and DCM

Flyback Converter	$V_o = V_{in} \{D/(1-D)\} (N_2/N_1)$
	$L_m = V_{in} D/(f_s \Delta i_{Lm})$ **(CCM)**
	$L_{mcritical} = \{V_{in}(N_2/N_1) - V_o\}DR/2f_sV_o$ **(DCM)**
Cuk Converter	$V_o = D (N_2/N_1) V_{in} / (1-D)$
	$L_1 = V_{in} D/(f_s \Delta i_{L1})$ **(CCM)**
	$L_o = V_o (1-D)/(f_s \Delta i_{Lo})$
	$C_1 = V_{in} (N_2/N_1)^2 D^2/\{Rf_s(1-D) \Delta V_{C1}\}$
	$C_2 = V_o D/(Rf_s \Delta V_{C2})$
	$L_{icritical} = R_L (1-D)^2/\{2Df_s(N_2/N_1)^2\}$ **(DCM)**
SEPIC Converter	$V_o = V_{in} (N_2/N_1)D/(1-D)$
	$L_1 = V_{in} D/(f_s \Delta i_{L1})$ **(CCM)**
	$L_m = V_o (1-D)/(n f_s \Delta i_{Lm})$
	$C_1 = (N_2/N_1)V_o D/(Rf_s \Delta V_{C1})$
	$L_{mcritical} = R_L (1-D)^2/\{2Df_s(N_2/N_1)^2\}$ **(DCM)**
Zeta Converter	$V_o = (N_2/N_1) V_{in} D/(1-D)$
	$L_m = V_{in} D/(f_s \Delta i_{Lm})$
	$L_o = V_o (1-D)/(f_s \Delta i_{Lo})$ **(CCM)**
	$C_1 = V_o D/(R f_s \Delta V_{C1})$
	$L_{mcritical} = R_L (1-D)^2/\{2Df_s(N_2/N_1)^2\}$ **(DCM)**
DC Link Capacitor for all Converters	$C_o = I_{av}/(2\omega \Delta V_o)$

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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_s)	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_f=5nF, L_m=37mH, C_o=24mF, K_p=0.2985, K_i=5.985
2	Cuk	4.52	0.999	1.000	0.999	1.56	0.15	L_i=27mH, C_1=87nF, L_o=0.37mH, C_2=8.7nF, C_o=24mF, K_p=0.3985, K_i=3.985
3	SEPIC	4.78	0.999	1.000	0.999	1.54	0.15	L_i=16mh, C_1=87nF, C_o=24mF, K_p=0.185, K_i=1.85
4	Zeta	3.48	0.999	1.000	0.999	1.47	0.15	C_f=9nF, L_m=3.3mH, C_1=174nF, L_o=1.64mH, C_o=24mF, K_p=0.485, K_i=4.85

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Comparison of Isolated Buck-Boost PFC Topologies with in CCM ($V_{o\ base}$=48V, $I_{o\ base}$=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	0.2	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_s)	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=37mF, C_f=3.4nF, C_o=24mF, K_p=0.4985, K_i=5.985
2	Cuk	4.56	0.999	0.997	0.996	1.42	0.15	L_i=5.2mH, C_1=0.22μF, L_o=15μH, C_2=22μF C_o=24mF, K_p=0.2985, K_i=5.861
3	SEPIC	4.91	0.999	0.998	0.997	1.47	0.15	L_1=2.1mH, C_1=0.22μf, L_2=120μH, C_o=24mF, K_p=0.125, K_i=2.251
4	Zeta	4.81	0.999	0.997	0.996	1.43	0.15	C_f=220nF, C_1=10μF, L_o=12μH, C_o=24mF, K_p=0.1985, K_i=2.851

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Comparison of Isolated Buck-Boost PFC Topologies with in DCM ($V_{o\,base}$=48V, $I_{o\,base}$=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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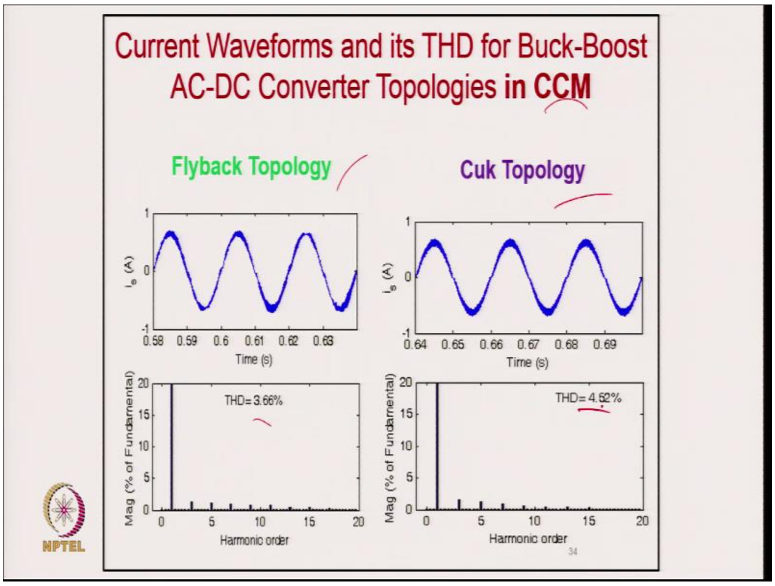

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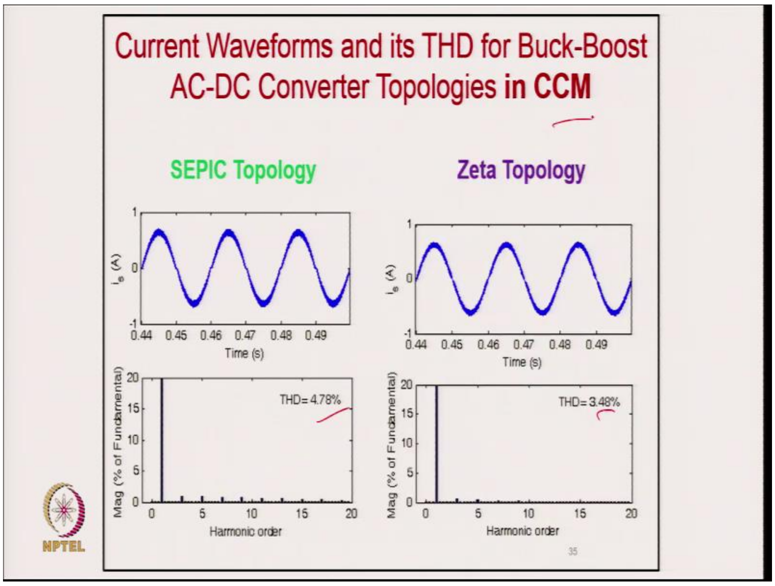

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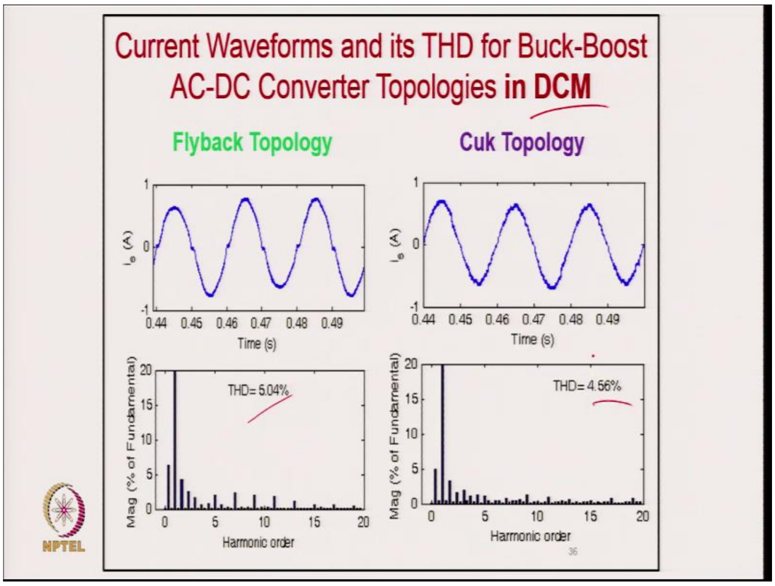

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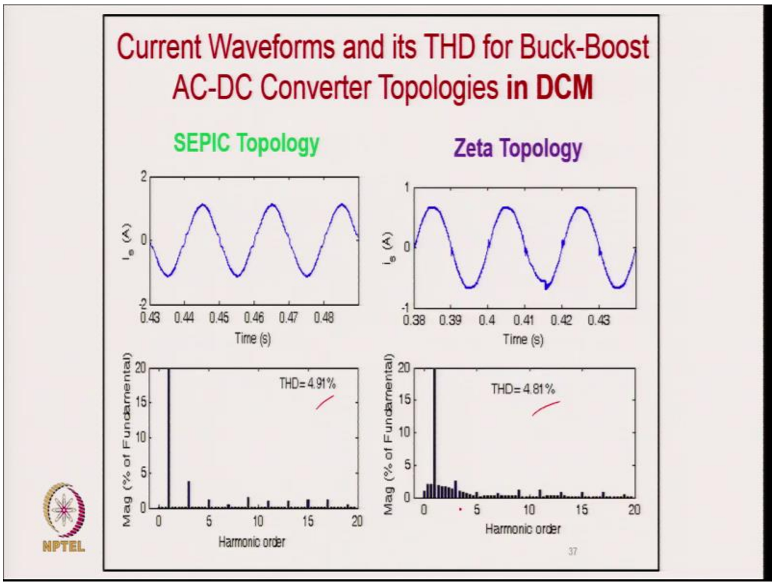

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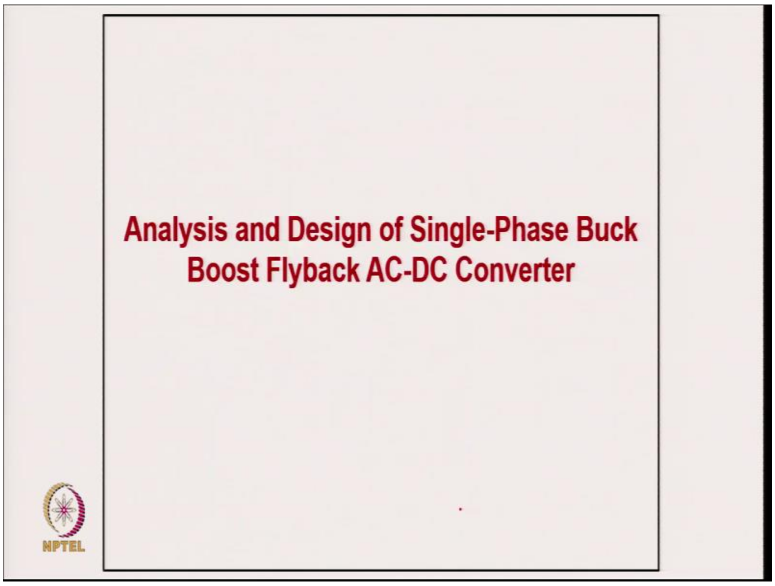

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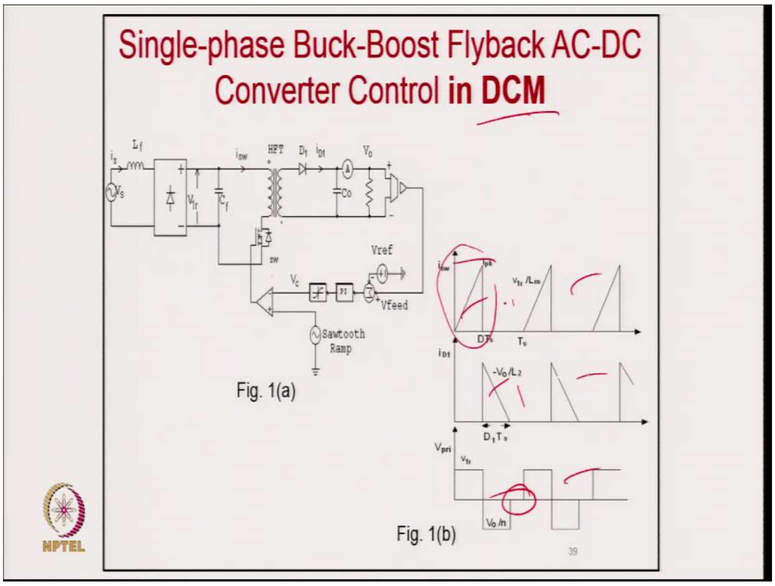

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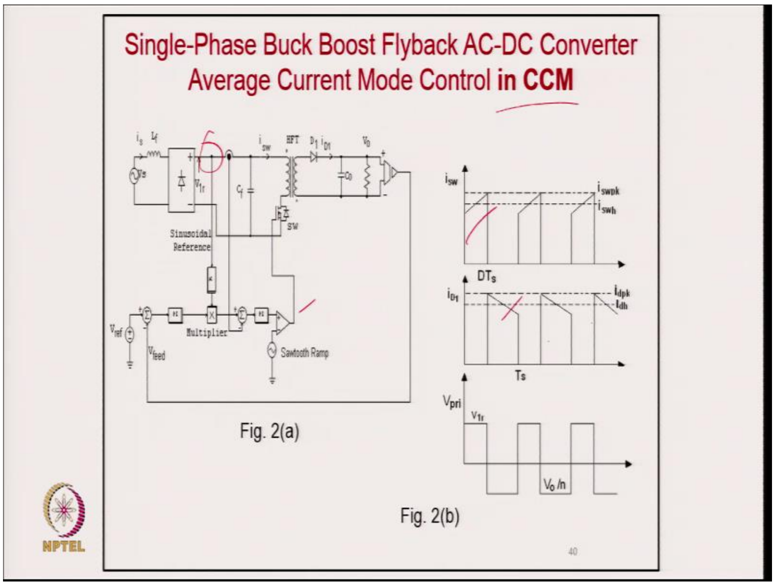

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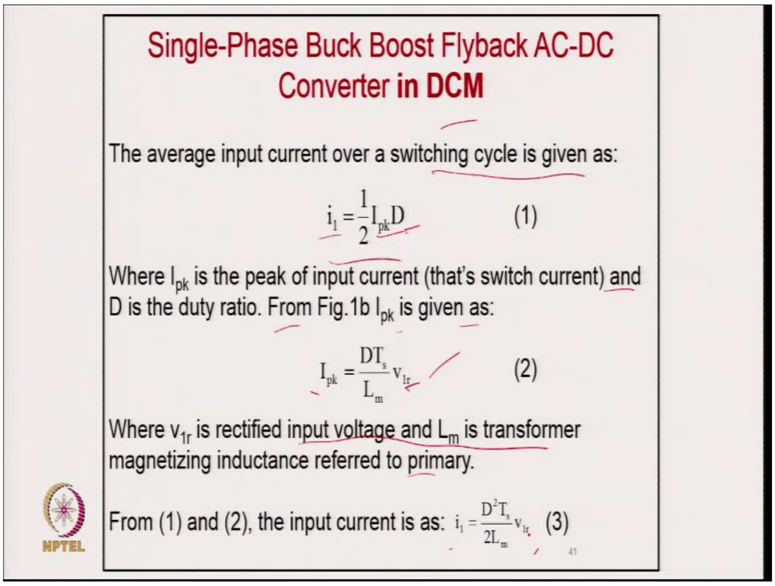

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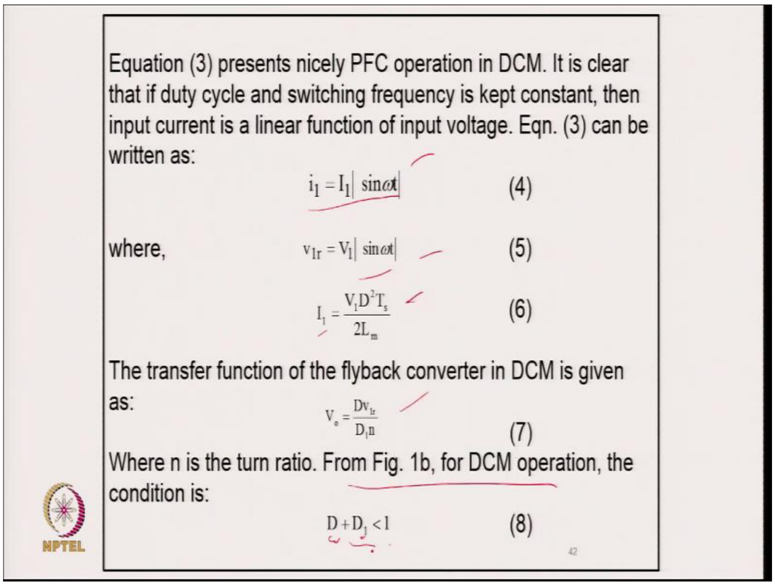

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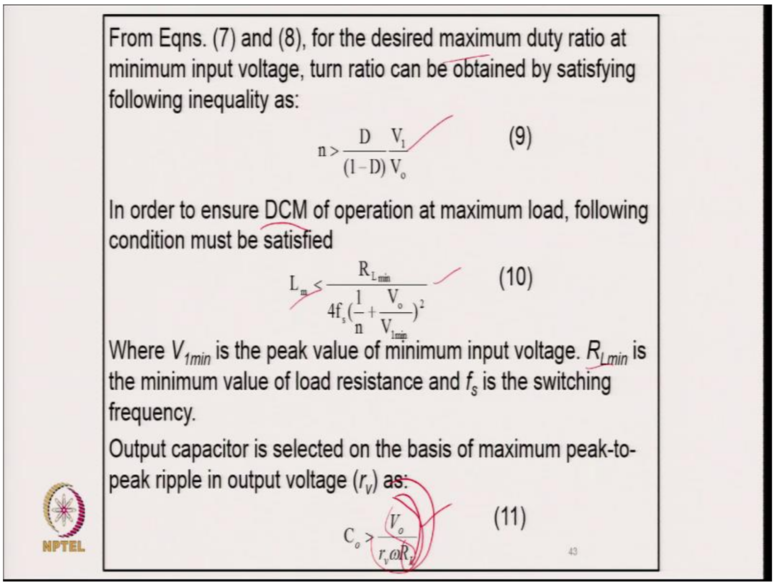

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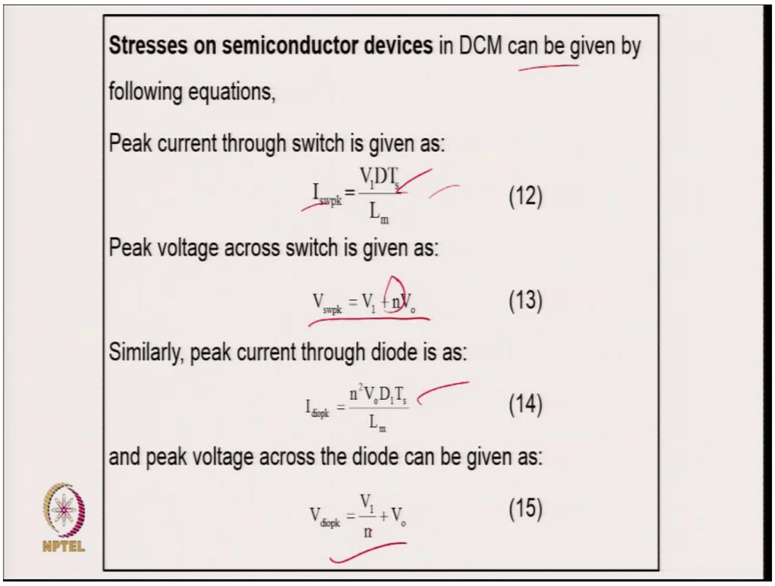

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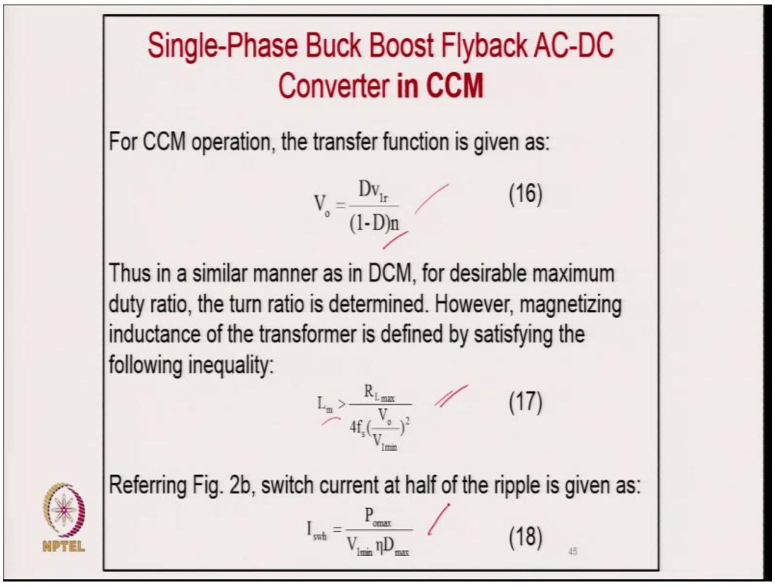

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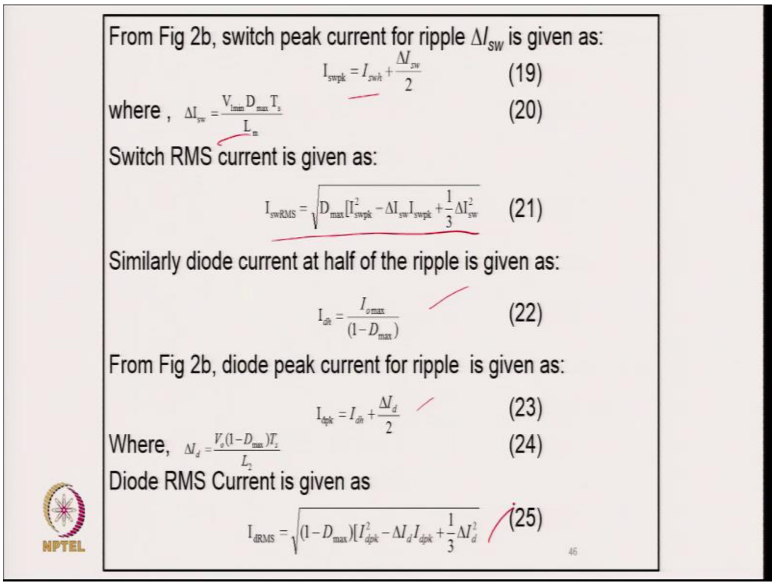

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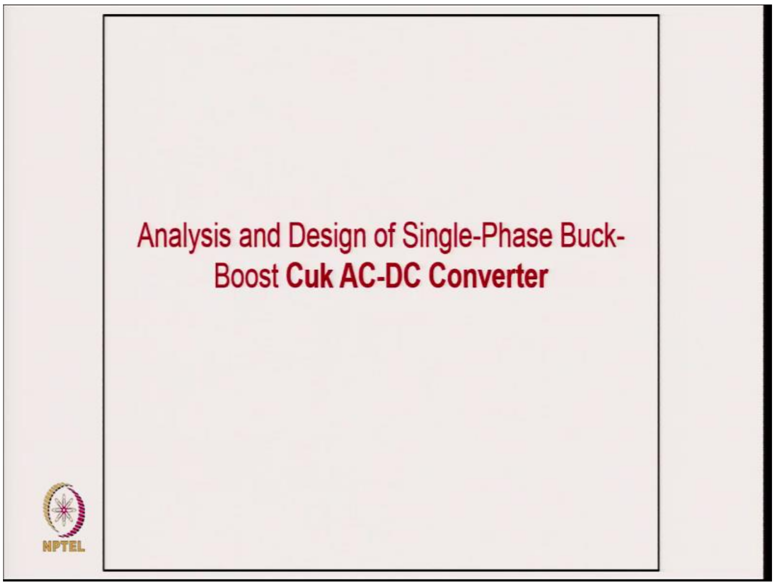

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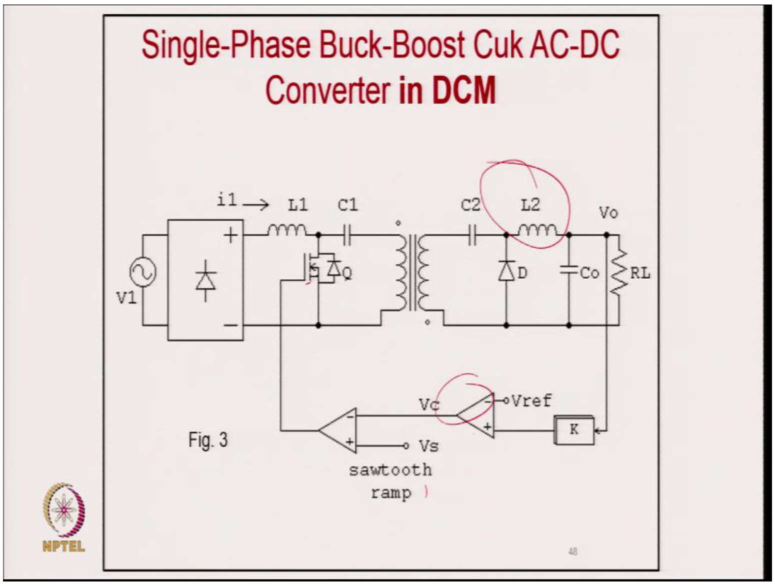

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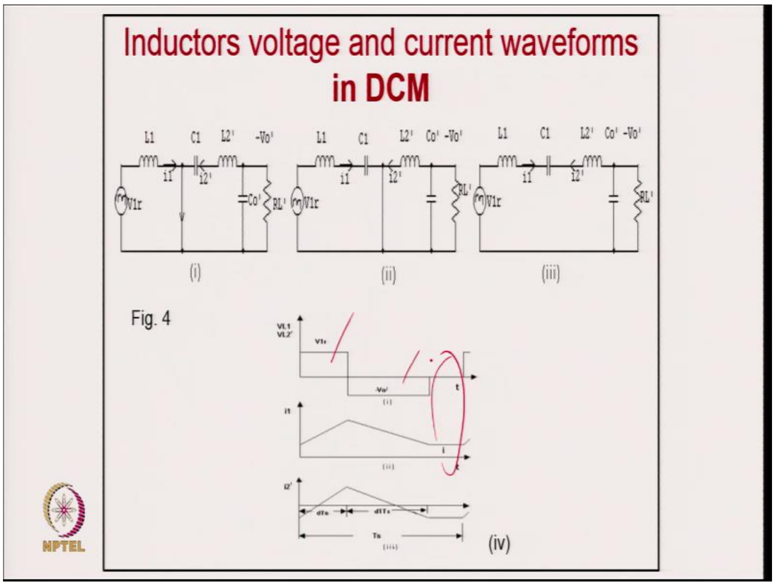

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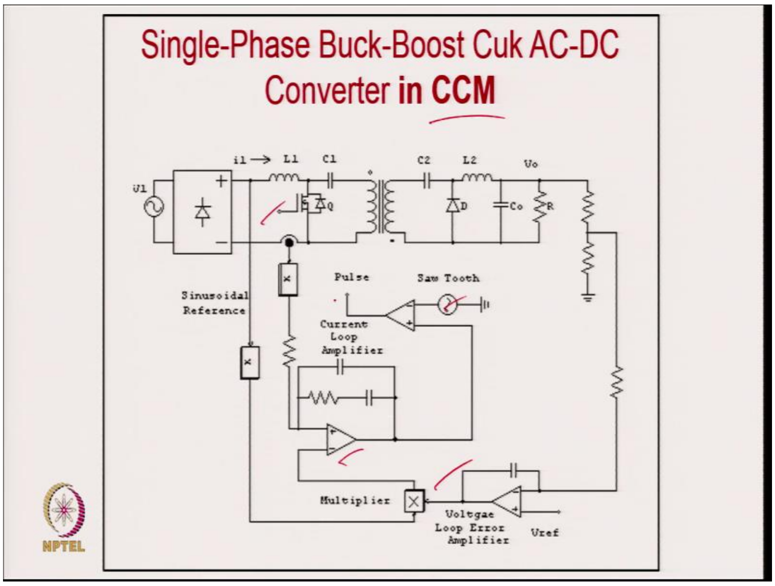

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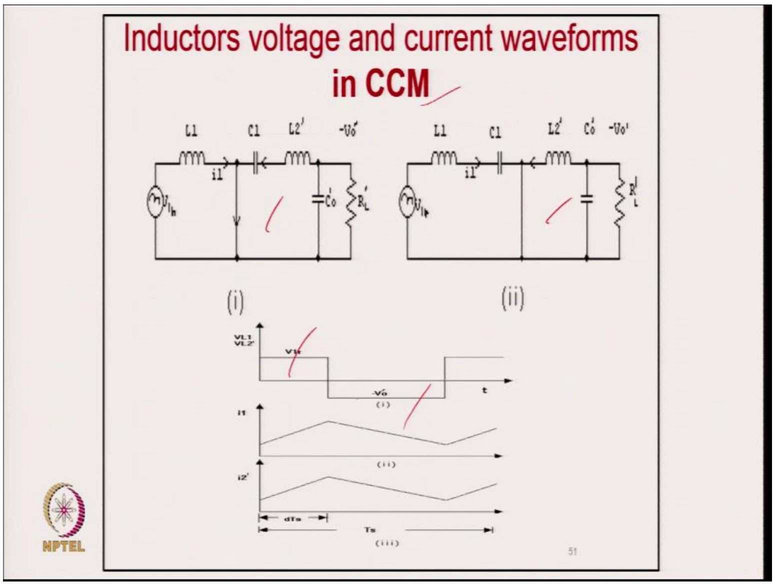

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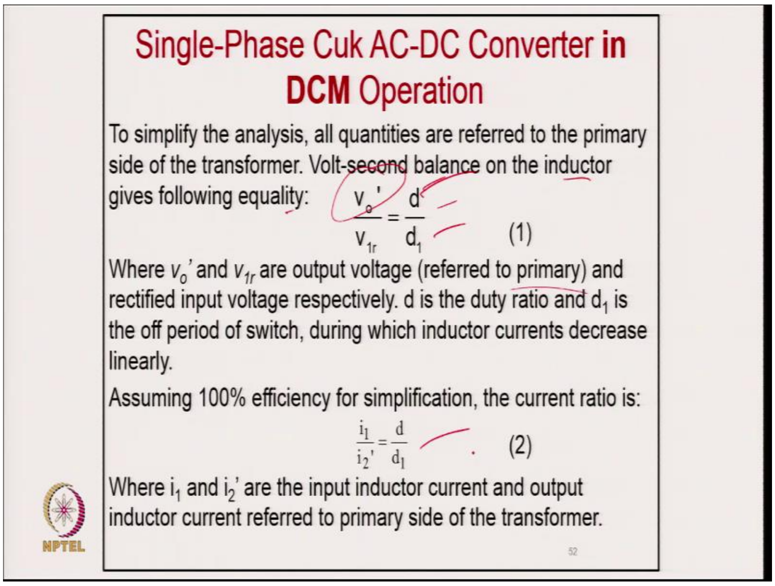

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- **First stage of Operation**

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:

$$i_1 = i + \frac{v_{1r}}{L_1} t \qquad (3)$$

$$i_2' = -i + \frac{v_{1r}}{L_2'} t \qquad (4)$$

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:

$$i_1 = -\frac{v_o'}{L_1} t + \frac{v_{1r}}{L_1} dT_s + i \qquad (5)$$

$$i_2' = -\frac{v_o'}{L_2'} t + \frac{v_{1r}}{L_2'} dT_s - i \qquad (6)$$

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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:

$$i_1 = \frac{v_{1r}}{2L_1} dT_s (d + d_1) + i \qquad (7)$$

$$i_2' = \frac{v_{1r}}{2L_2'} dT_s (d + d_1) - i \qquad (8)$$

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

$$i_1 + i_2' = \frac{1}{2} \frac{v_{1r}}{L_{eq}} dT_s \left(1 + \frac{d_1}{d}\right) d \qquad (9)$$

where,

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

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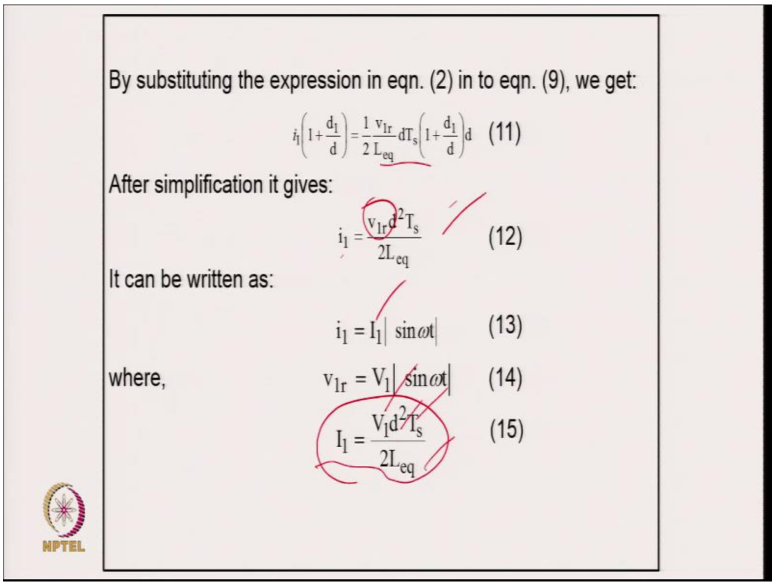

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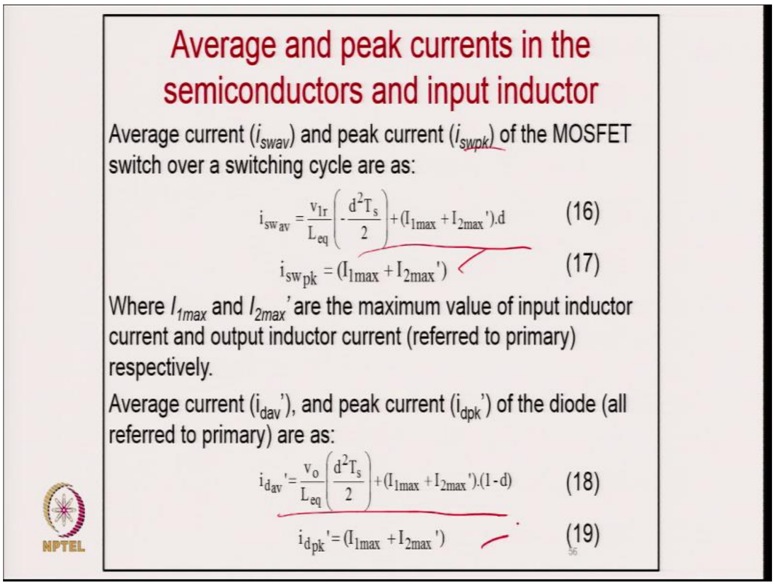

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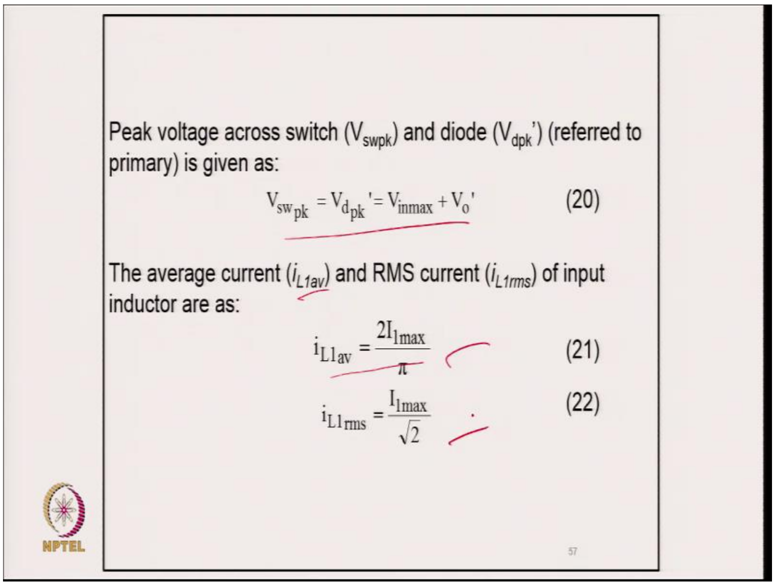

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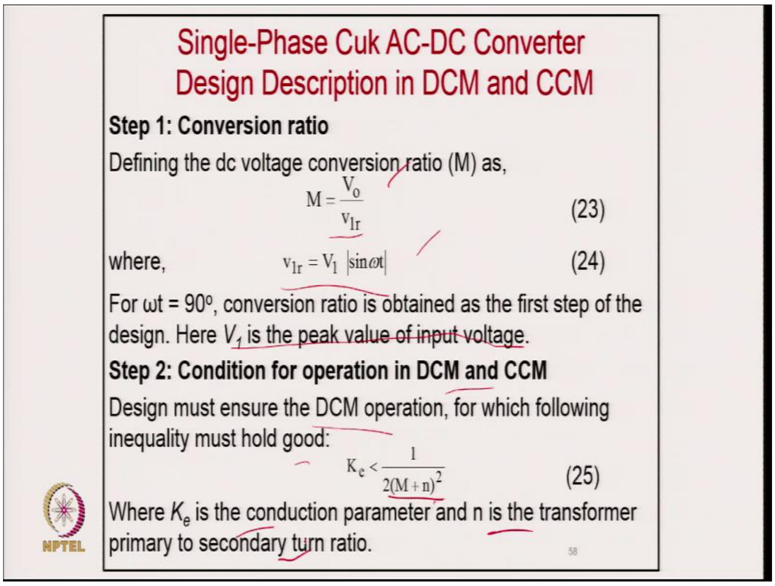

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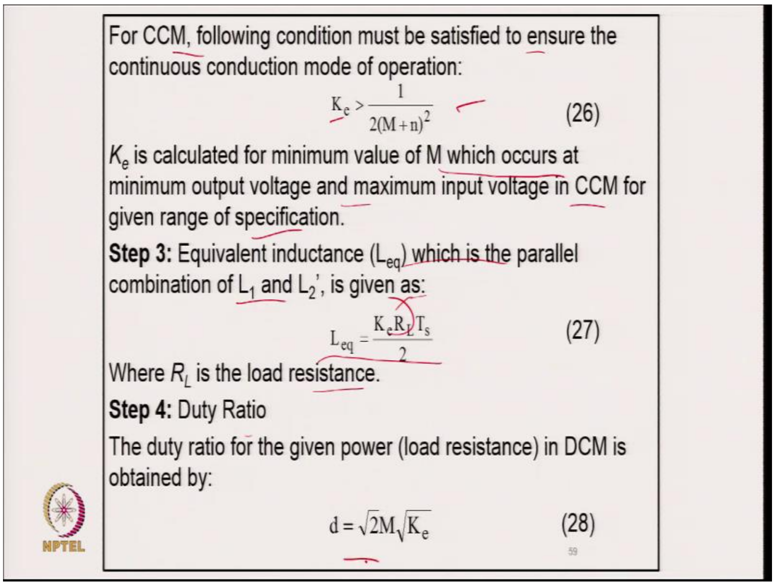

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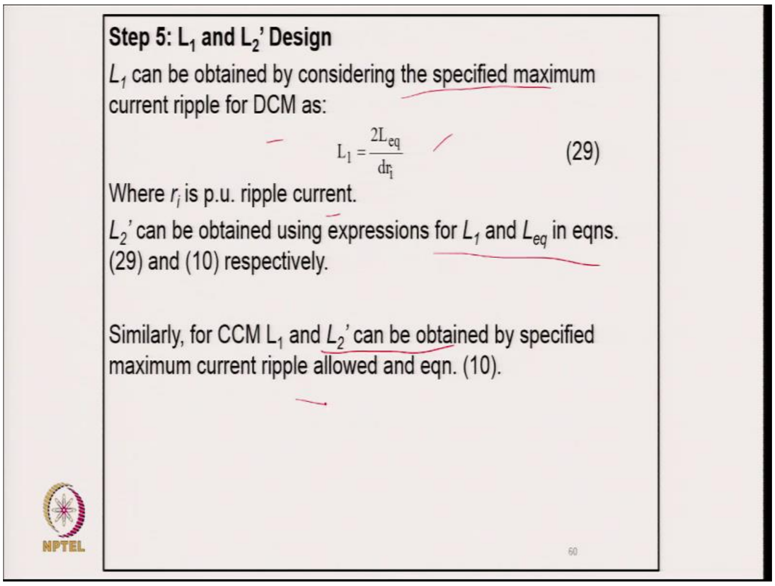

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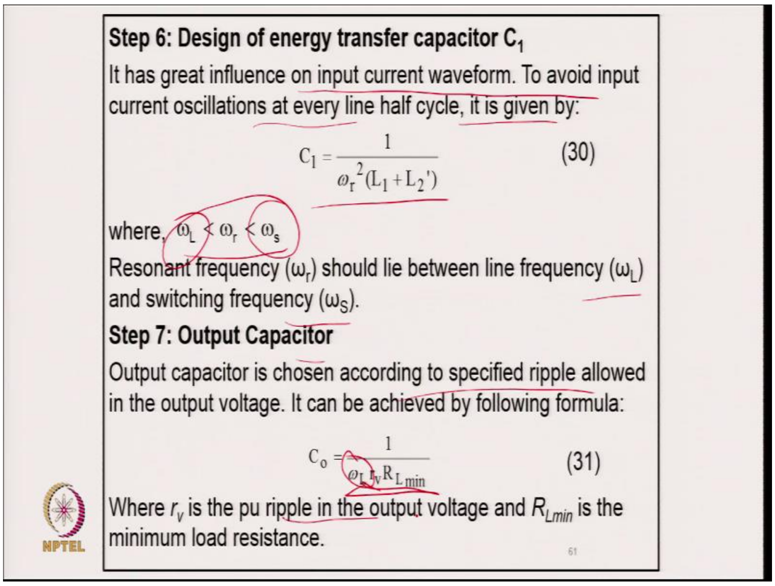

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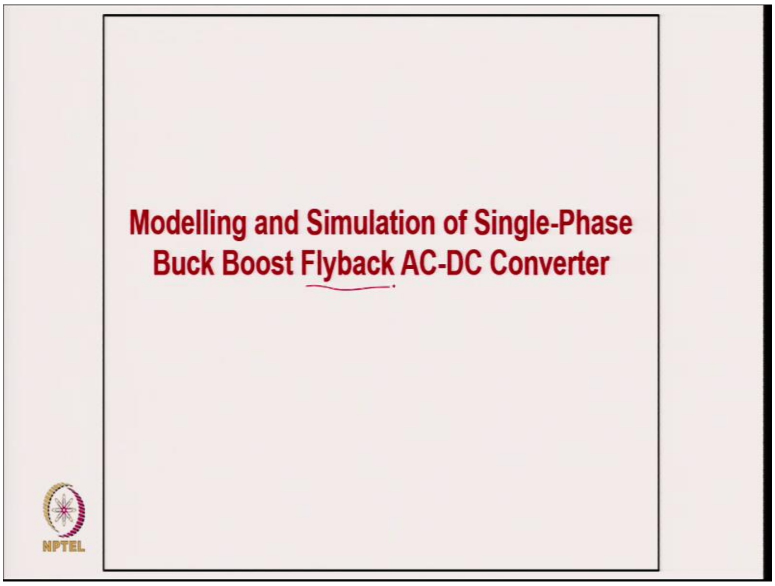

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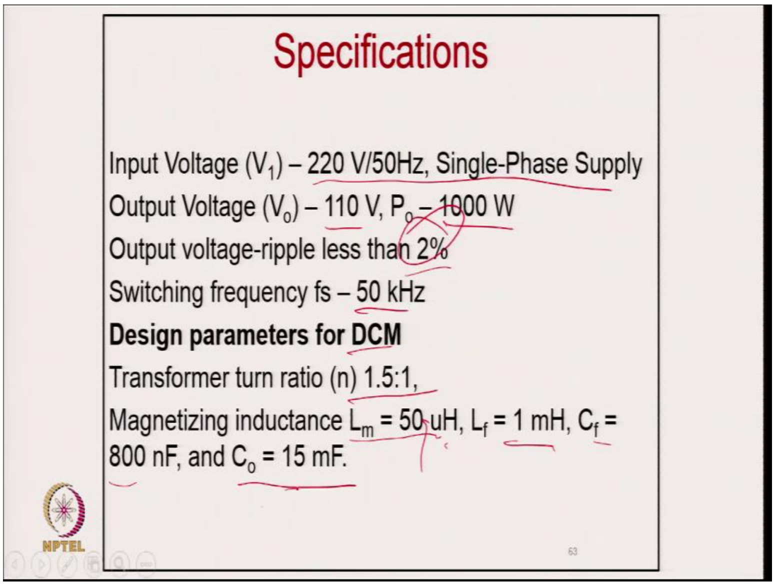

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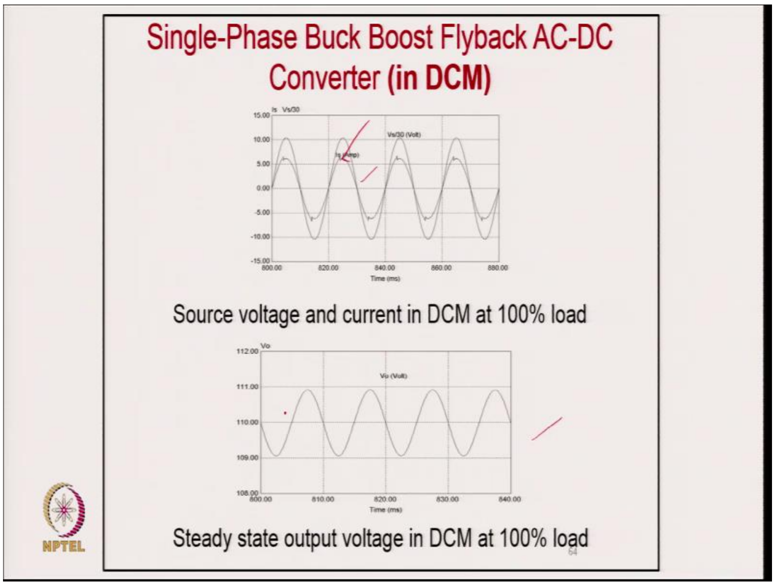

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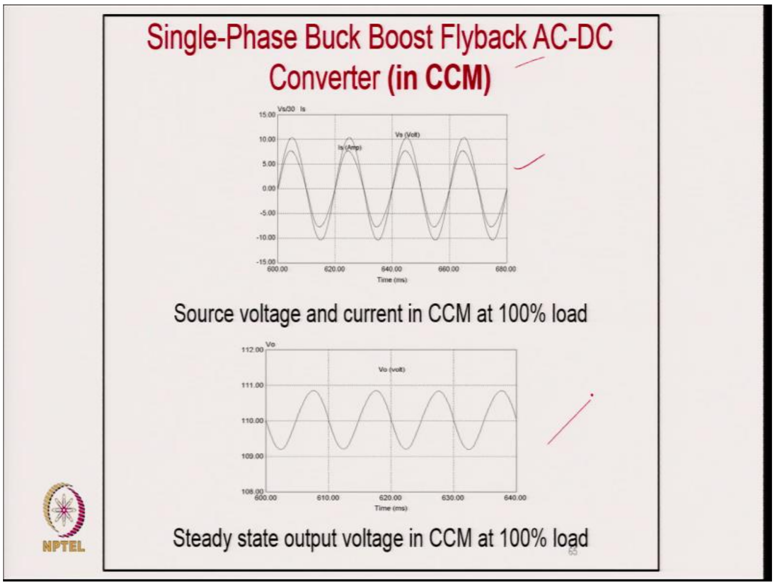

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Comparisons of Buck Boost Flyback AC-DC Converter Operation in DCM and CCM

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	6.53	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	

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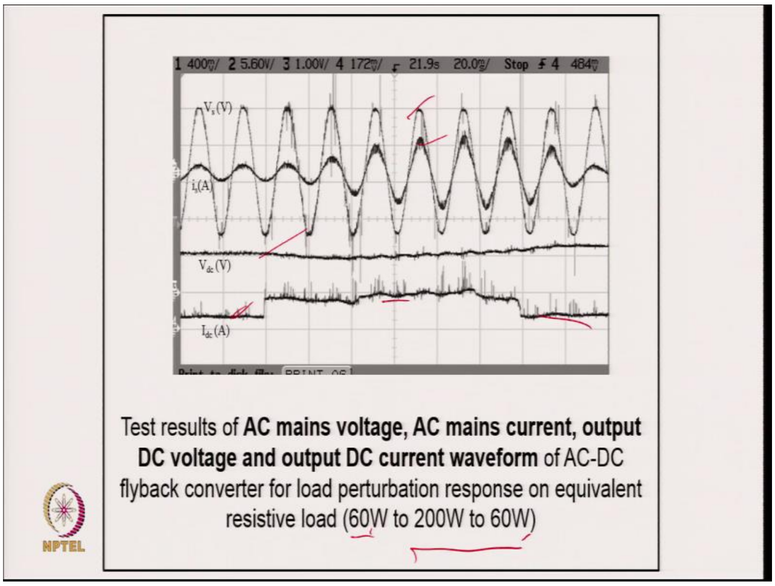

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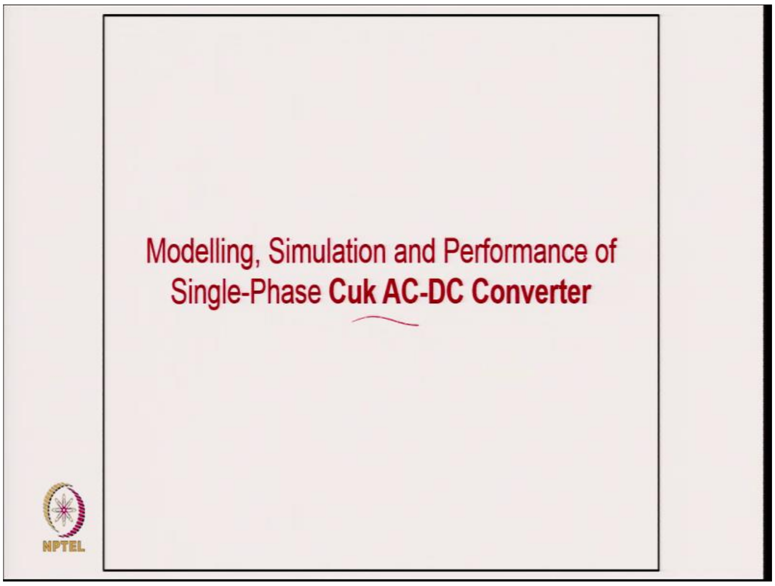

Now, coming to the Cuk converter modelling and simulation performance.

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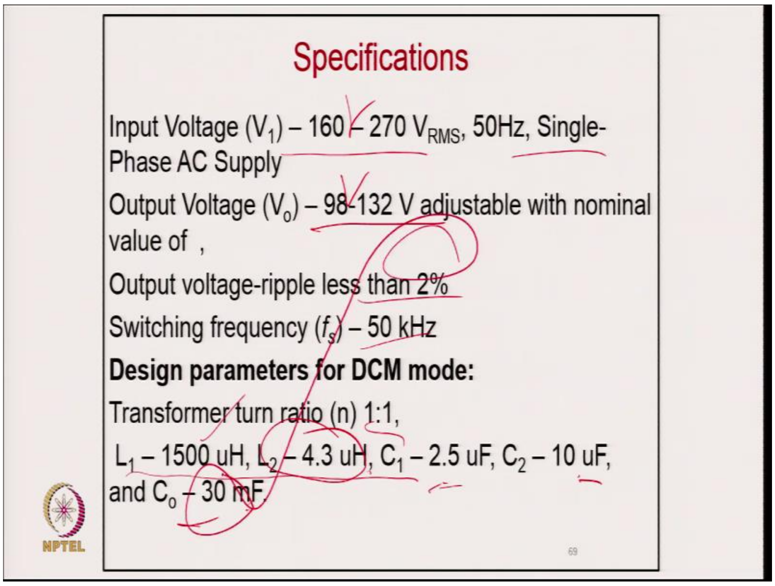

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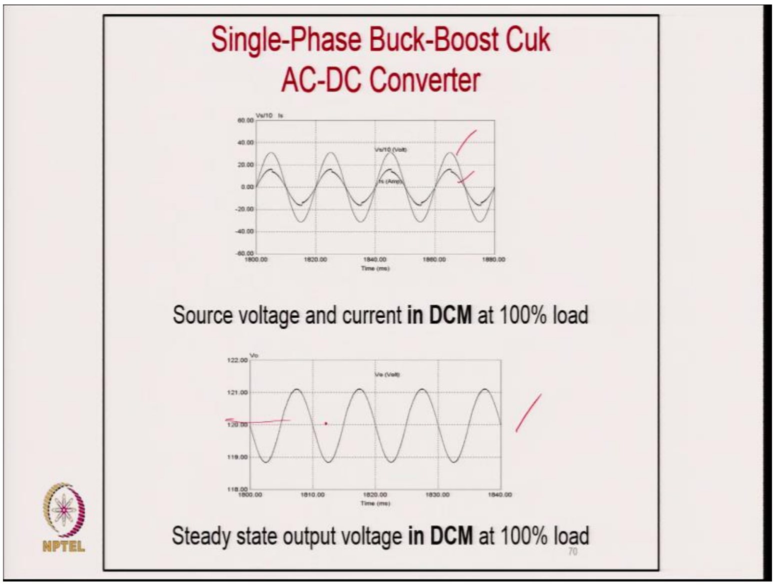

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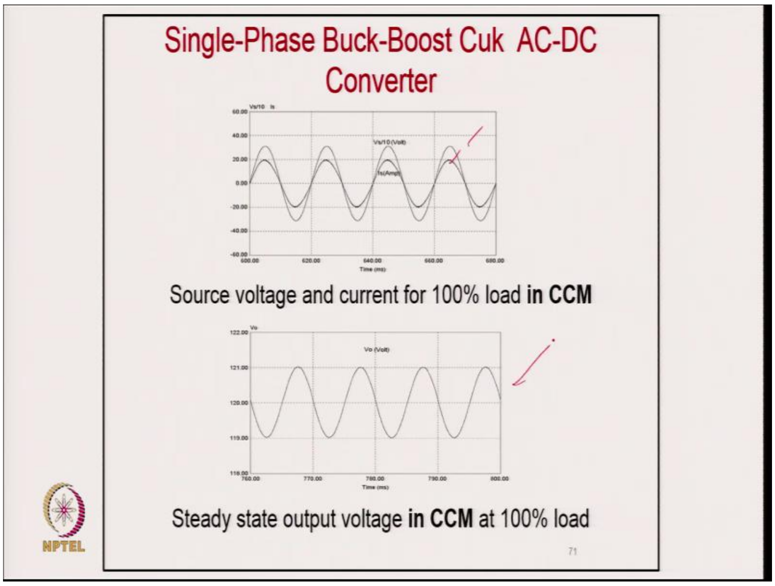

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Comparisons of Cuk Converter Operation in DCM and CCM at Full Load

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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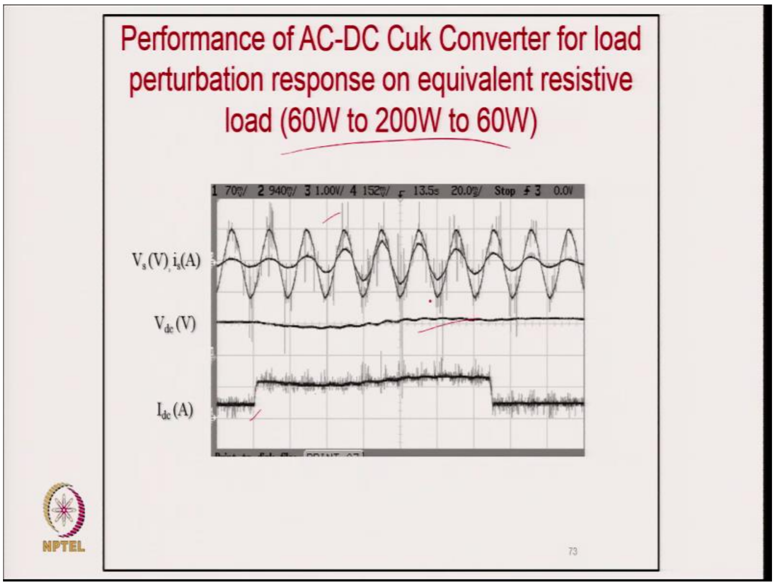

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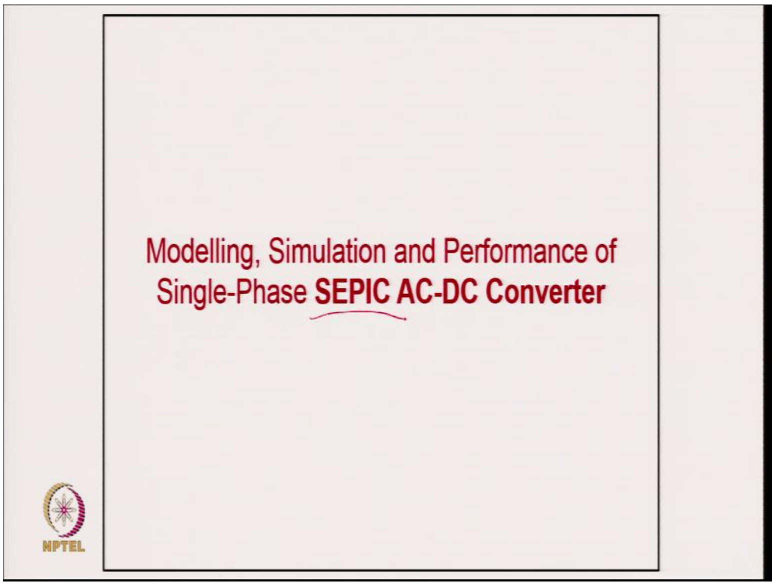

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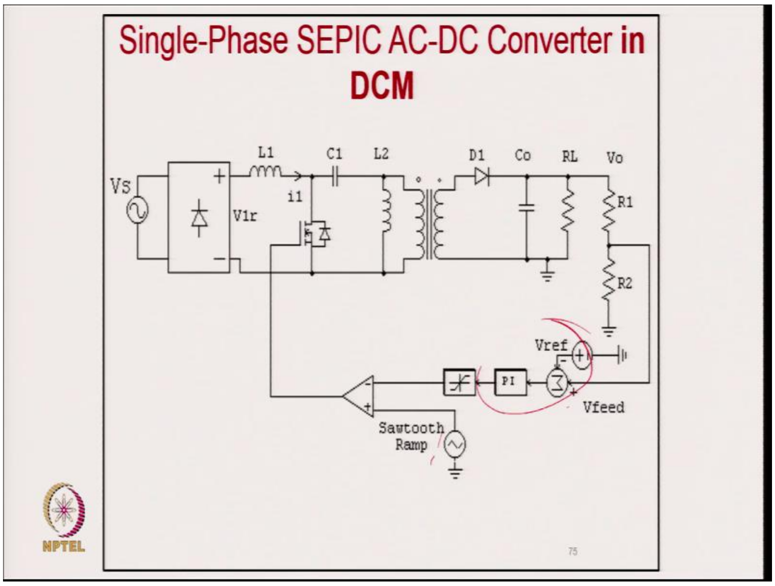

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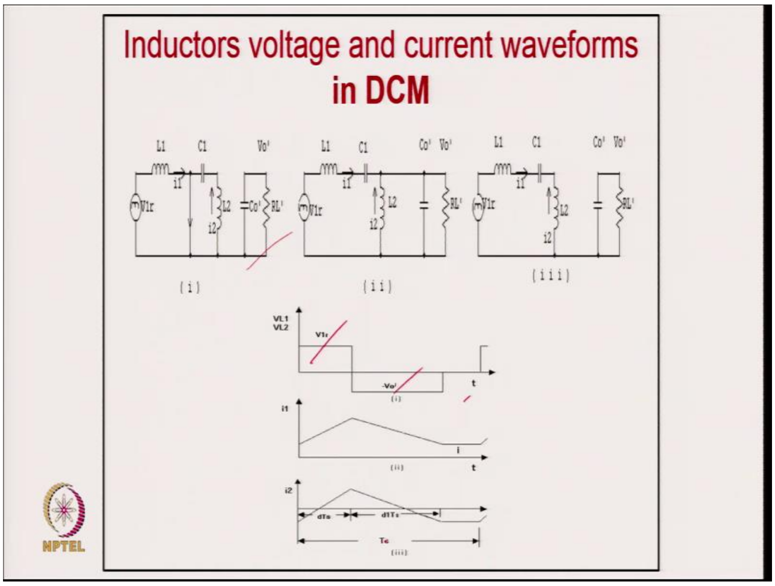

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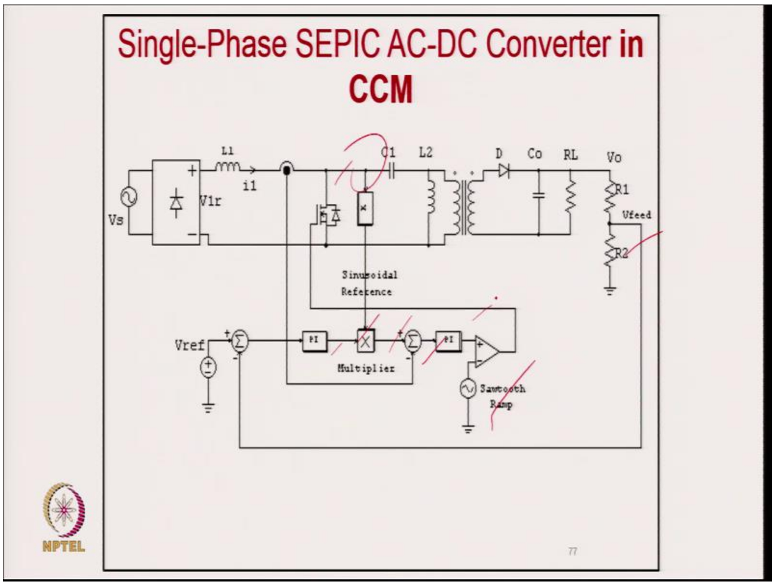

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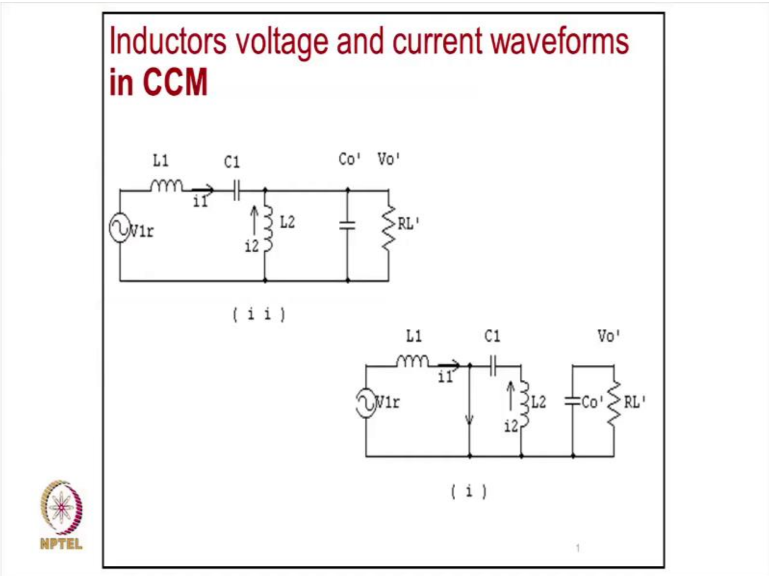

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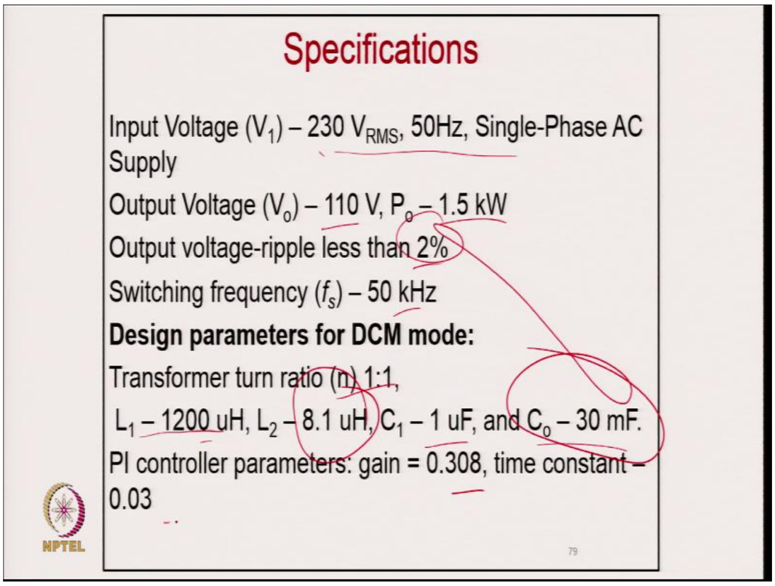

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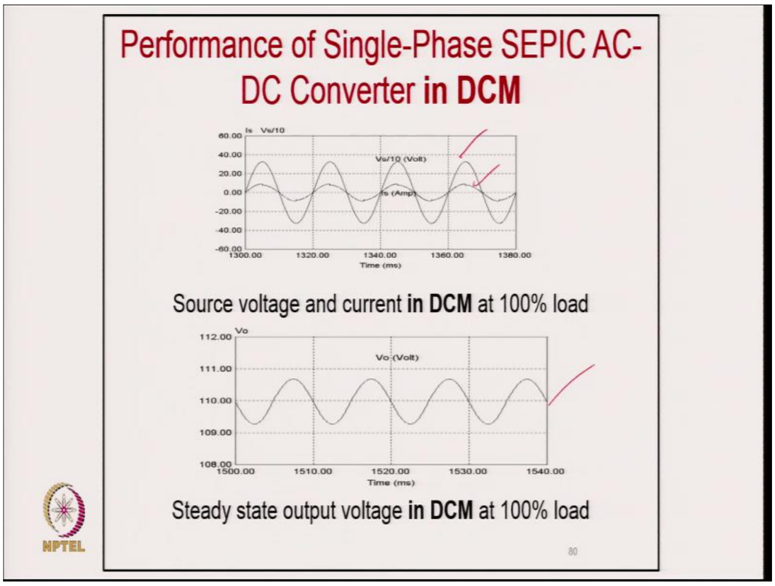

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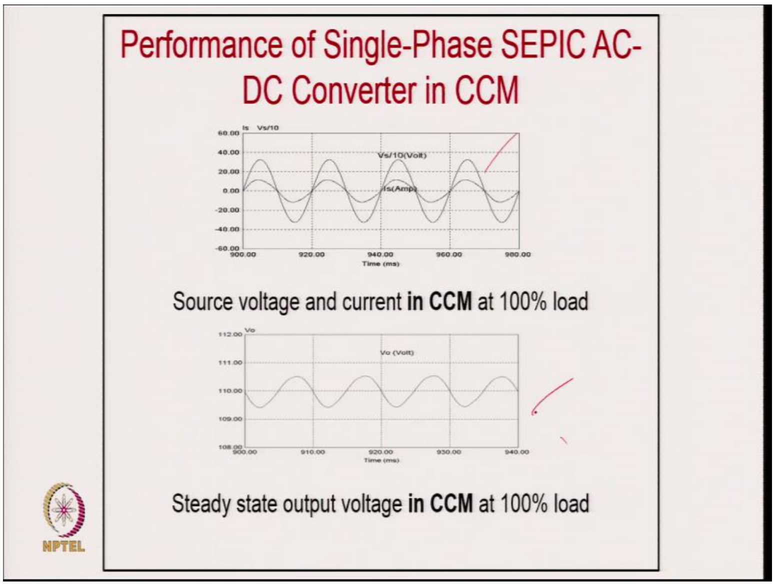

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Comparisons of SEPIC Converter Operation in DCM and CCM

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	3.24pu	3.14pu
	Average	0.76pu	0.77pu	0.71pu	0.78pu
	RMS	4.60pu	2.18pu	1.50pu	1.39pu
Normalized Current of Diode	Peak	15.2pu	10.94pu	3.17pu	3.15pu
	Average	1.47pu	1.27pu	0.93pu	0.98pu
	RMS	7.22pu	3.34pu	1.68pu	1.56pu
Control Technique		Voltage Mode Control		Average Current Control	
Size of Converter		Small		Large	
Circuit Simplicity		Simple		Complex	

NPTEL

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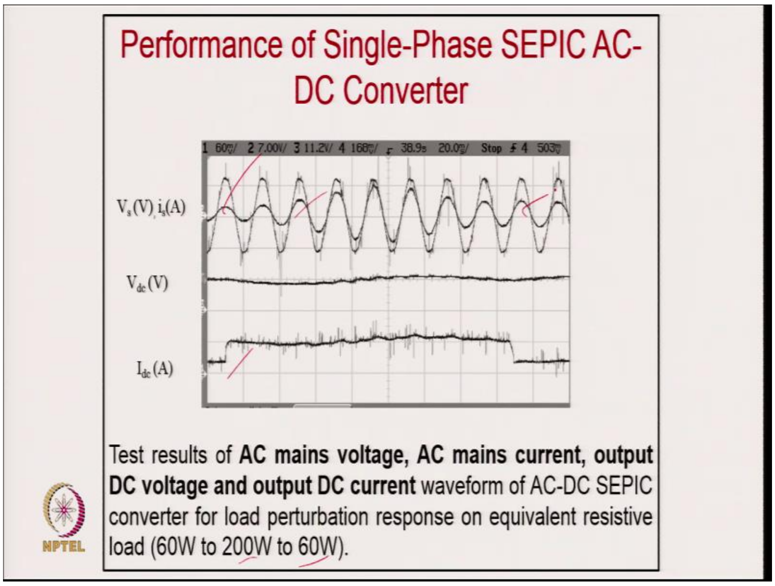

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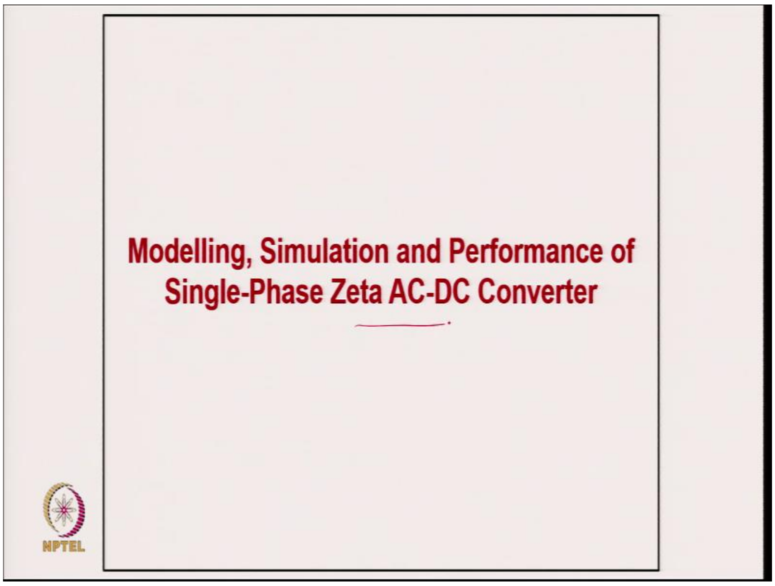

Now coming to the modelling and simulation performance of single phase zeta AC DC converter.

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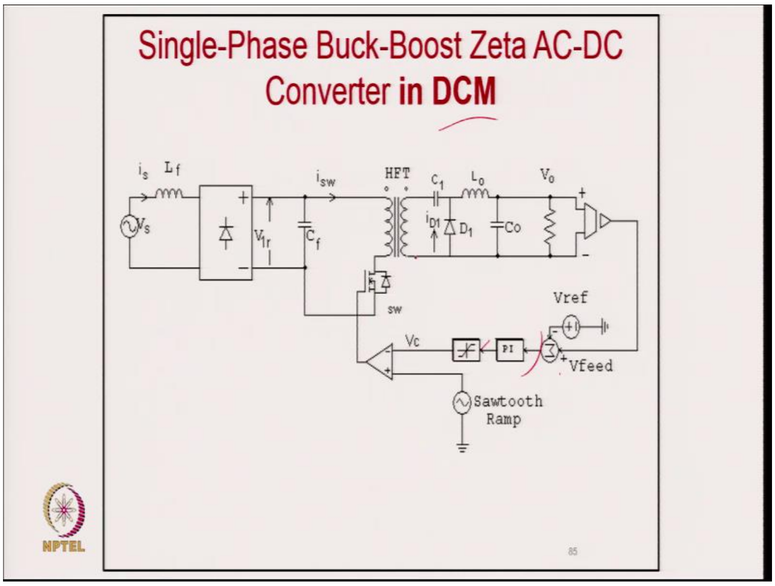

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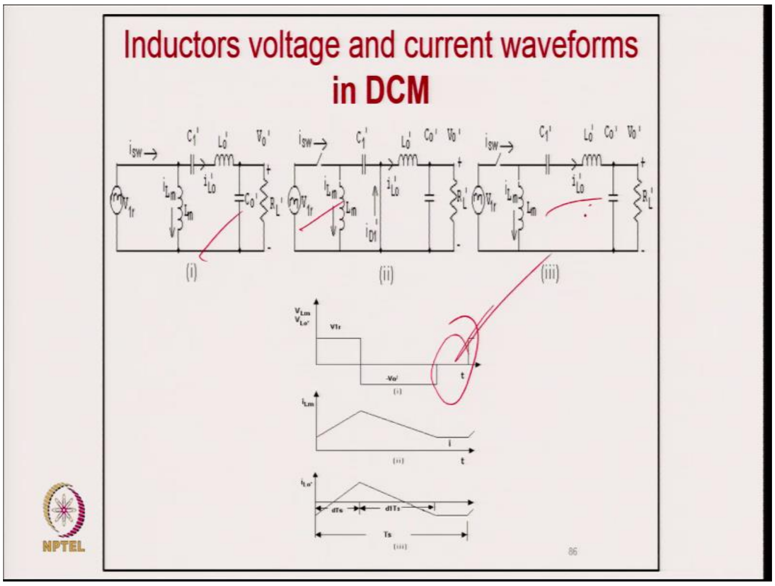

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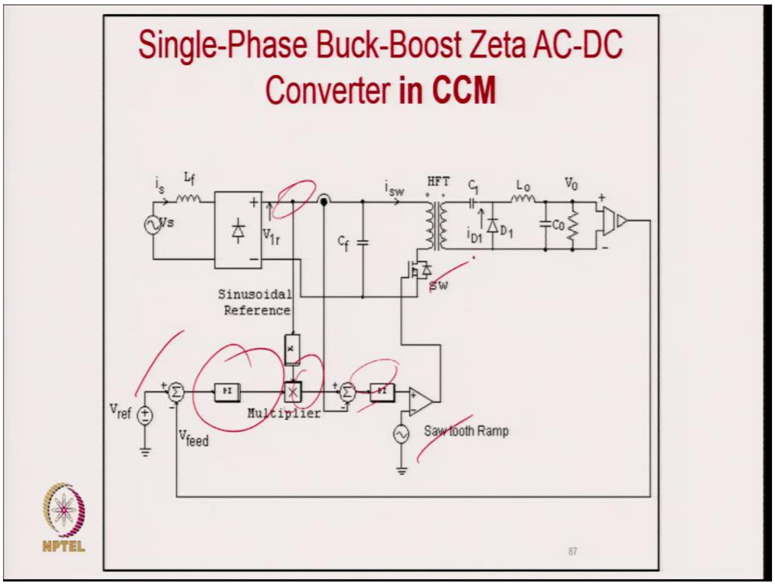

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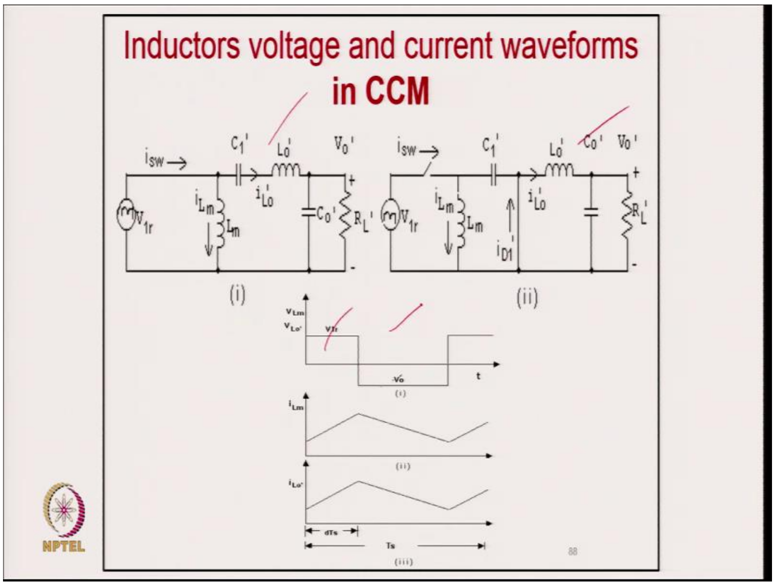

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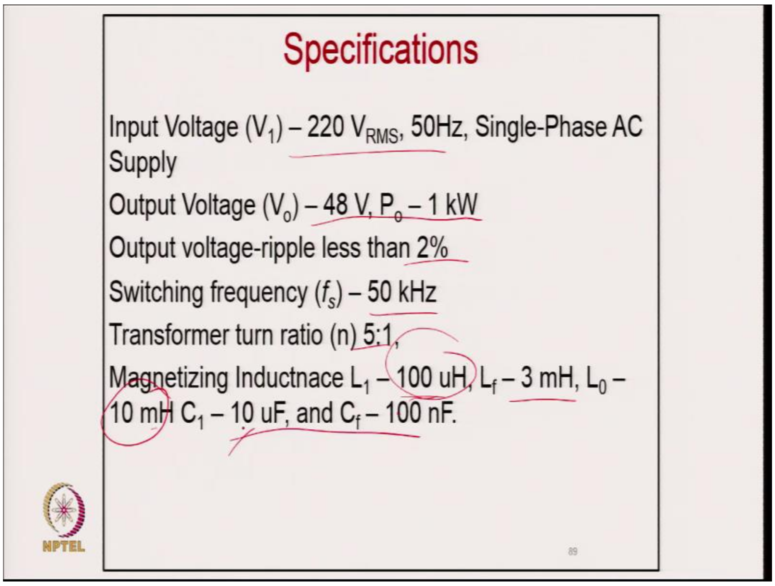

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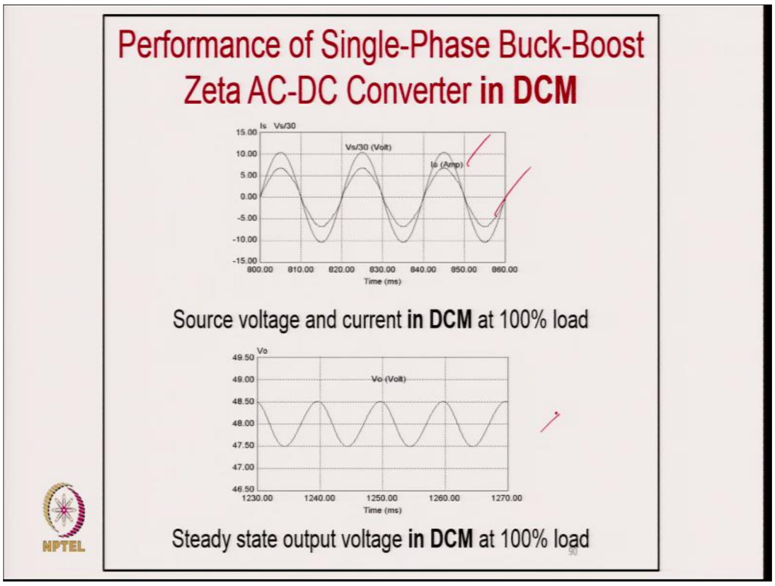

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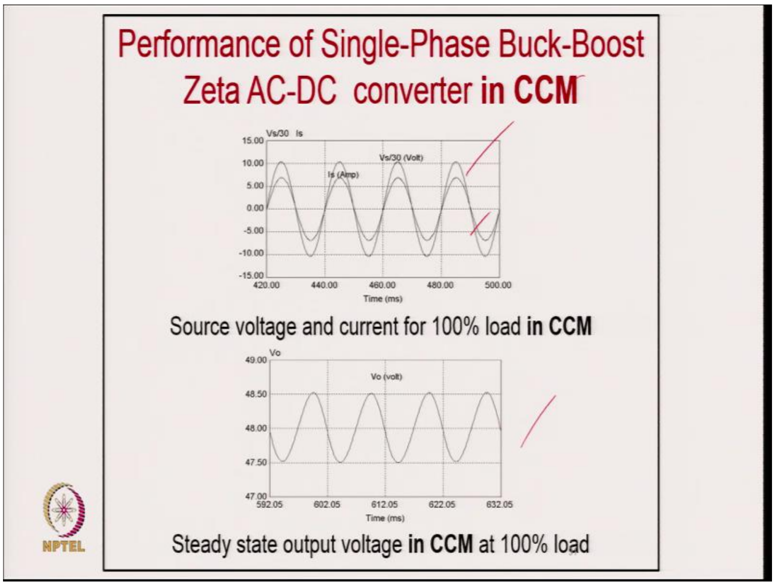

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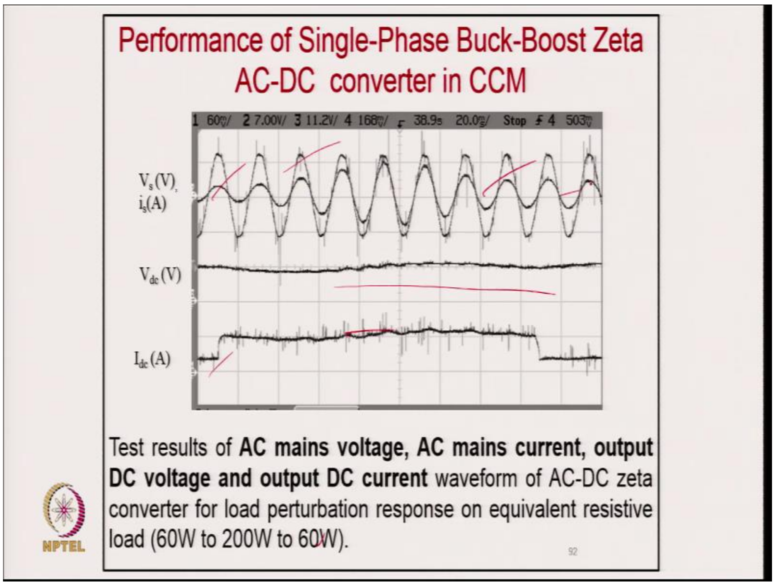

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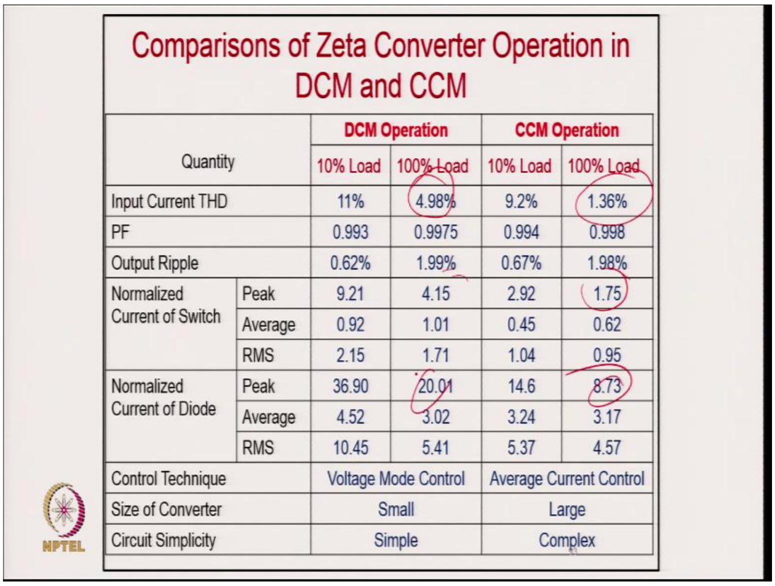

Comparisons of Zeta Converter Operation in DCM and CCM

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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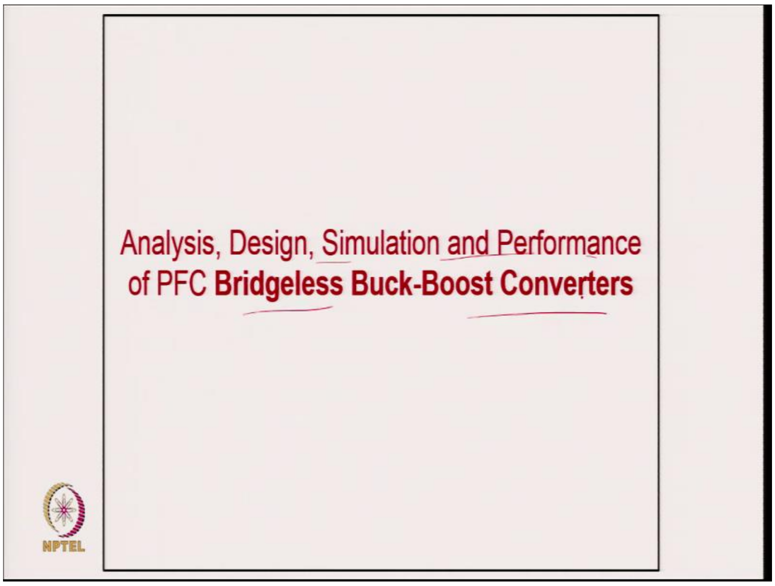

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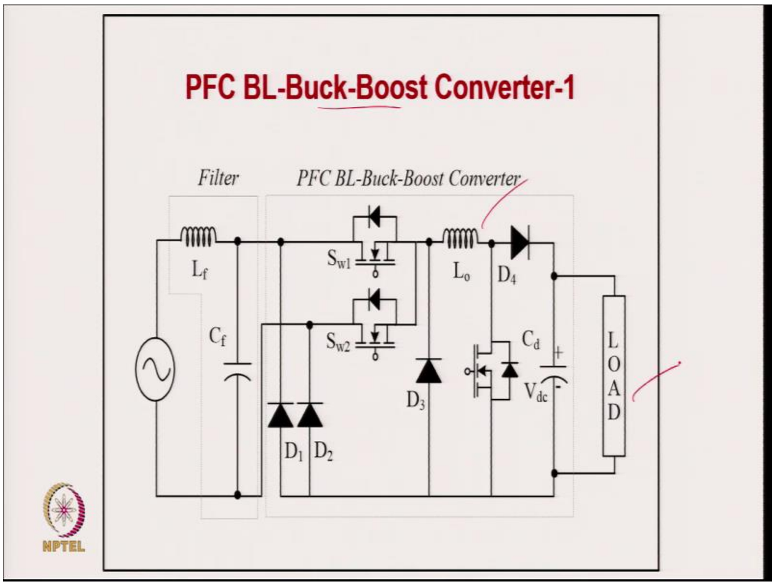

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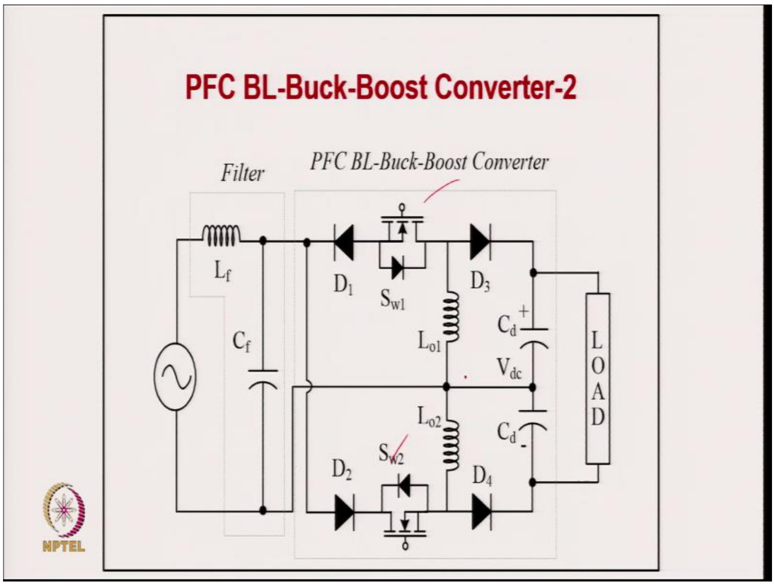

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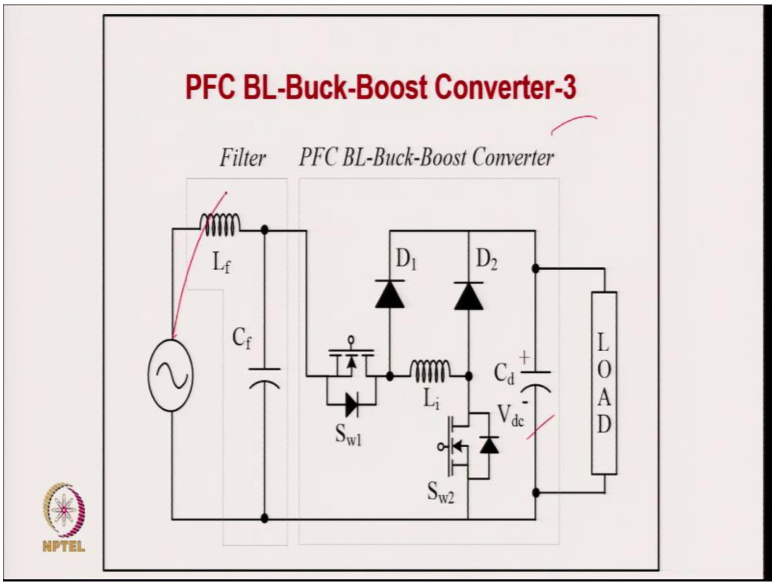

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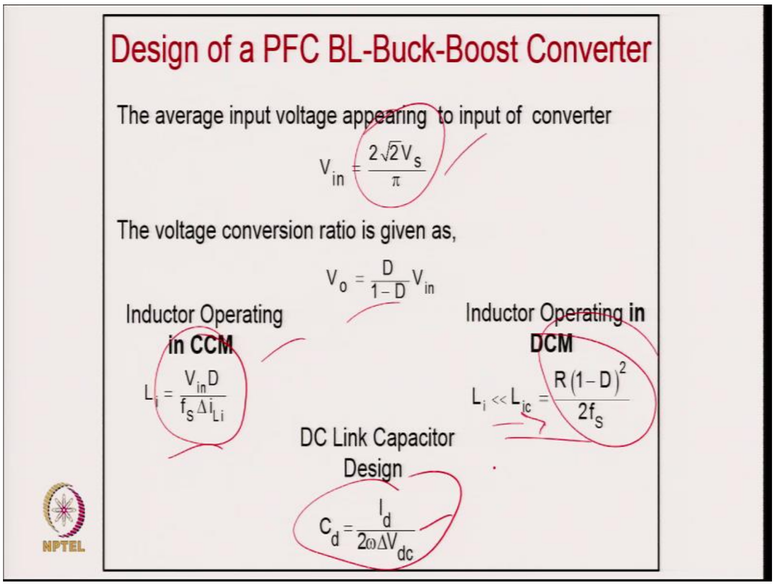

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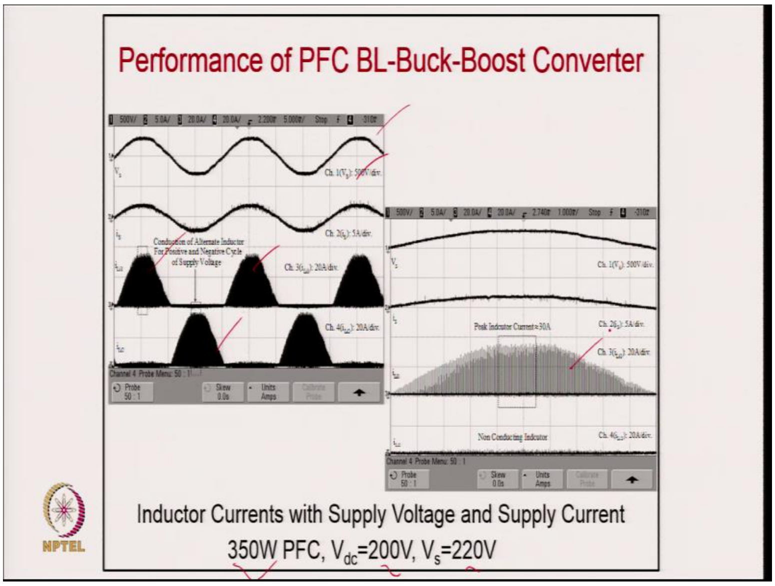

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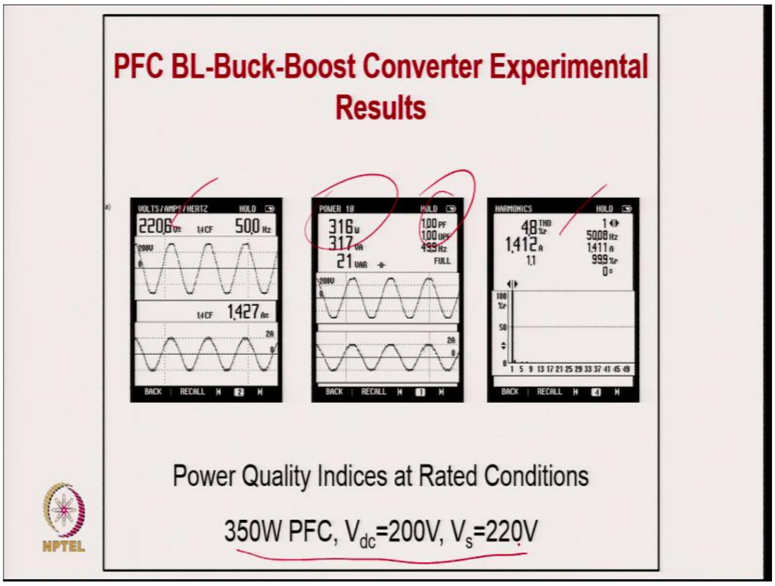

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Coming to the analysis, design, and simulation of PFC bridgeless Cuk converter.

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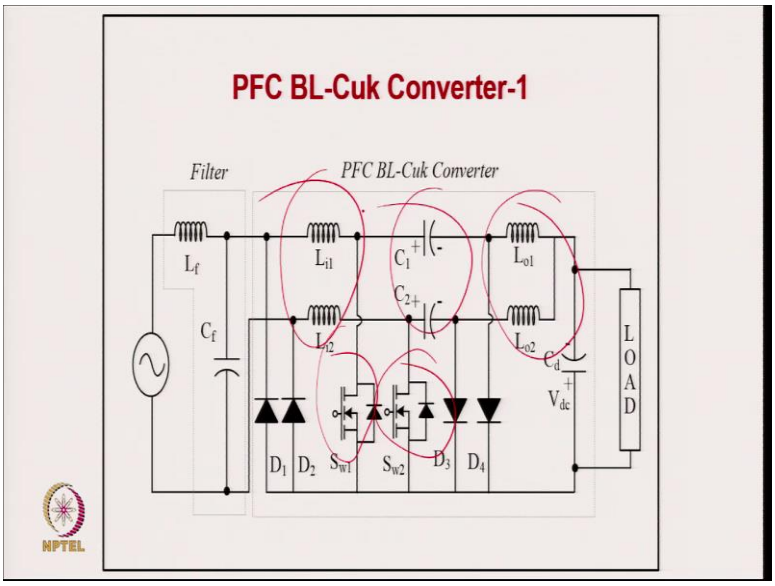

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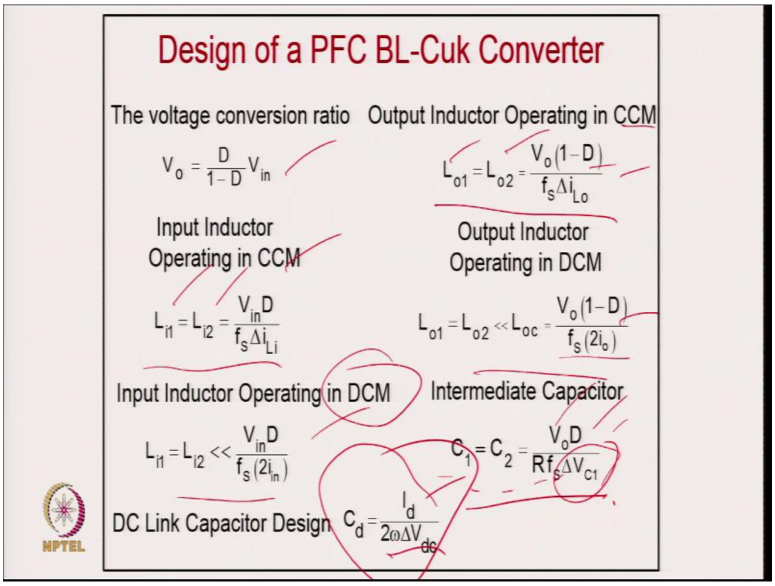

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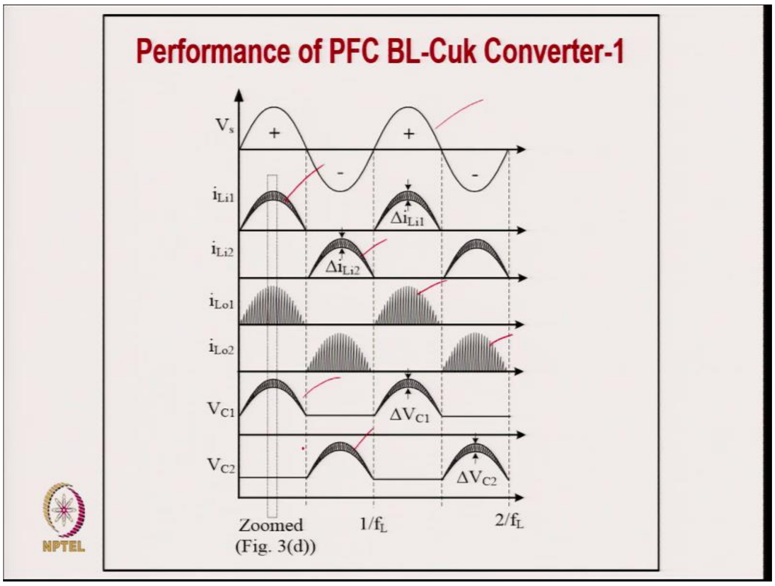

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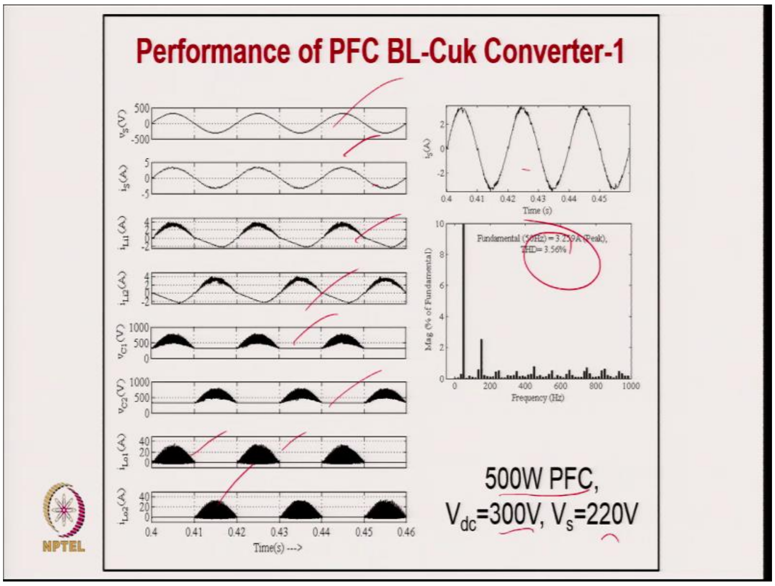

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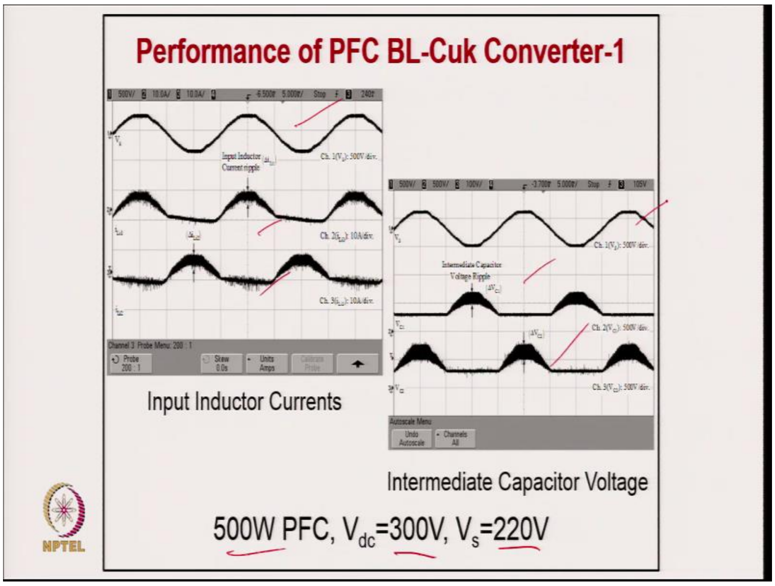

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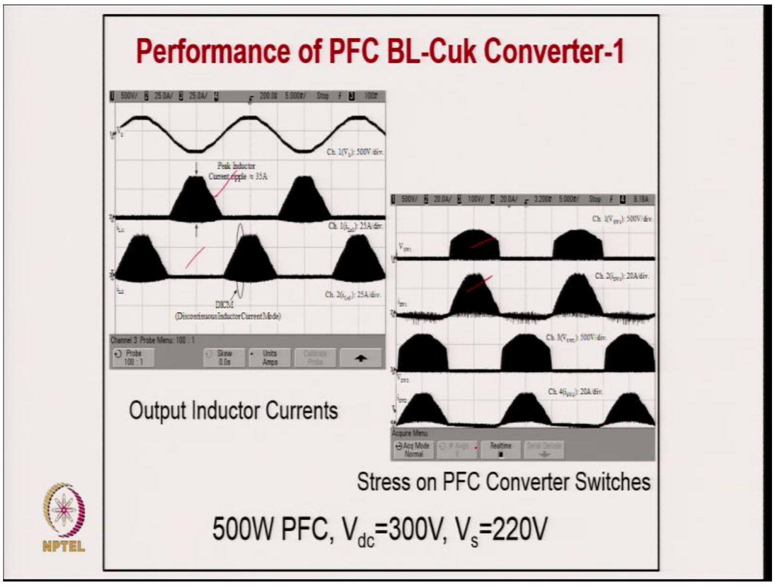

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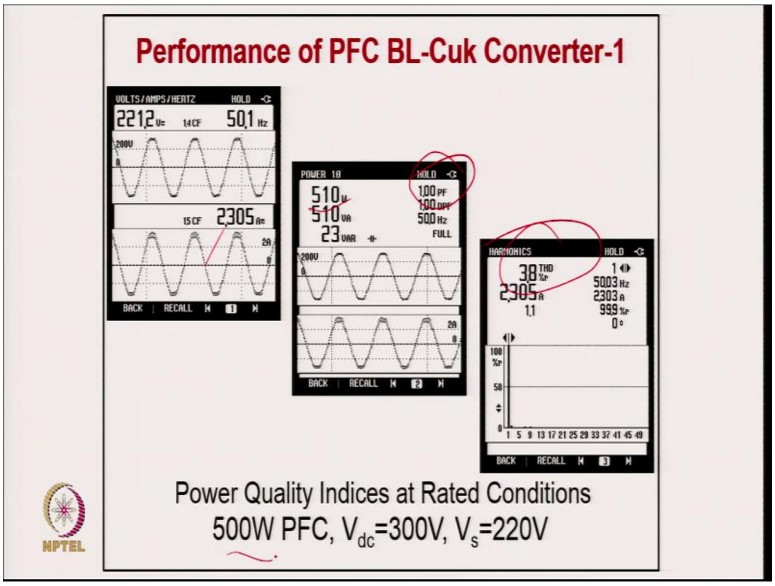

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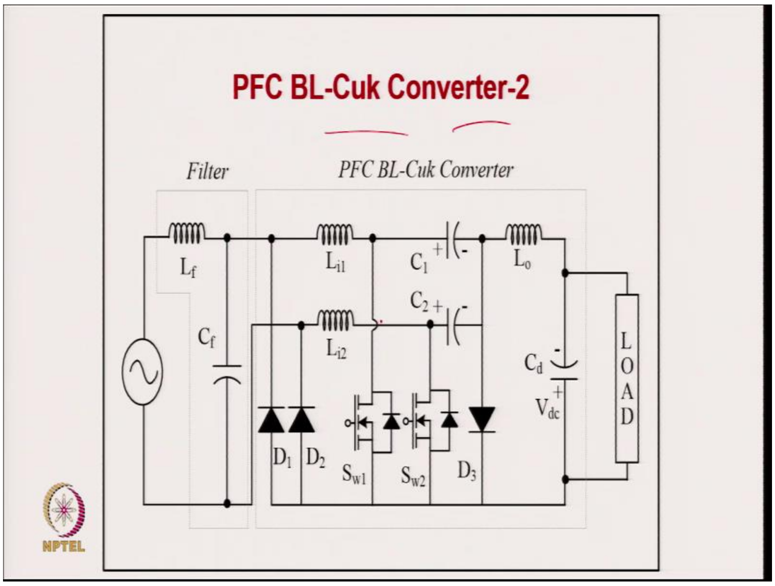

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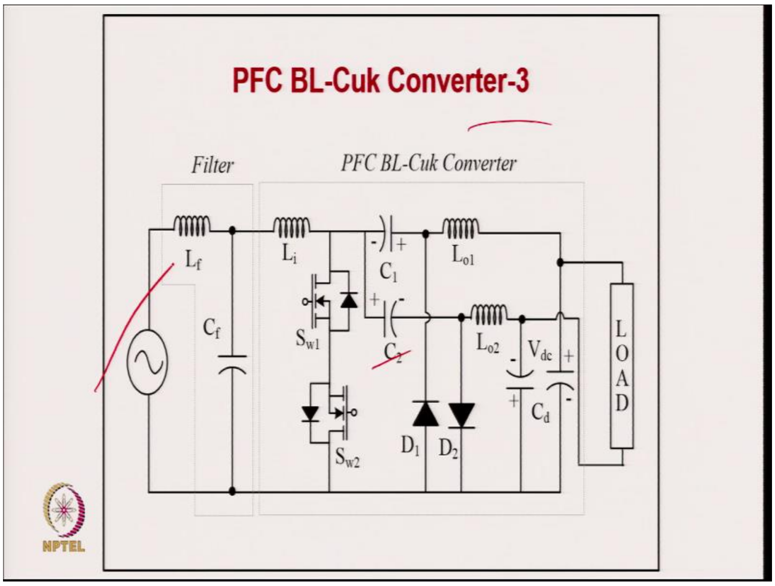

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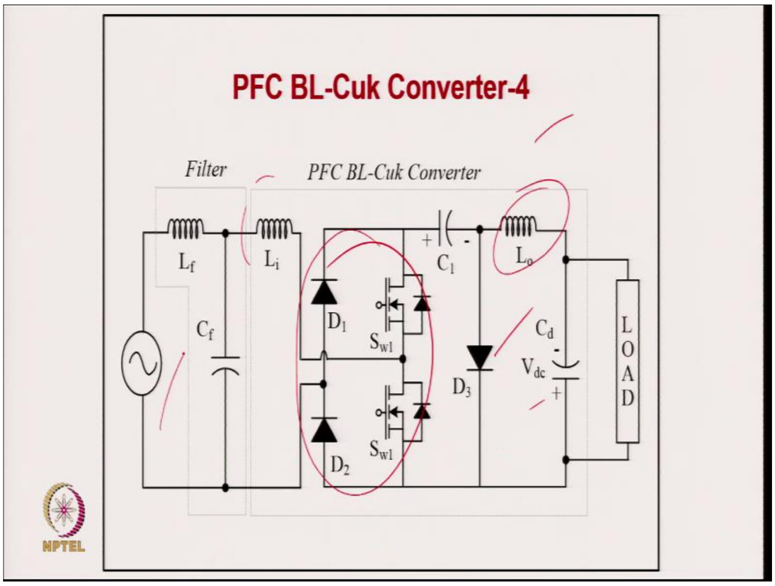

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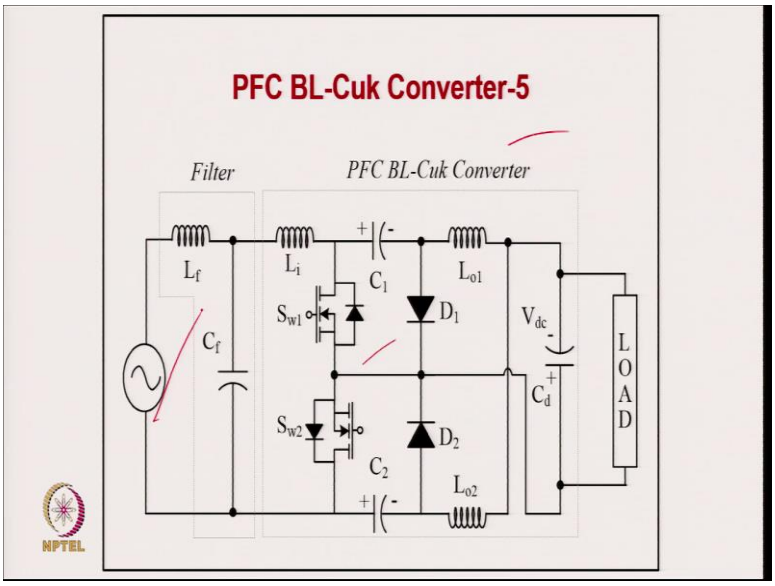

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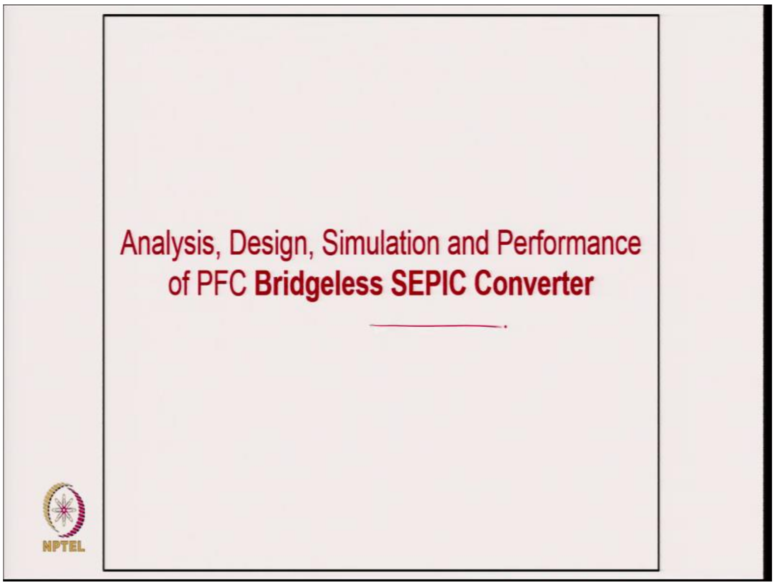

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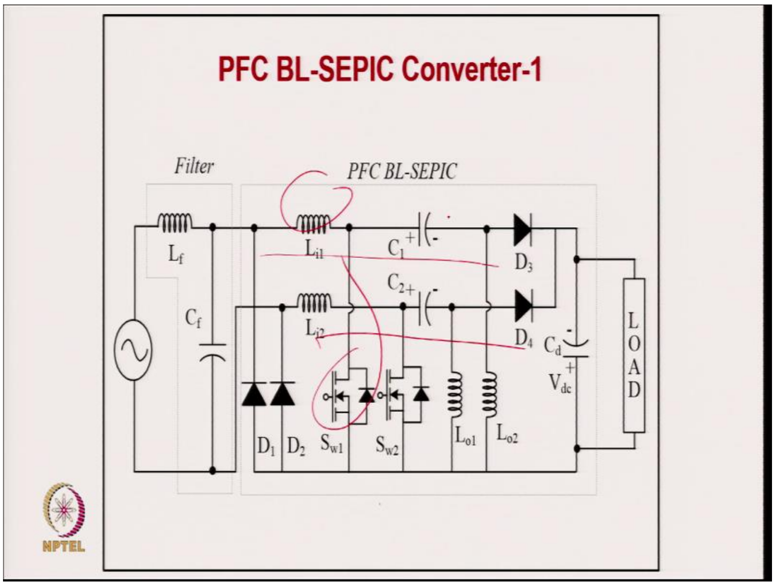

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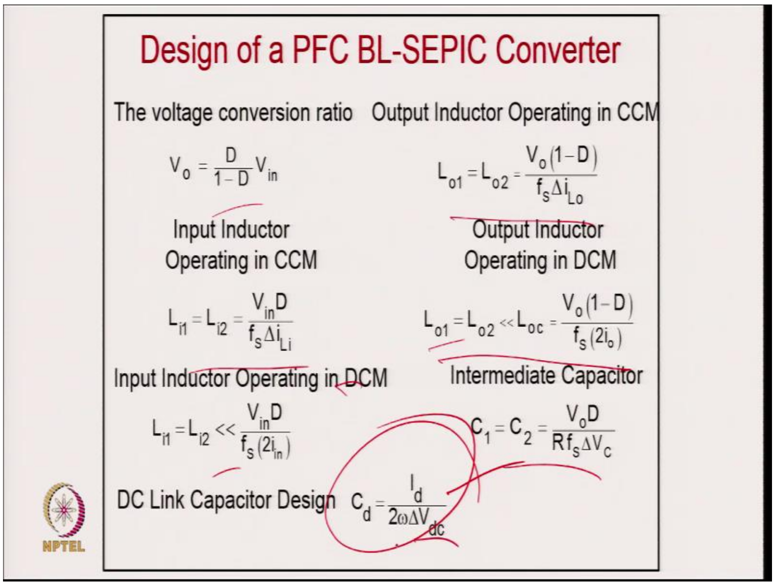

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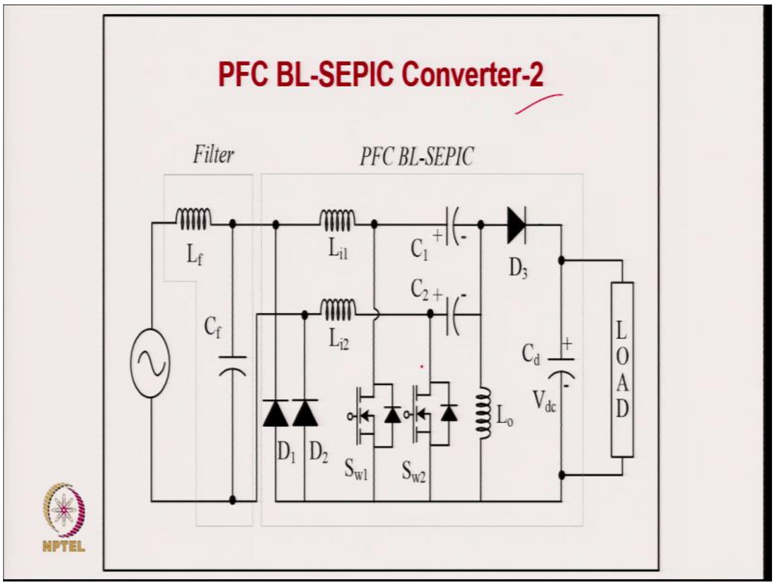

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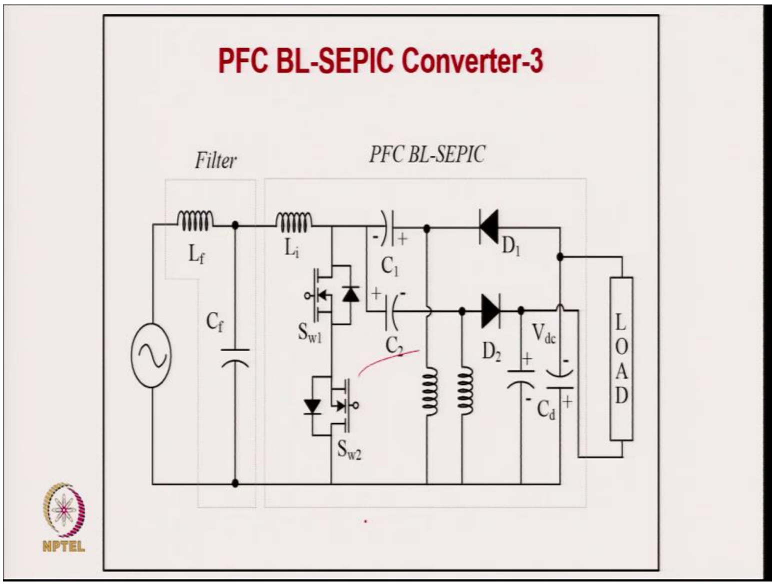

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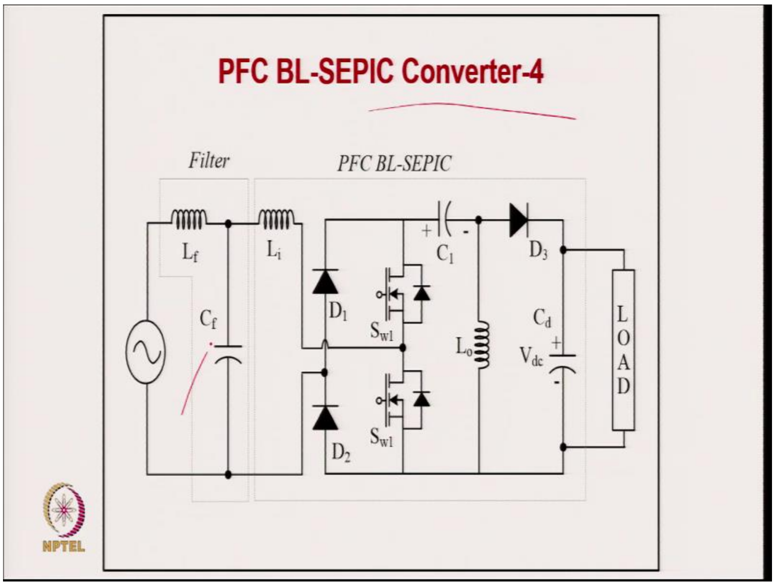

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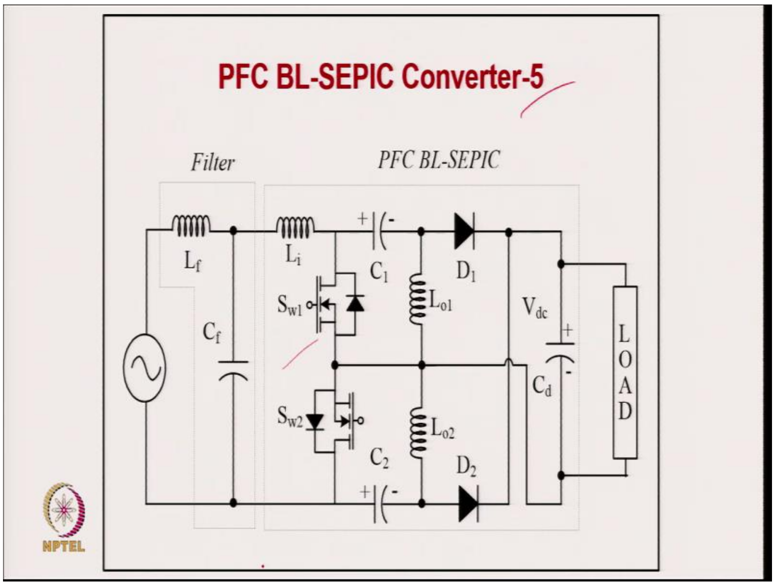

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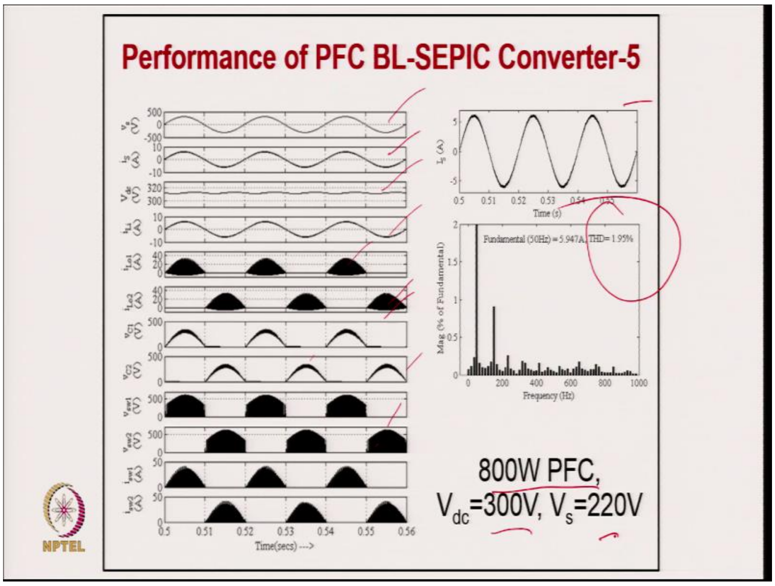

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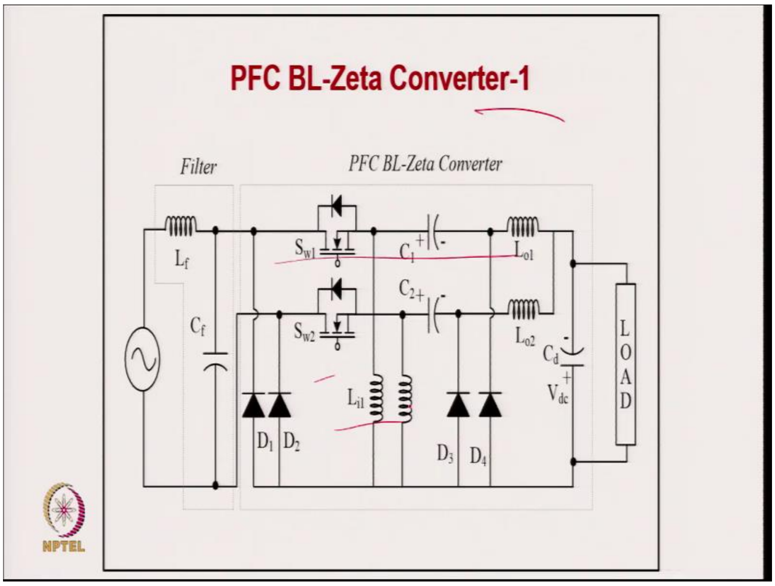

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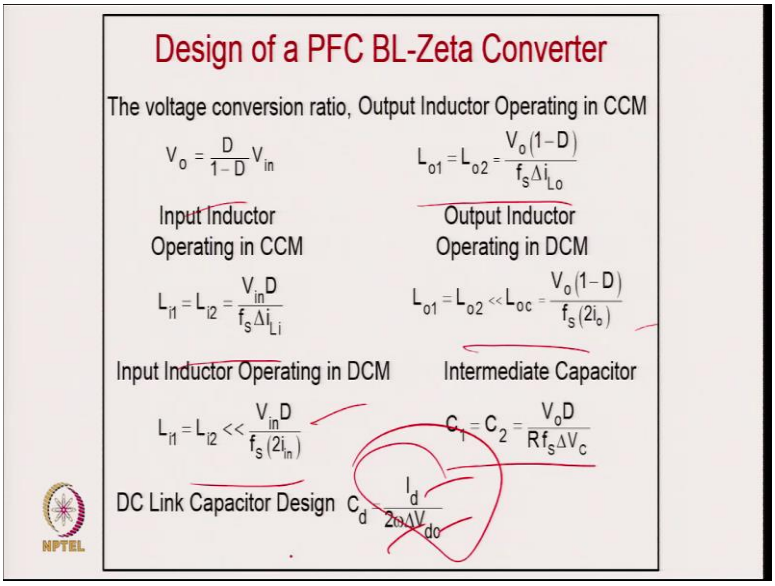

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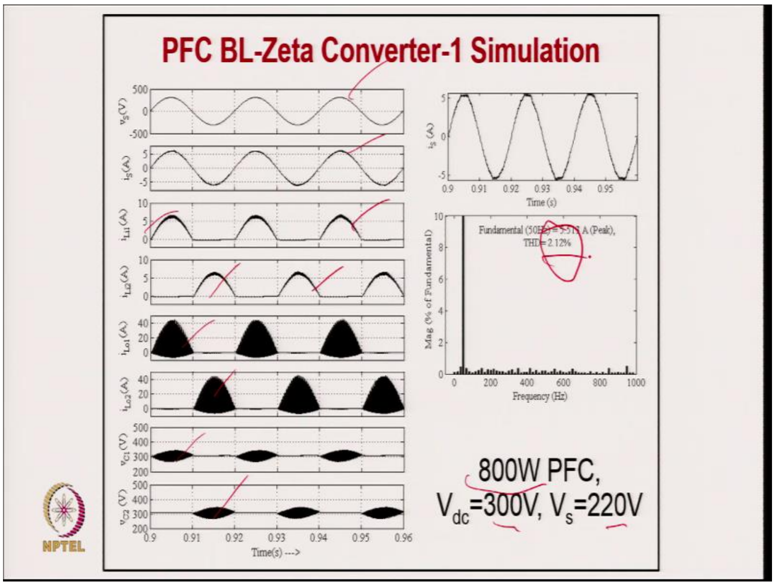

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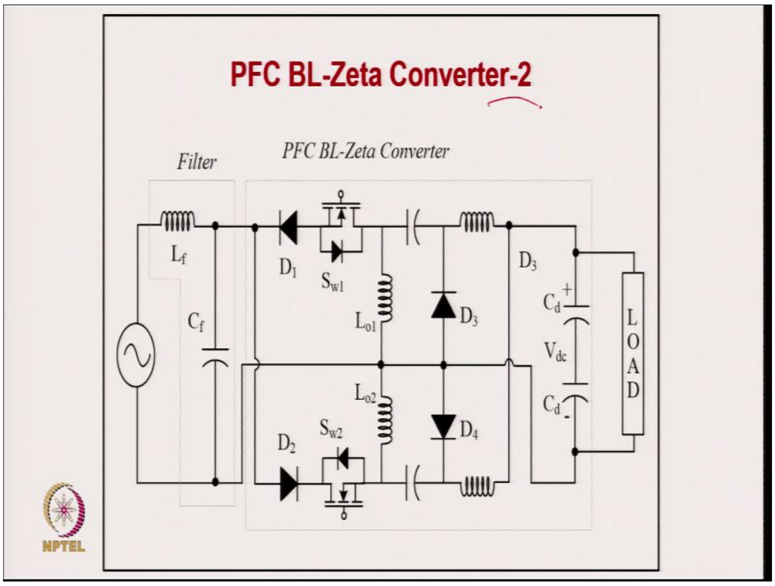

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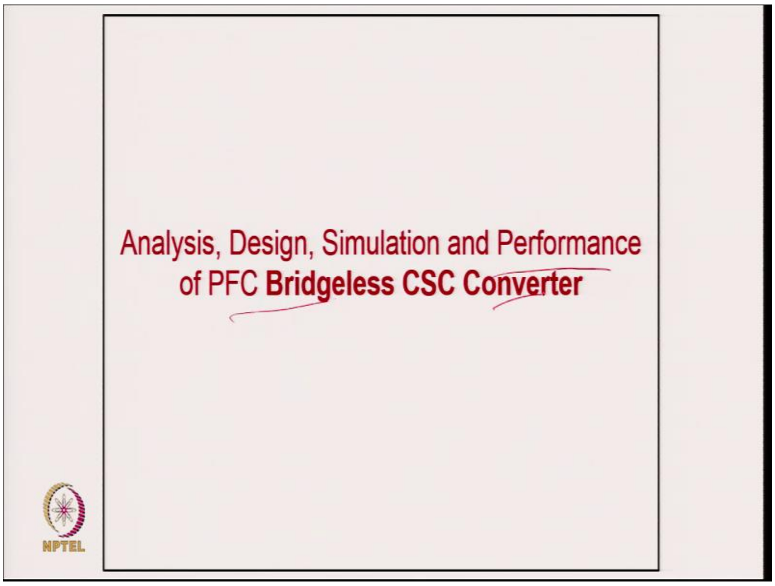

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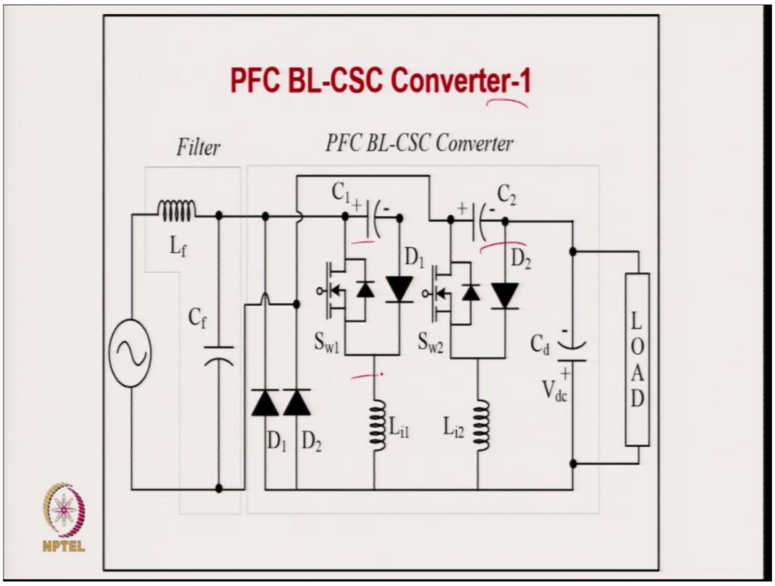

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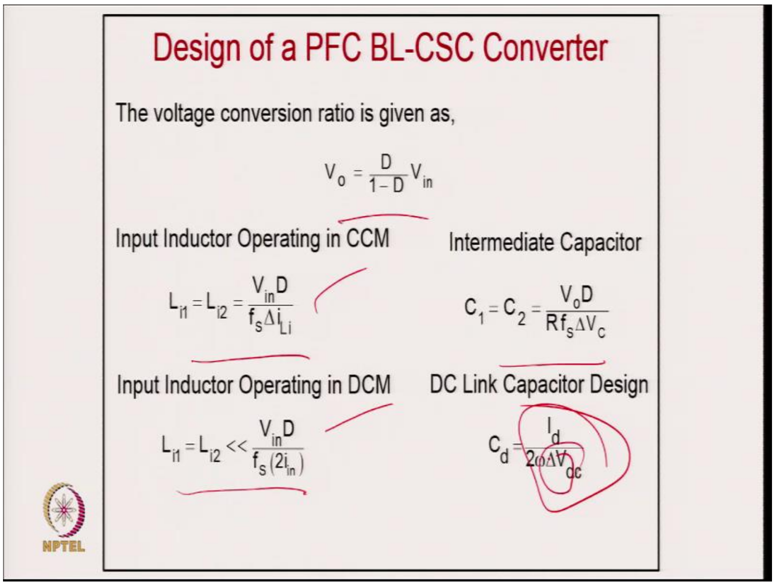

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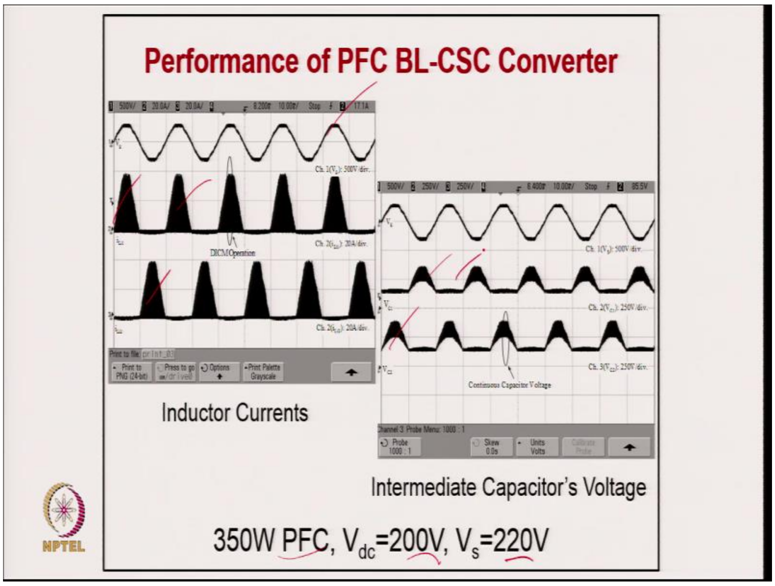

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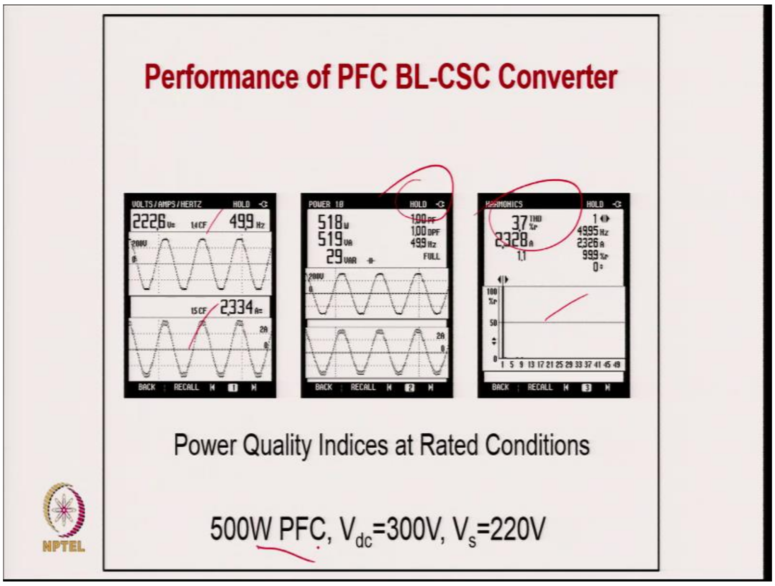

Thank you.