Power Quality
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Chapter - 14
Lecture - 37
Multipulse Converters

Welcome to the course on Power Quality and we will cover this Multipulse Converters which are used for power quality improvement on AC mains because these are AC-DC converters.

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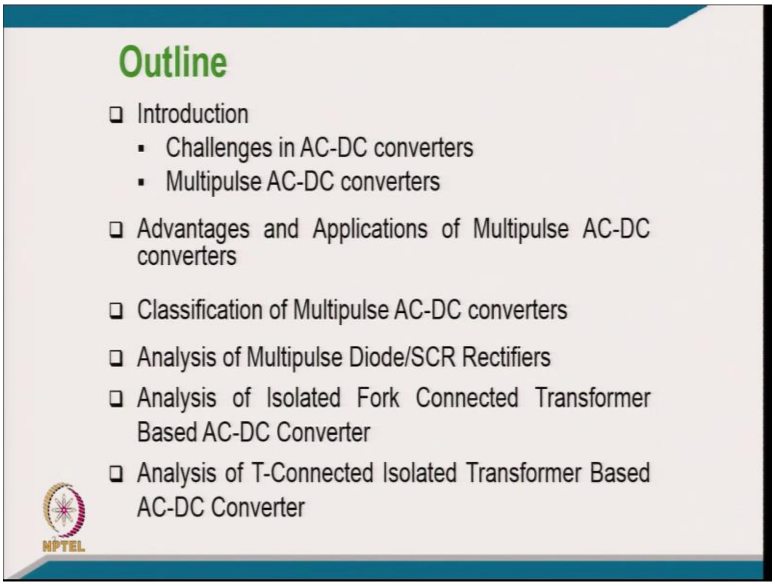

These are the outlines of this lecture.

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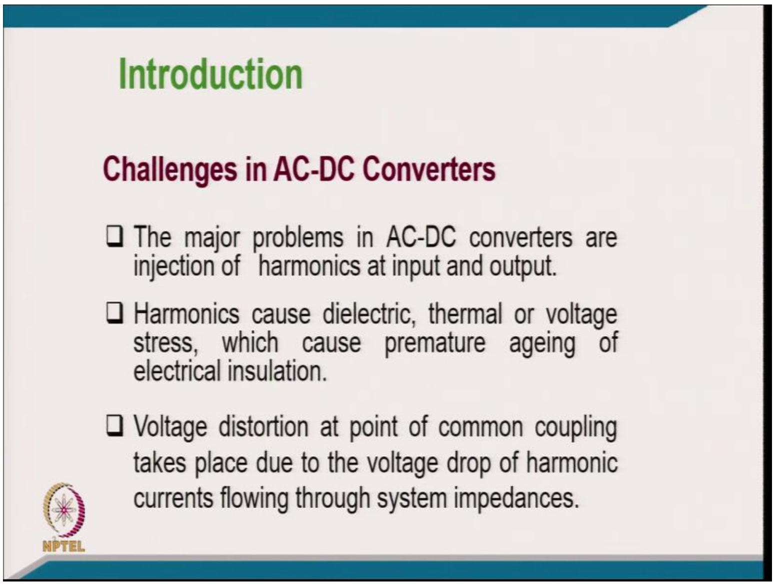

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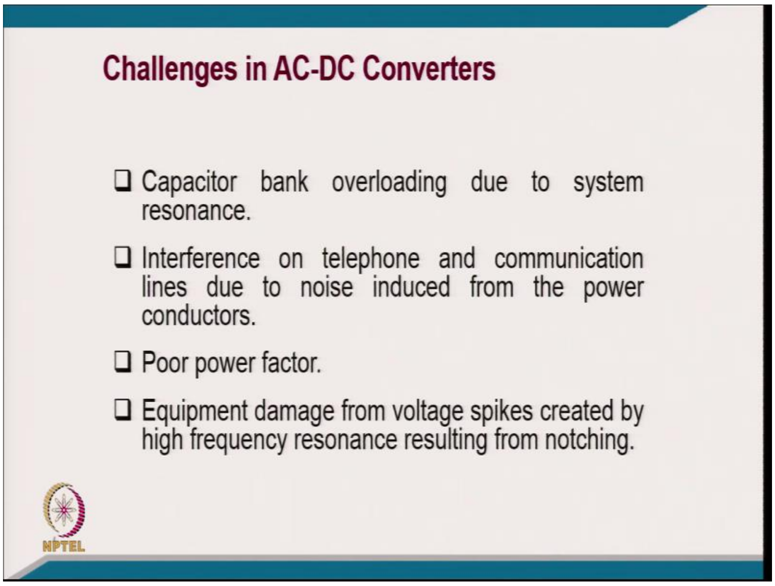

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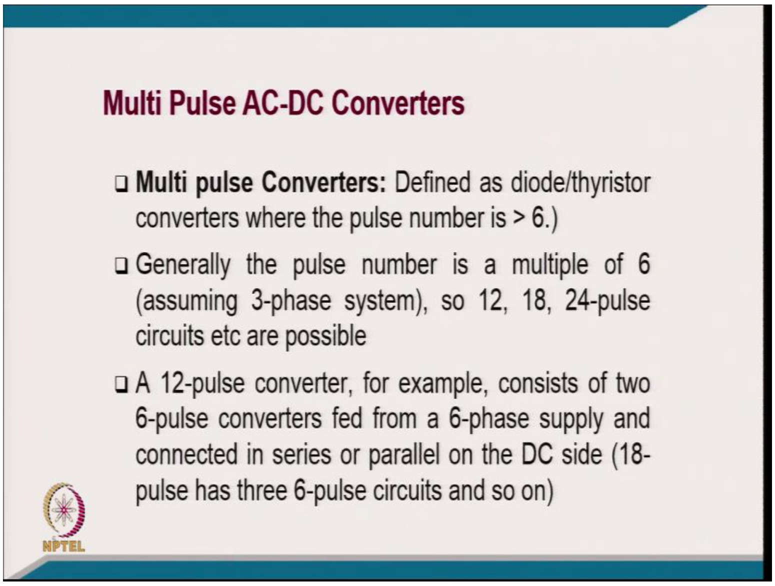

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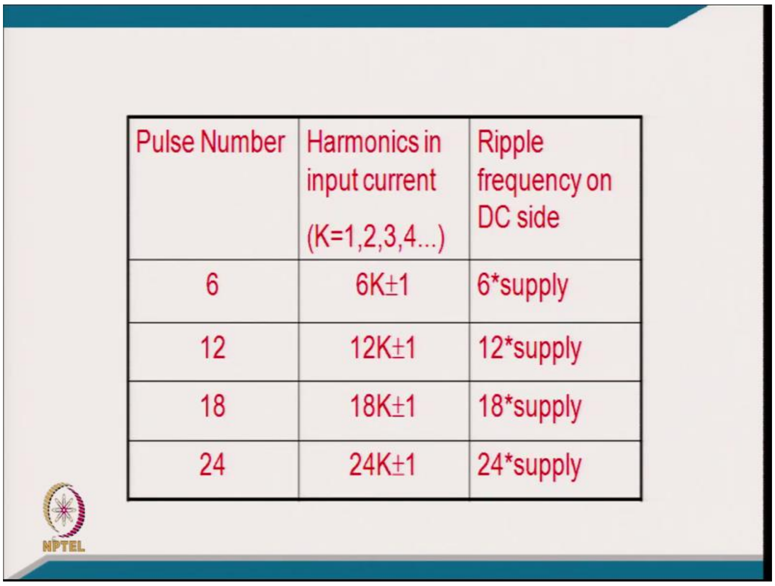

Pulse Number	Harmonics in input current (K=1,2,3,4...)	Ripple frequency on DC side
6	6K±1	6*supply
12	12K±1	12*supply
18	18K±1	18*supply
24	24K±1	24*supply

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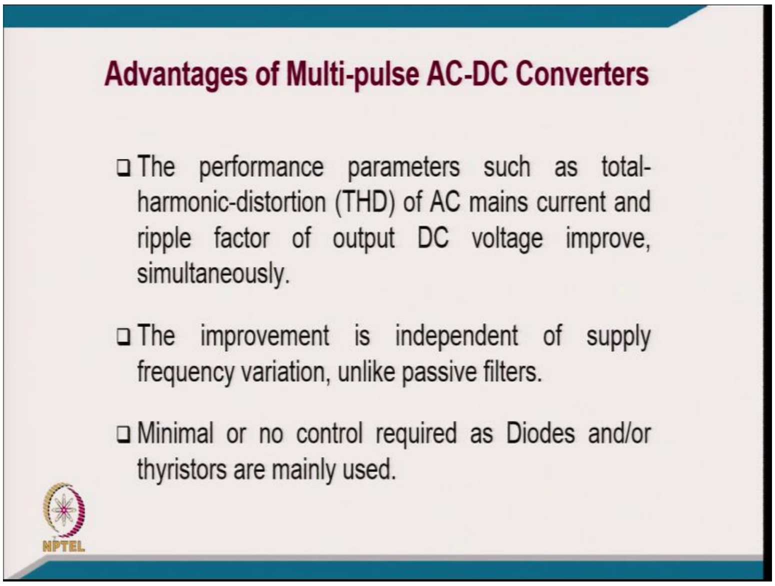

These are the advantages of multipulse AC-DC Converters

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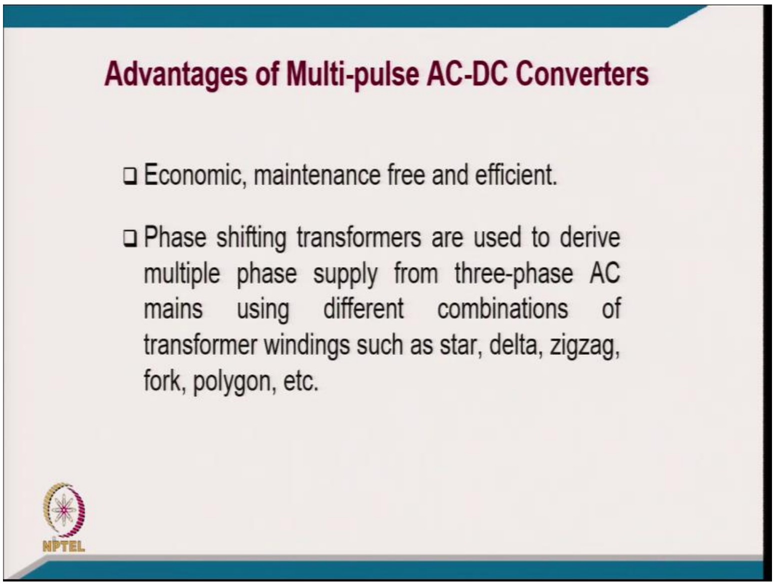

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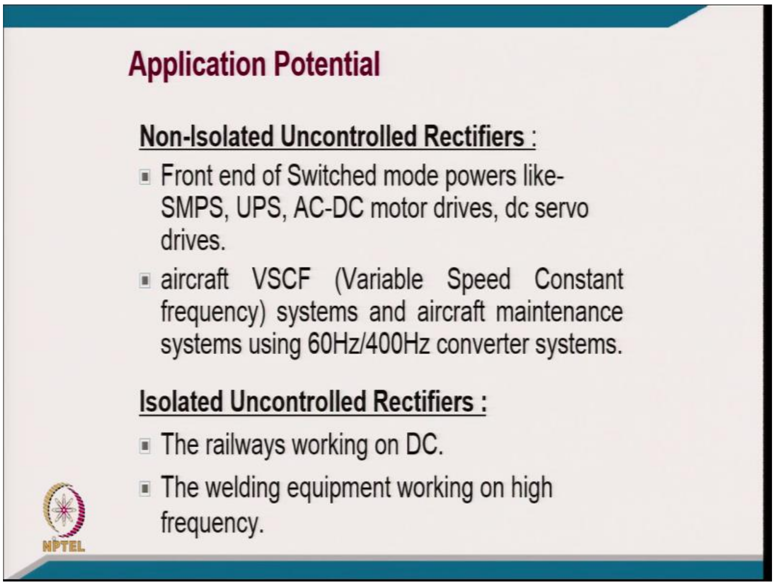

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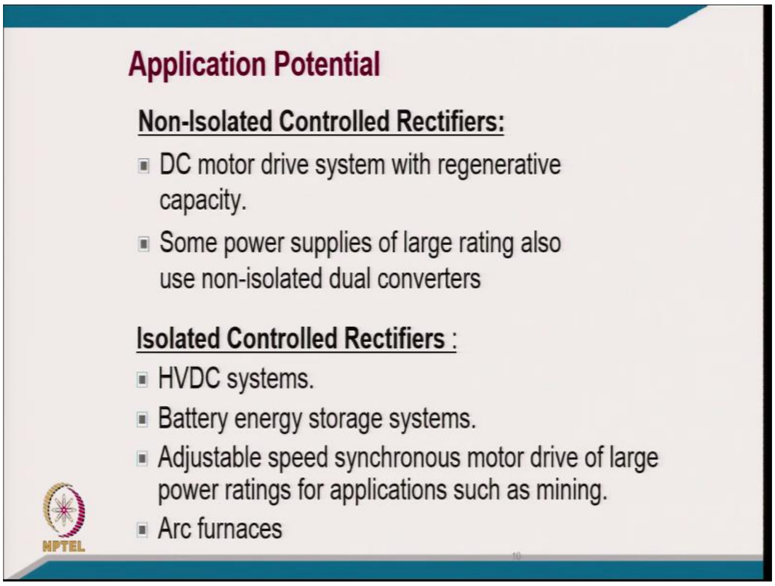

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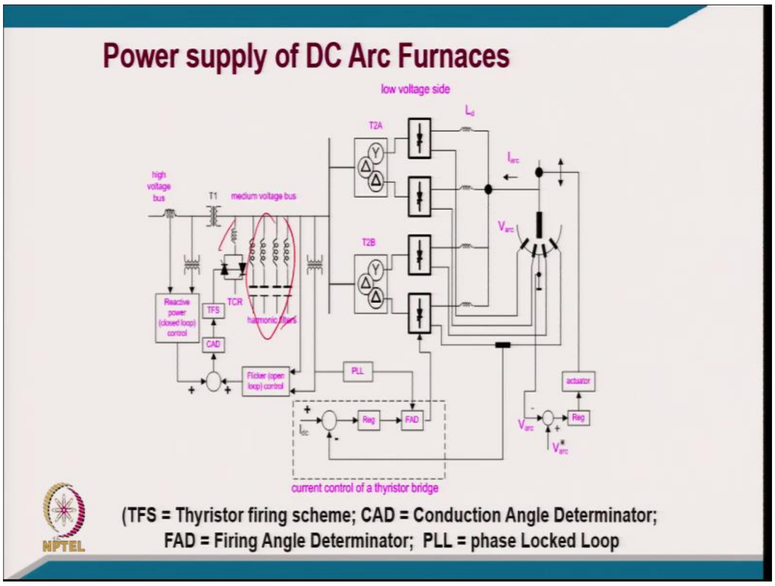

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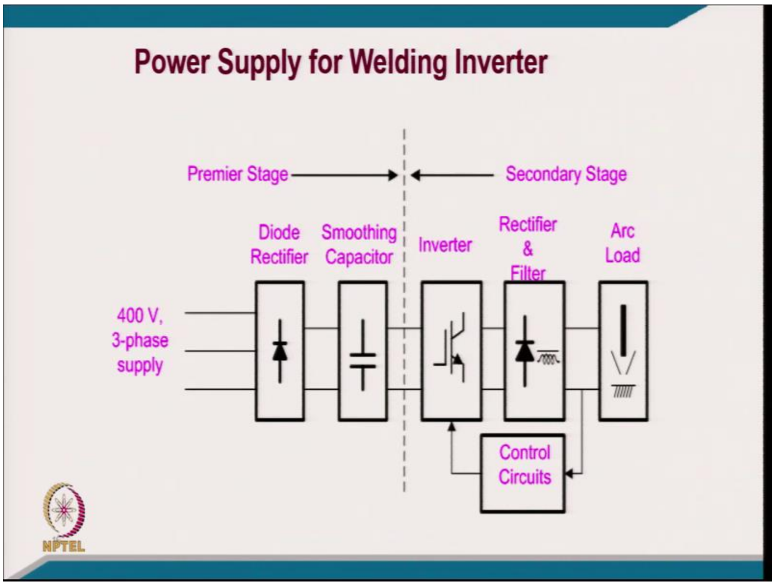

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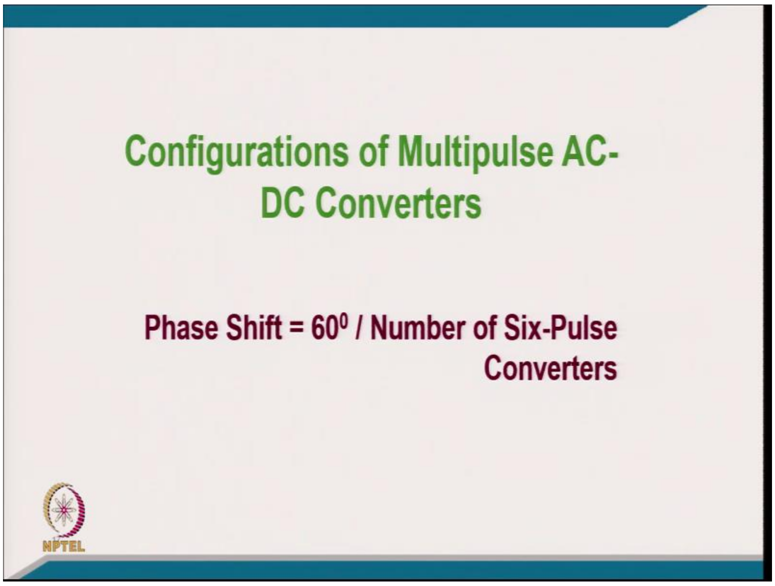

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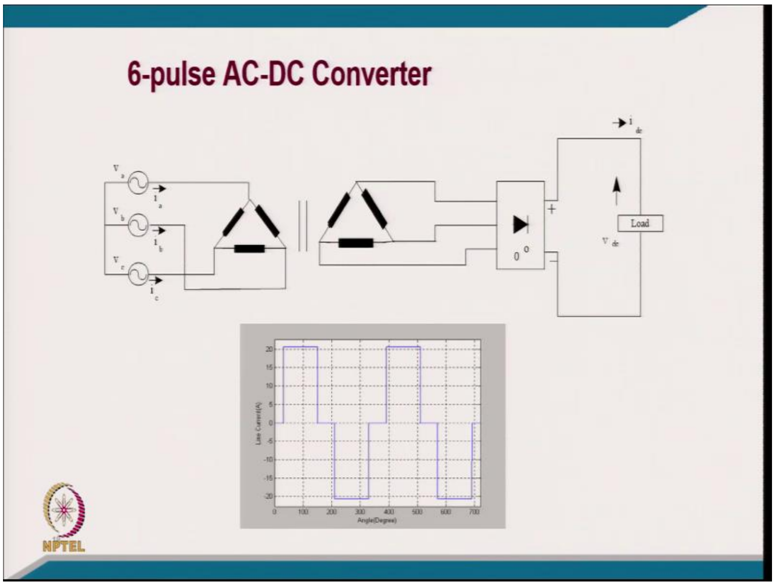

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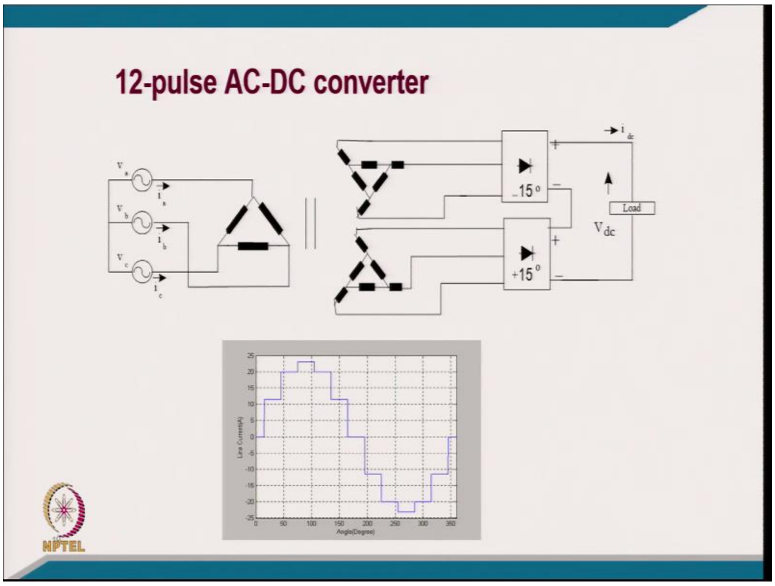

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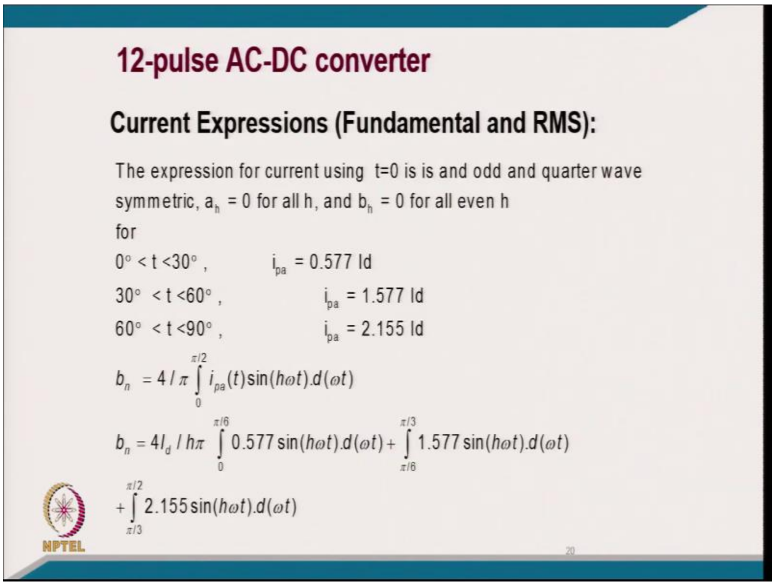

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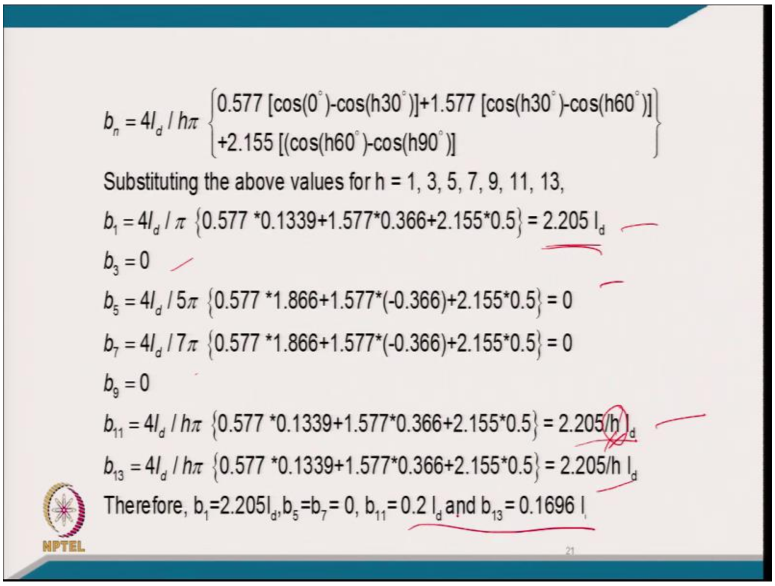

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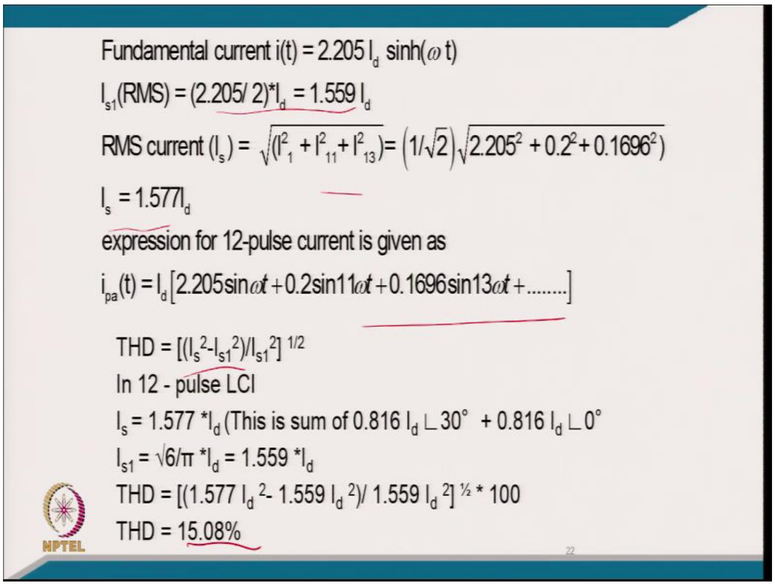

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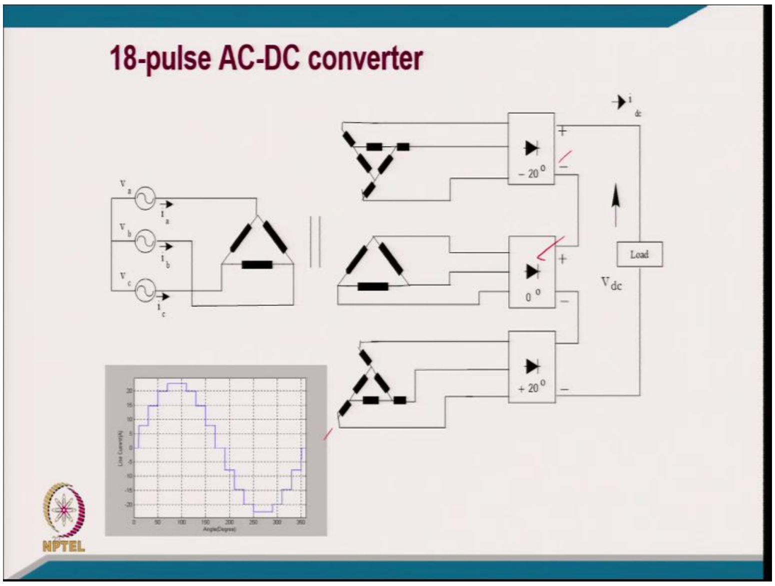

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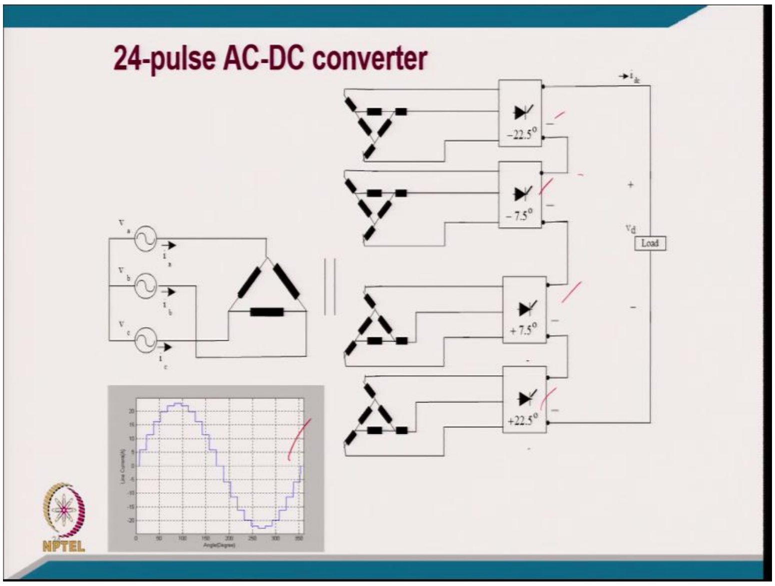

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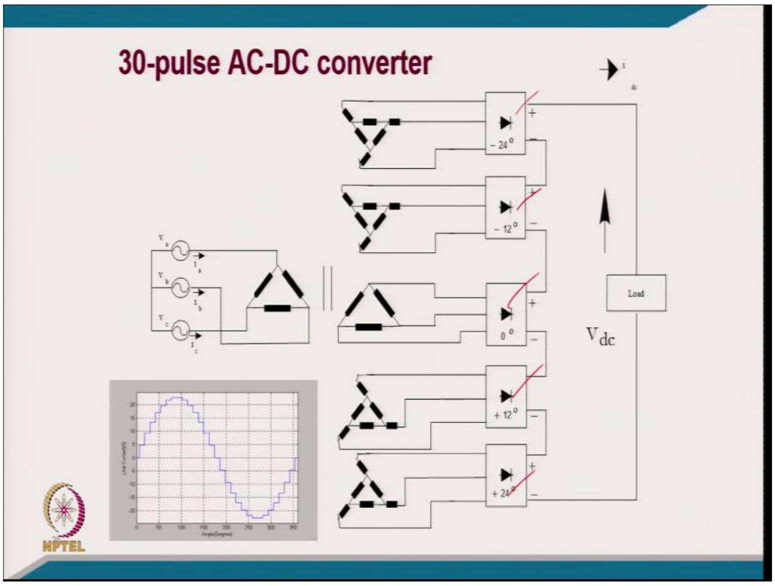

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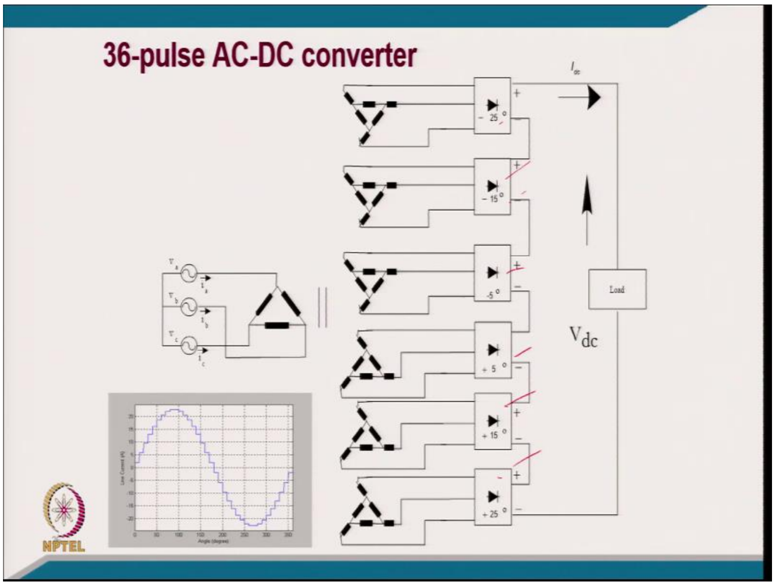

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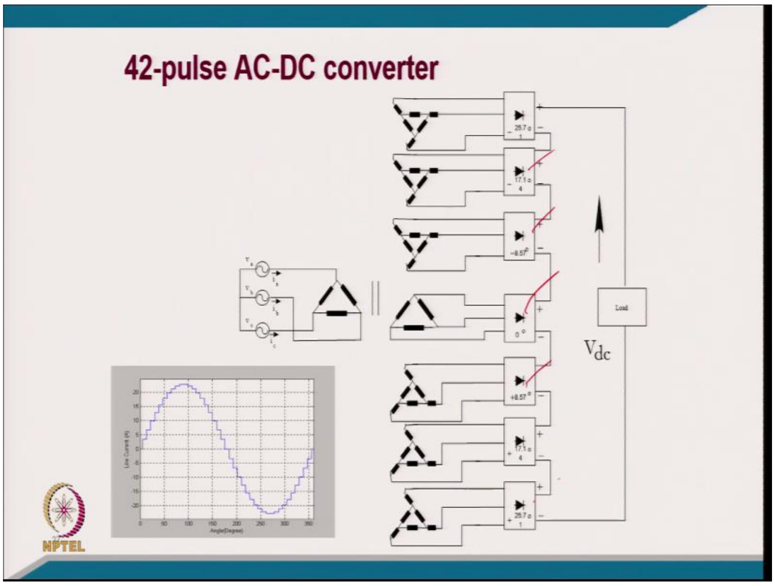

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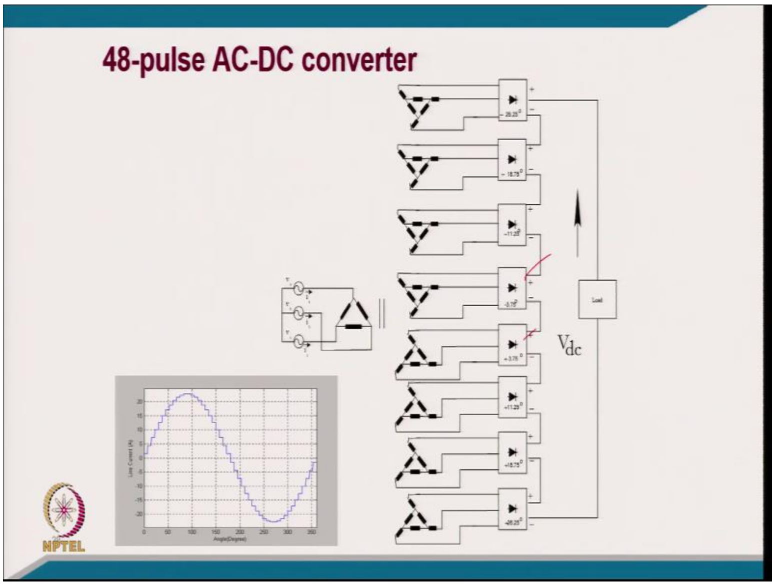

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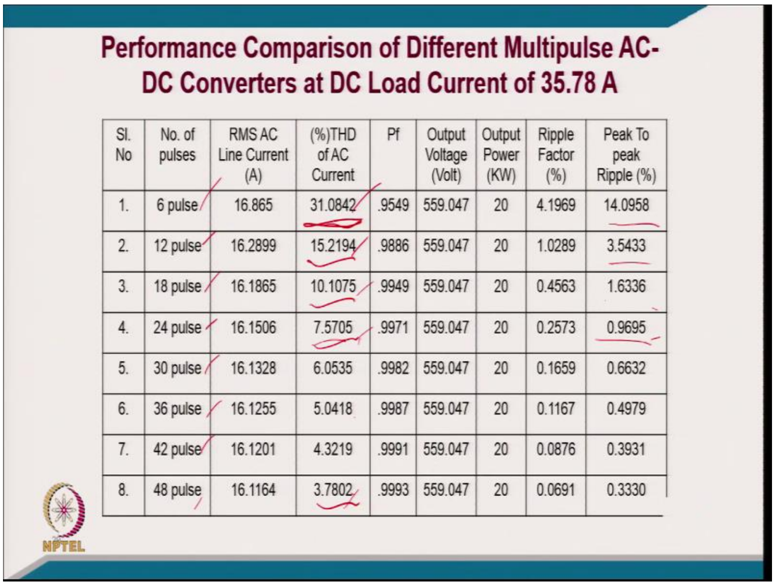

Performance Comparison of Different Multipulse AC-DC Converters at DC Load Current of 35.78 A

Sl. No	No. of pulses	RMS AC Line Current (A)	(%)THD of AC Current	Pf	Output Voltage (Volt)	Output Power (KW)	Ripple Factor (%)	Peak To peak Ripple (%)
1.	6 pulse	16.865	31.0842	.9549	559.047	20	4.1969	14.0958
2.	12 pulse	16.2899	15.2194	.9886	559.047	20	1.0289	3.5433
3.	18 pulse	16.1865	10.1075	.9949	559.047	20	0.4563	1.6336
4.	24 pulse	16.1506	7.5705	.9971	559.047	20	0.2573	0.9695
5.	30 pulse	16.1328	6.0535	.9982	559.047	20	0.1659	0.6632
6.	36 pulse	16.1255	5.0418	.9987	559.047	20	0.1167	0.4979
7.	42 pulse	16.1201	4.3219	.9991	559.047	20	0.0876	0.3931
8.	48 pulse	16.1164	3.7802	.9993	559.047	20	0.0691	0.3330

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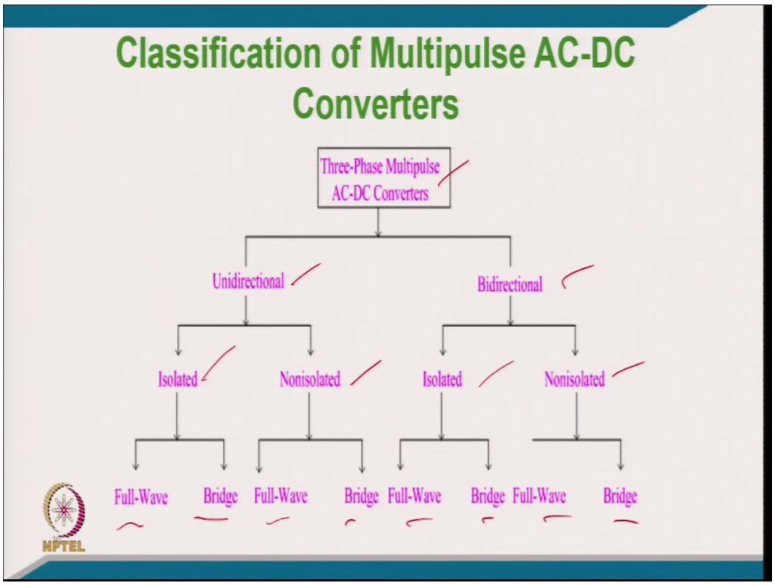

This is the classification of multipulse AC-DC Converters.

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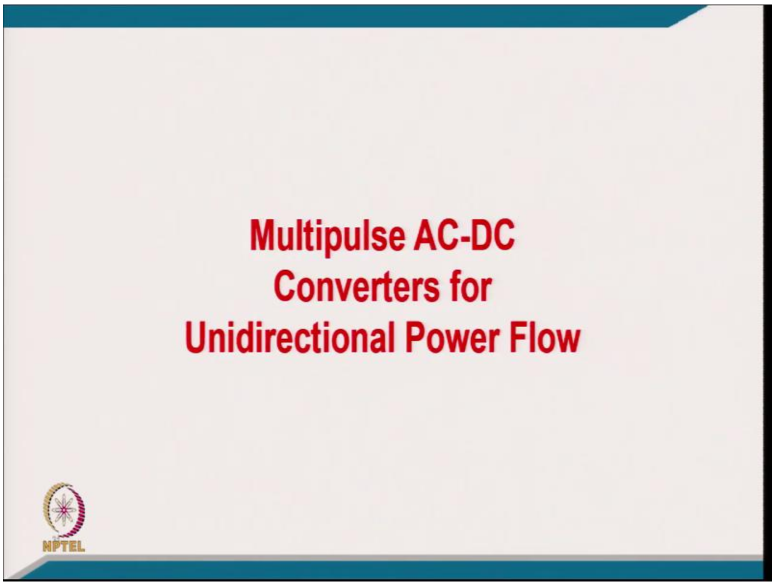

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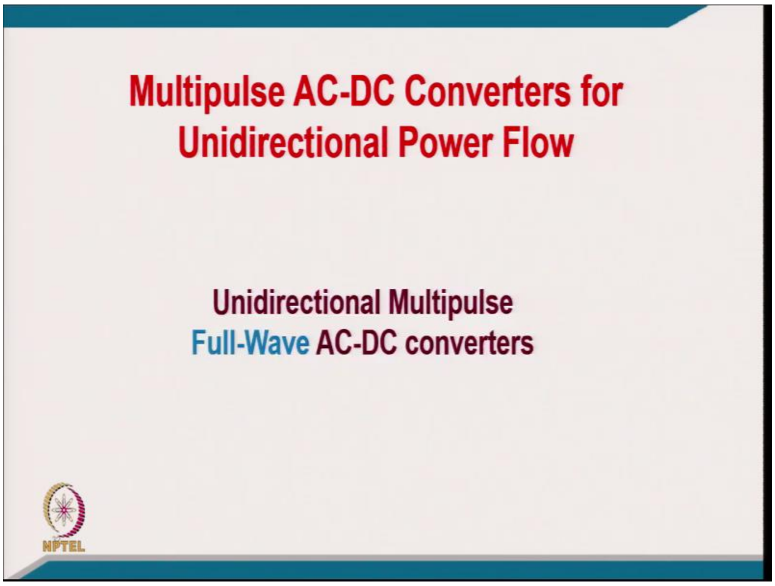

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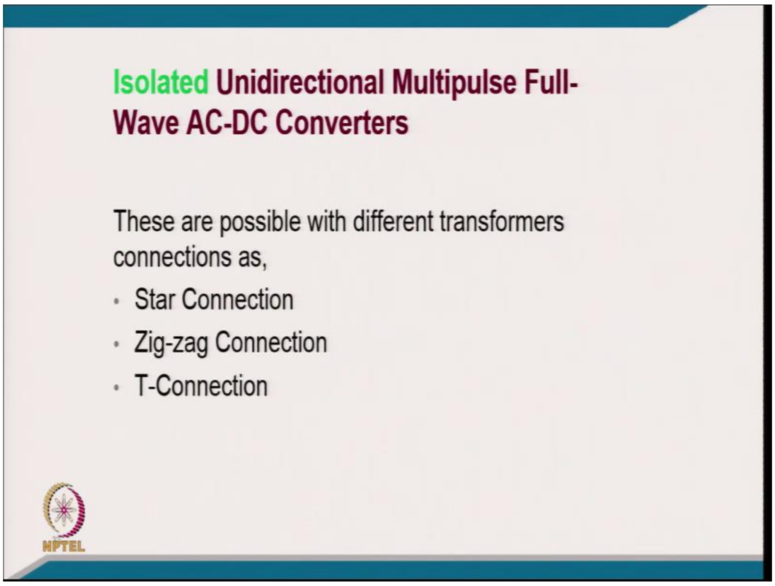

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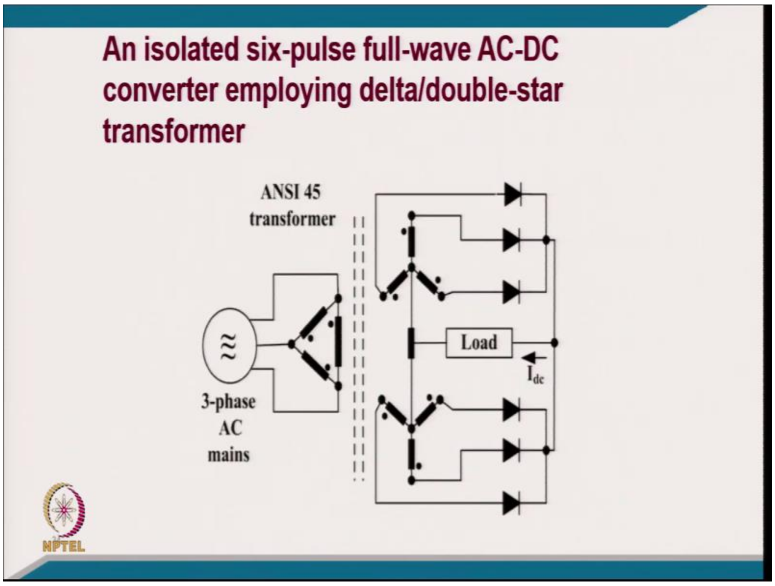

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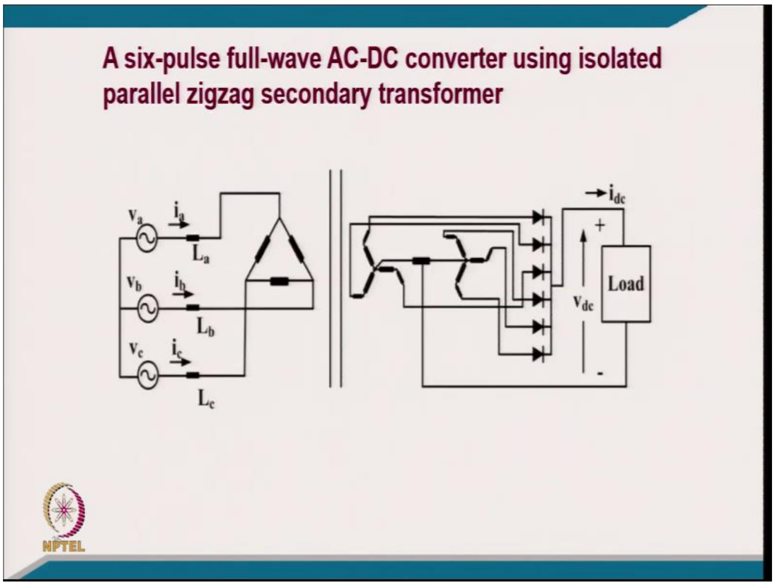

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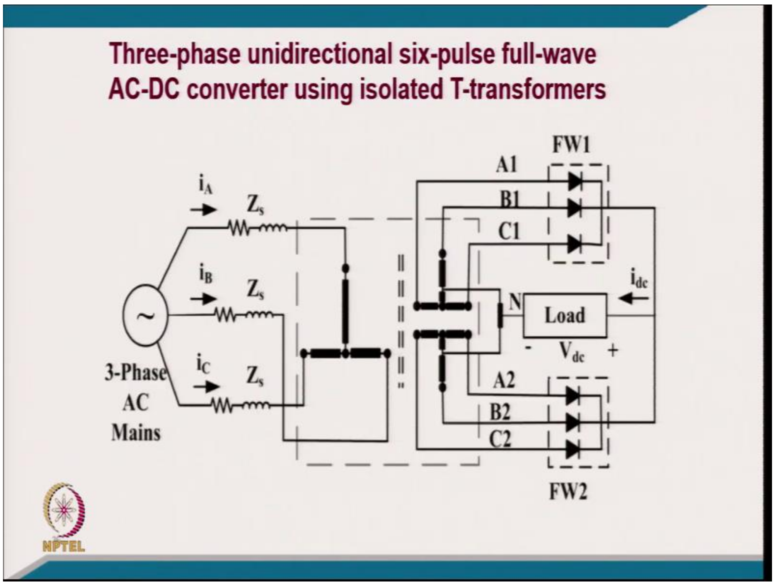

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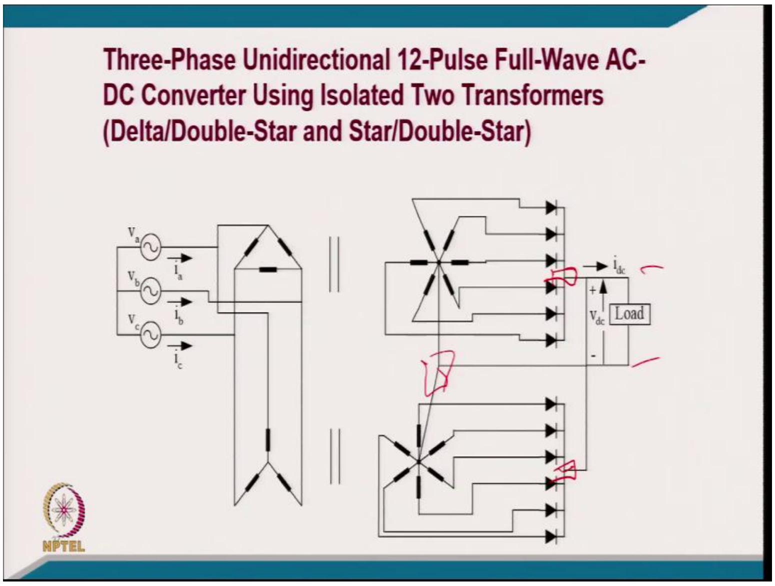

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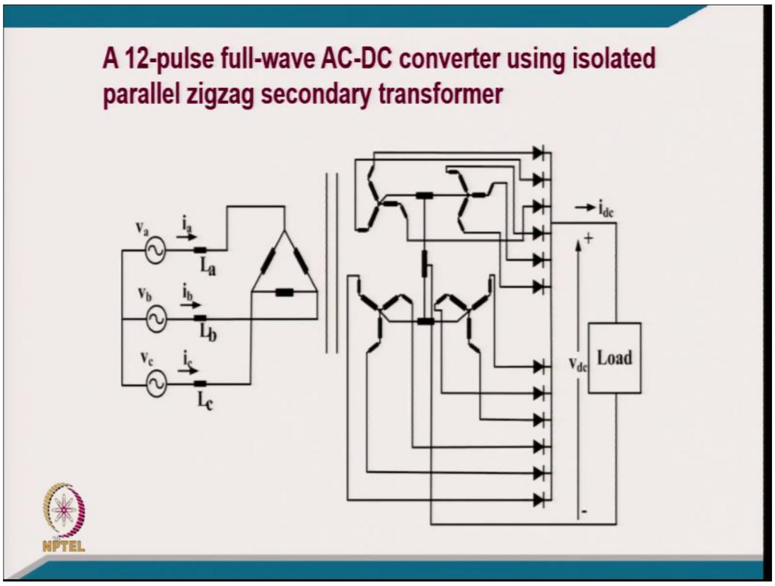

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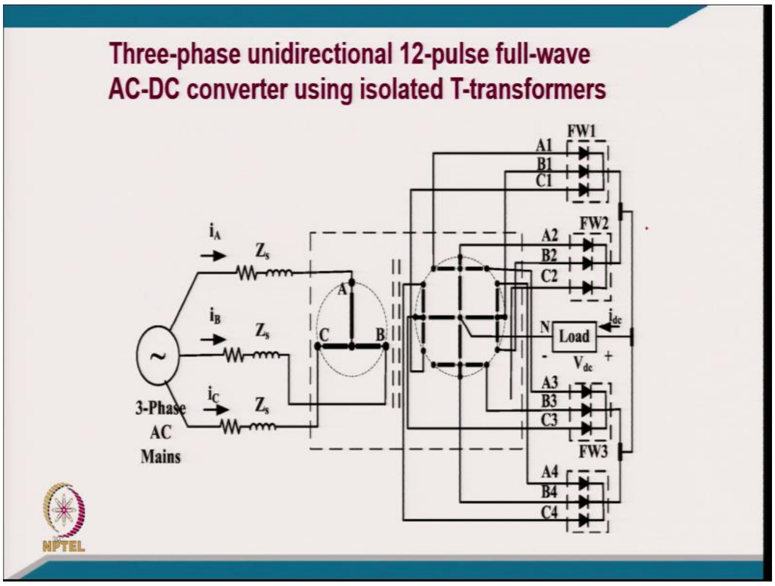

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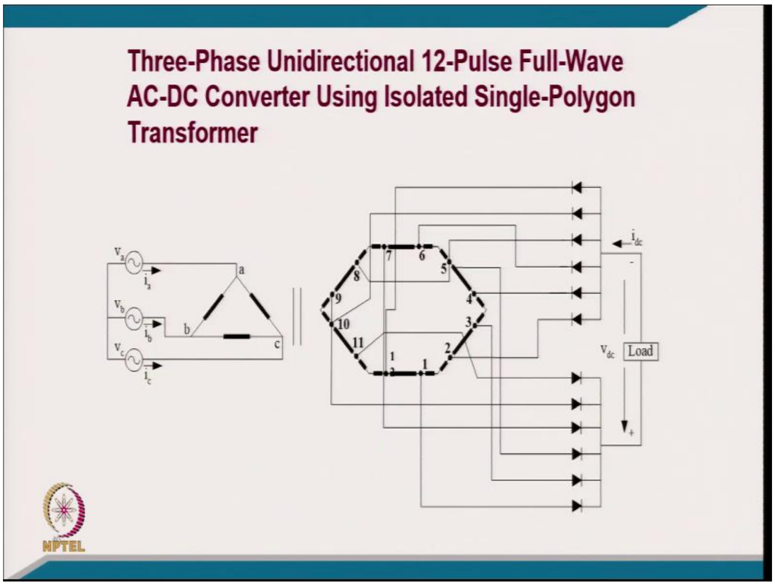

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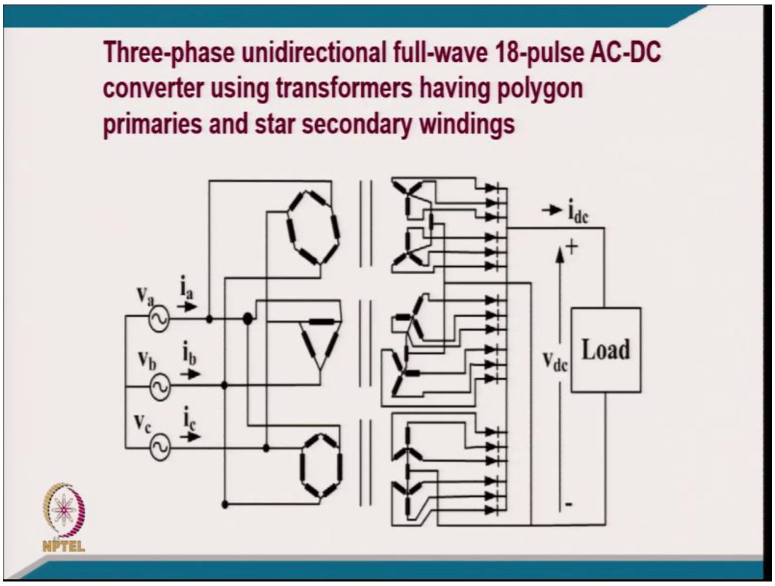

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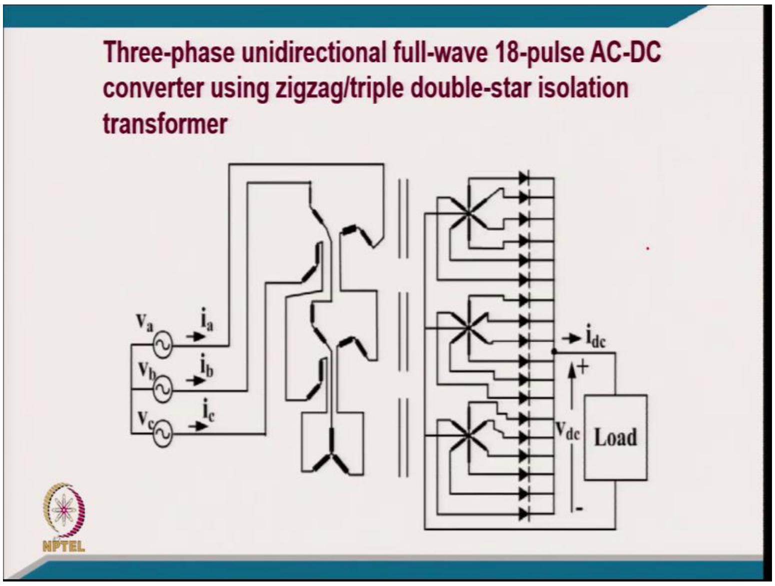

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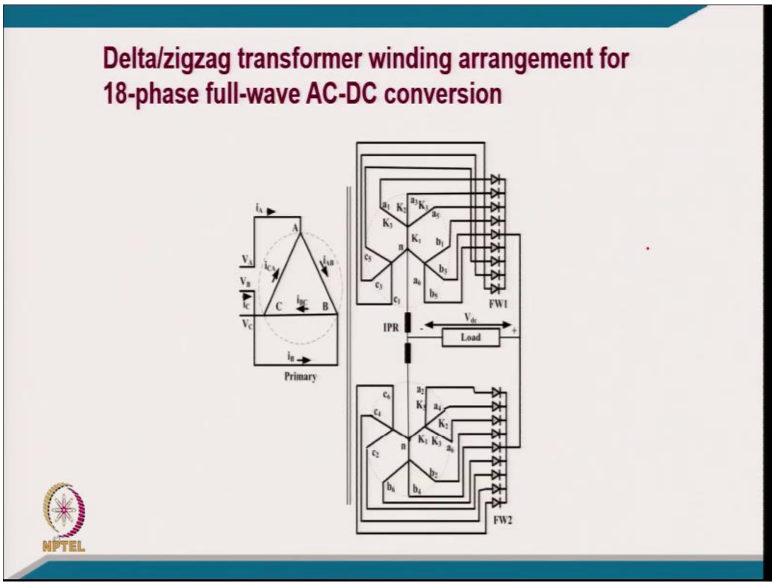

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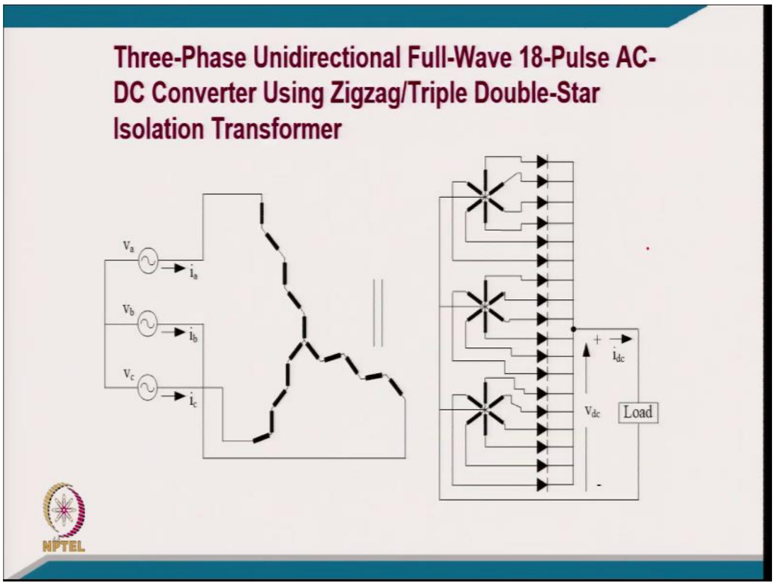

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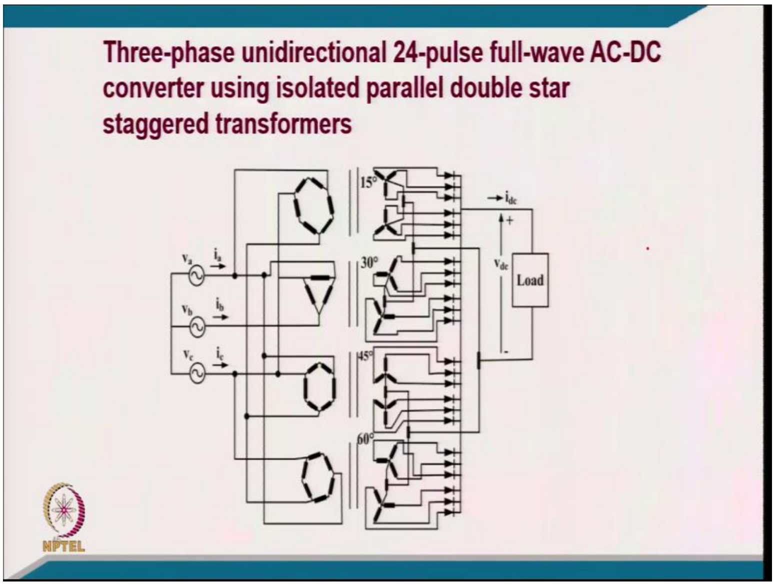

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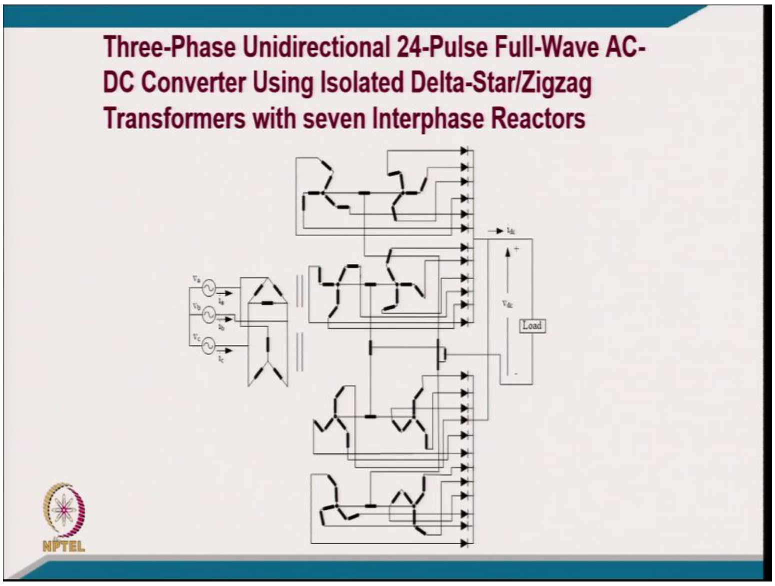

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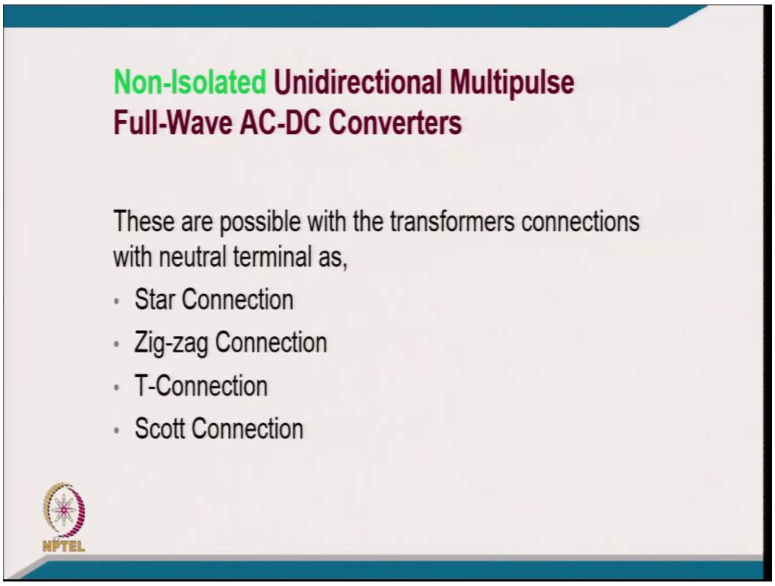

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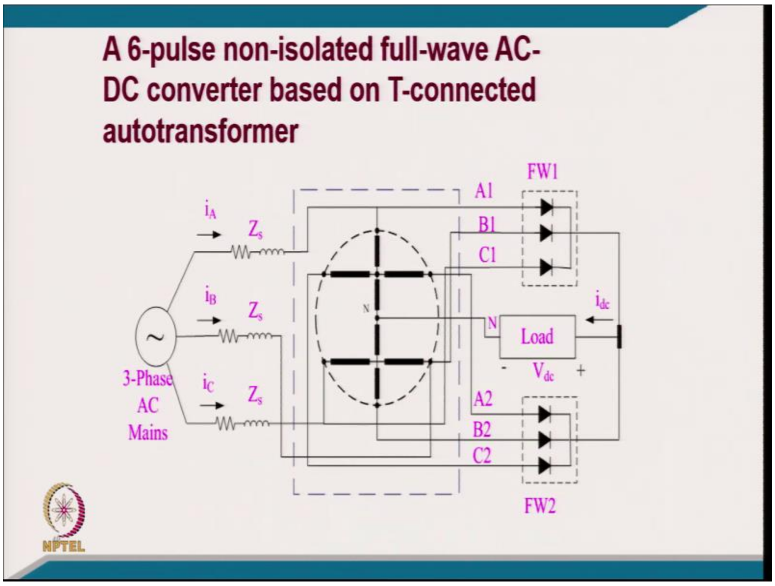

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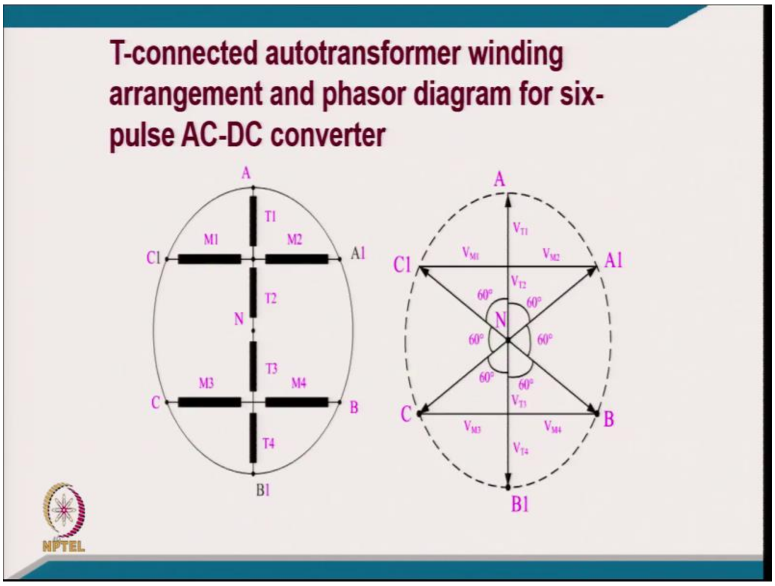

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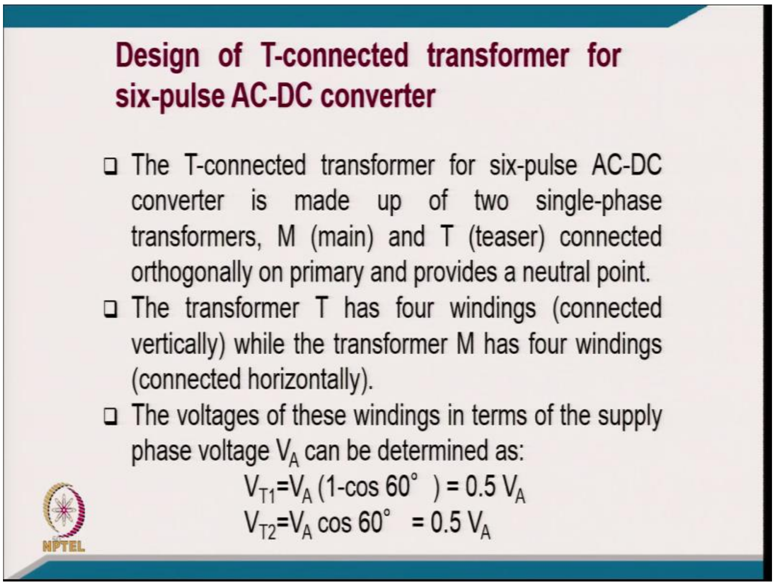

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$$V_{M1} = V_A \sin 60^\circ = 0.866\ V_{LP}$$

$$V_{M2} = V_{M1}$$

- The values of constants giving winding voltage as the fraction of input phase voltage for 12-pulse, 18-pulse and 24-pulse converter configurations can be determined in a similar way and these are found as:

12-Pulse converter: K_1=0.07735; K_2=0.5; K_3=0.2886;

18-Pulse converter: K_{21}= 0.0603; K_{23}= 0.1736; K_{23}=0.766; K_{24}=0.5; K_{25}=0.1736; K_{26}=0.1188; K_{27}=0.866; K_{28}=0.342; K_{29}=0.6428

24-Pulse converter: K_{31}=0.0114; K_{32}=0.0333; K_{33}=0.0529; K_{34}=0.2356; K_{35}=0.1666; K_{36}=0.0863; K_{37}=0.2357; K_{38}=0.2886

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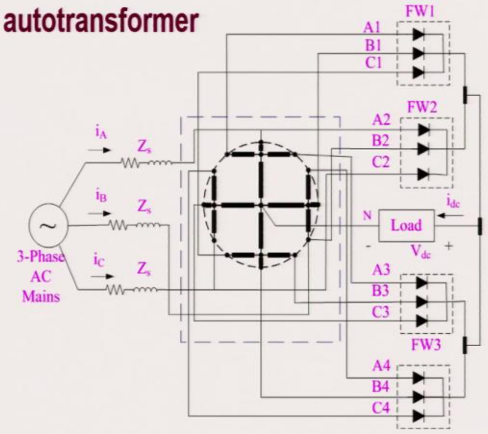
A 12-pulse non-isolated full-wave AC-DC converter based on T-connected autotransformer



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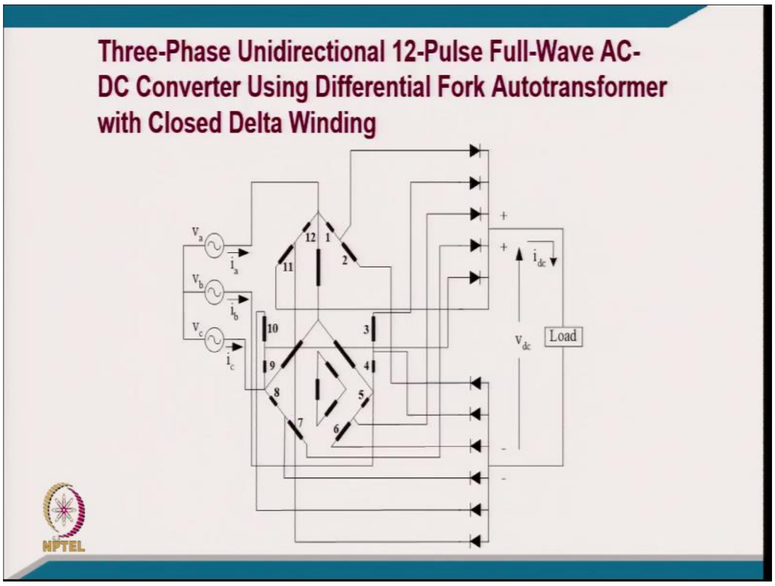

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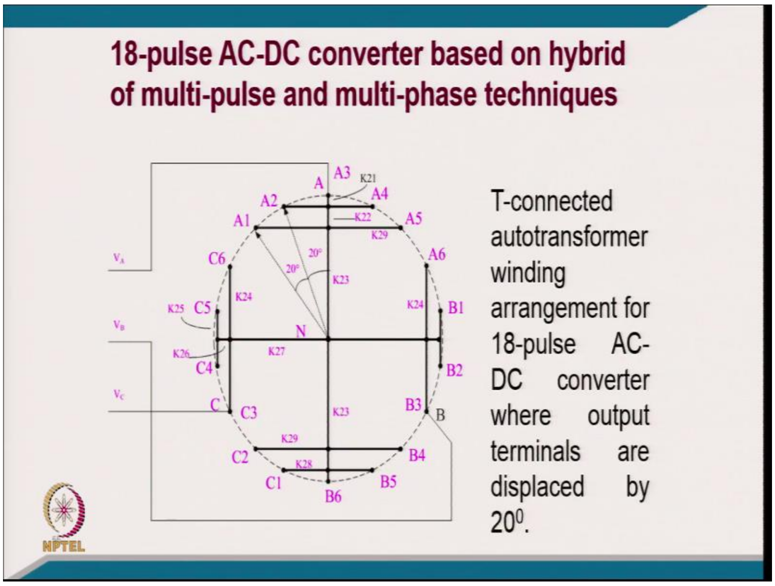

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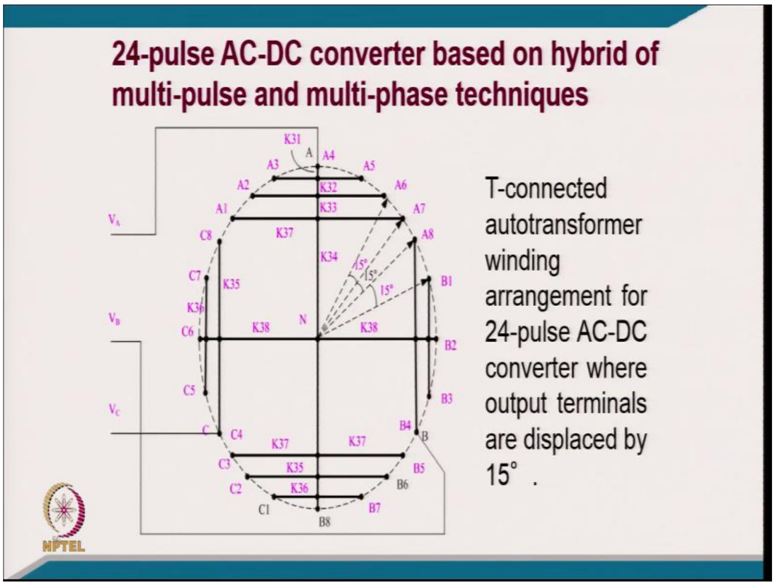

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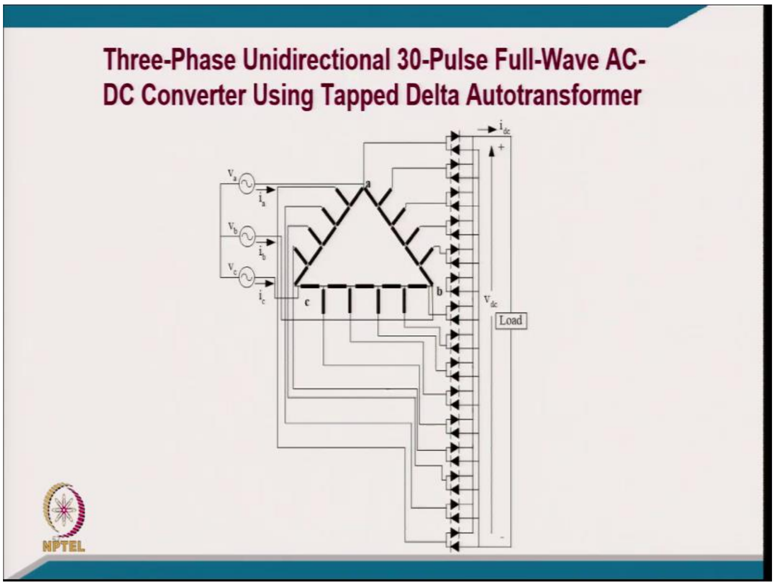

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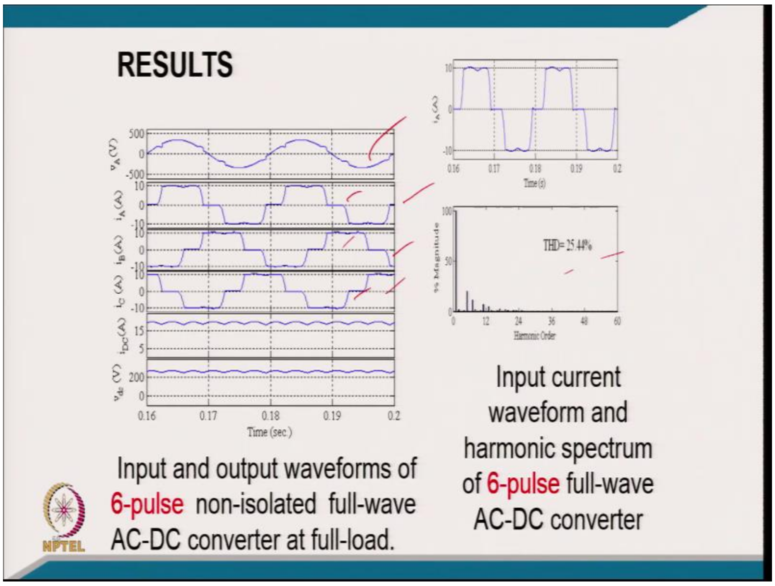

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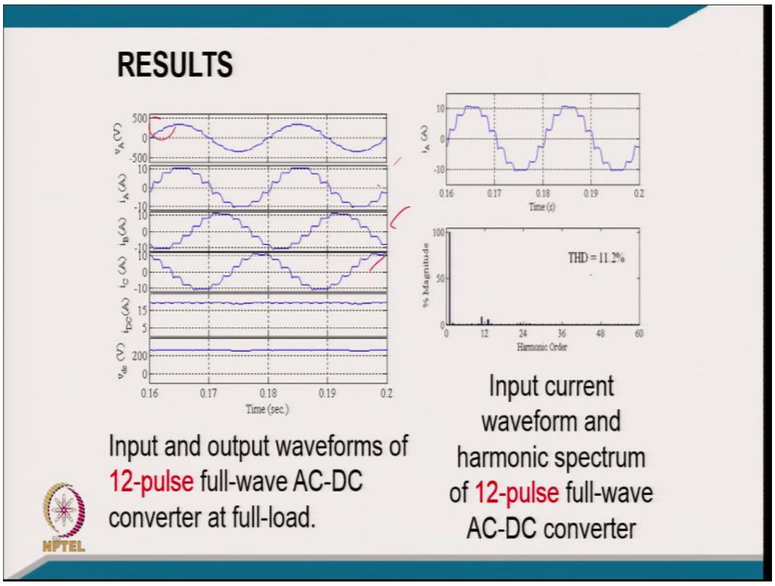

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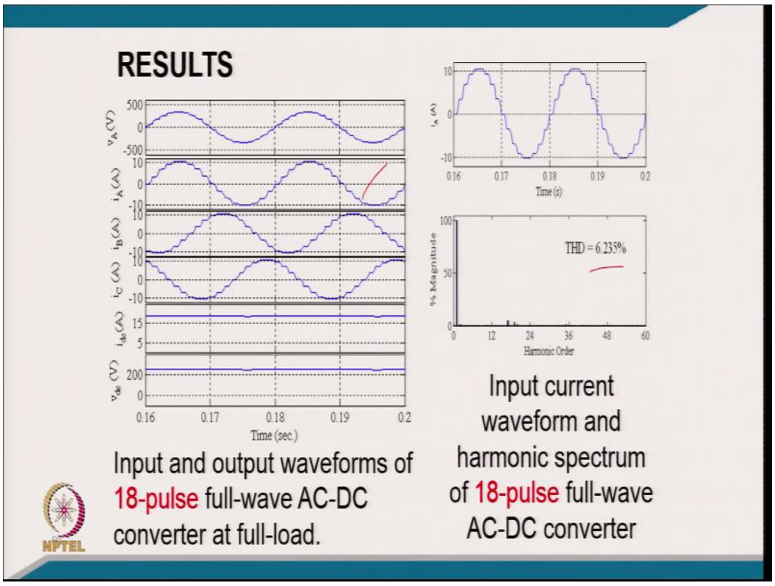

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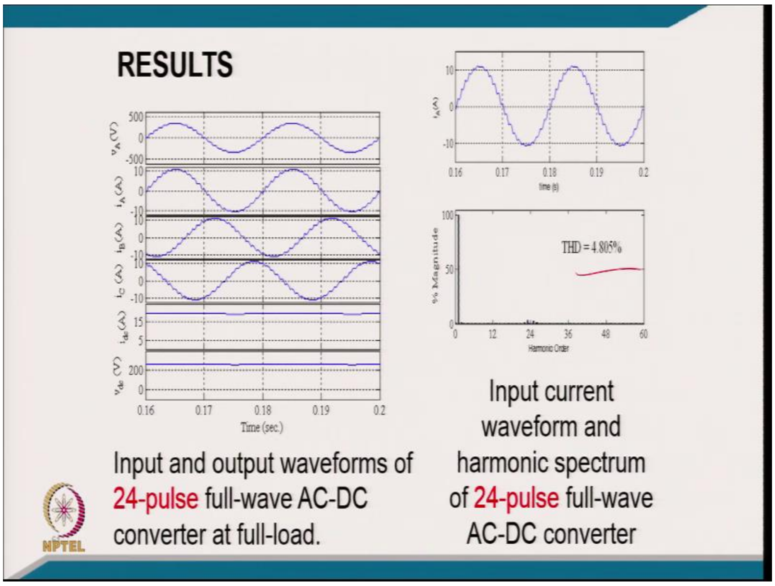

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Power quality parameters of T-connected non-isolated six-pulse full-wave AC-DC converters

Topo-logy	Input Power, % Full-Load	%THD of V_A	AC Mains Curr-ent I_A (A)	% THD of I_A,	Distortion Factor, DF	Displace-ment Factor DPF	Power Factor, PF	DC Voltag e (V_{dc})	Load Current I_{dc} (A)	RF
6-pulse	20	**2.05**	1.675	28.67	0.9611	0.9989	0.960	276.5	4.09	4.43
	40	**3.42**	3.288	27.68	0.9632	0.9958	0.959	273.4	8.09	4.00
	50	**4.01**	4.077	27.24	0.964	0.9943	0.958	271.9	10.06	3.74
	60	**4.57**	4.857	26.83	0.9648	0.9929	0.958	270.5	12.0	3.49
	80	**5.58**	6.387	26.09	0.9661	0.9904	0.956	267.5	15.83	3.04
	100	**6.49**	7.879	25.44	0.9671	0.9881	0.955	264.7	19.58	2.69

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Comparison of power quality parameters of the T-connected non-isolated full-wave AC-DC converters

Sr. No.	Topo-logy	% THD of V_A	AC Mains Current I_A (A)		% THD of I_A		Distortion Factor		Displacement Factor		Power Factor		DC Voltage (V)	
			Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load
1	A*	4.24	1.647	7.815	27.58	24.09	0.9825	0.9712	0.9945	0.9771	0.9586	0.949	285.3	277
2	6-pulse	6.49	1.675	7.879	28.67	25.44	0.9611	0.9671	0.9989	0.9881	0.9601	0.9556	276.5	264.7
3	12-pulse	4.97	1.621	7.55	14.06	11.2	0.9901	0.9926	0.9999	0.9959	0.99	0.9885	275.9	262.3
4	18-pulse	4.00	1.671	7.394	7.872	6.235	0.9968	0.9973	0.9977	0.9963	0.9945	0.9936	274.5	254.4
5	24-pulse	3.70	1.63	7.605	7.458	4.805	0.9971	0.9982	0.9938	0.9998	0.991	0.998	276.4	264.3

*Topology 'A' is a T-connected isolated 6-pulse AC-DC converter having 1:0.5 transformation ratio.

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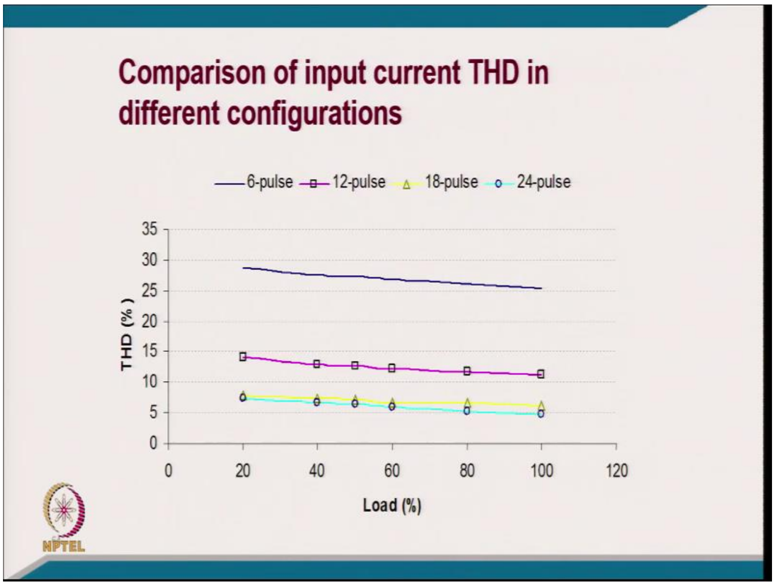

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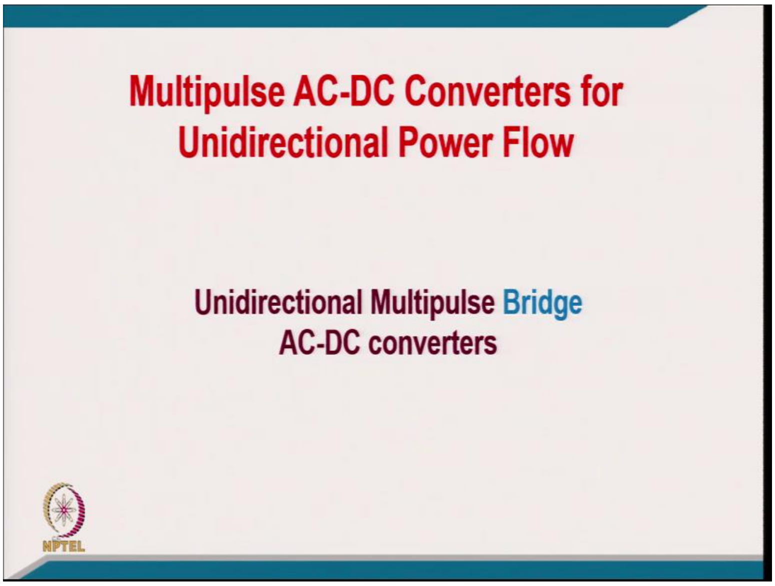

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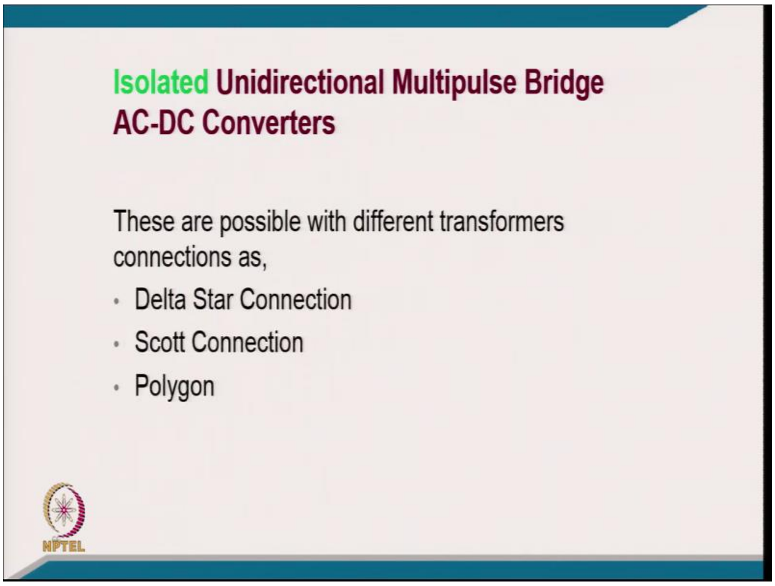

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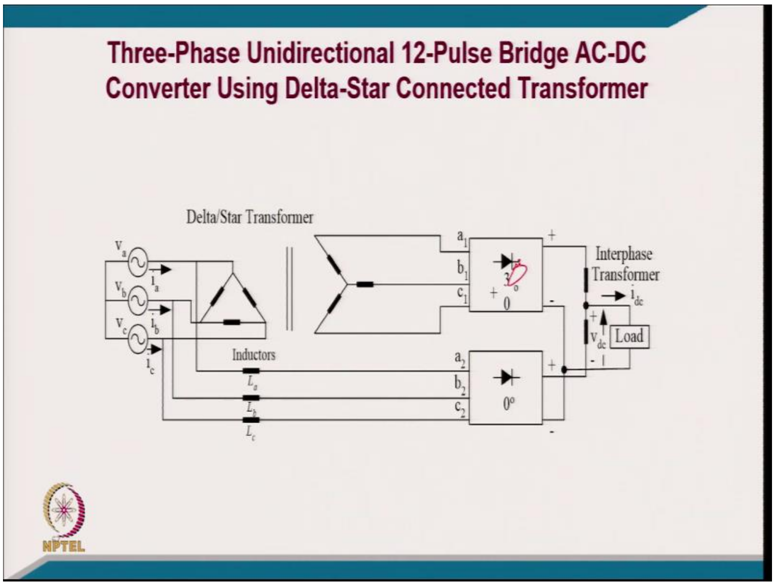

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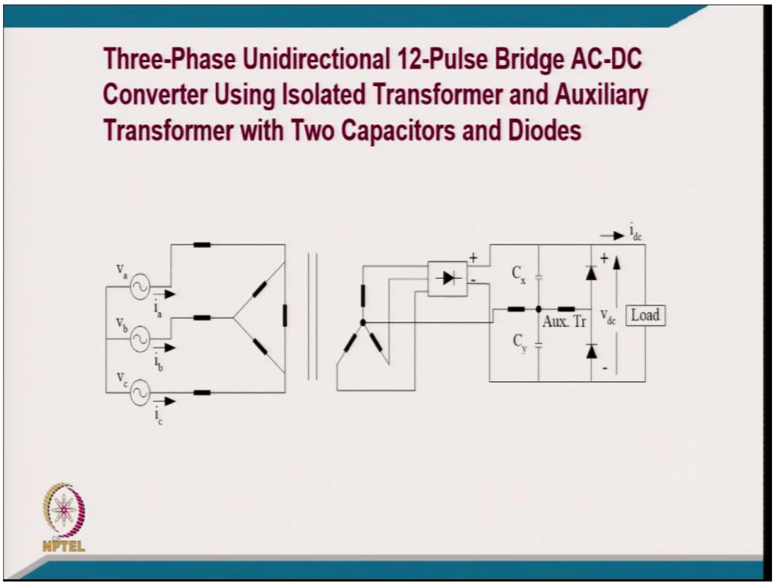

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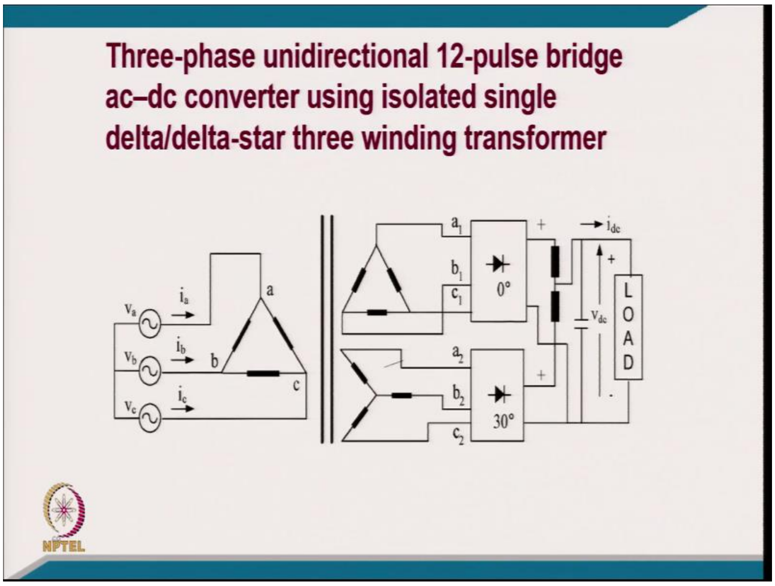

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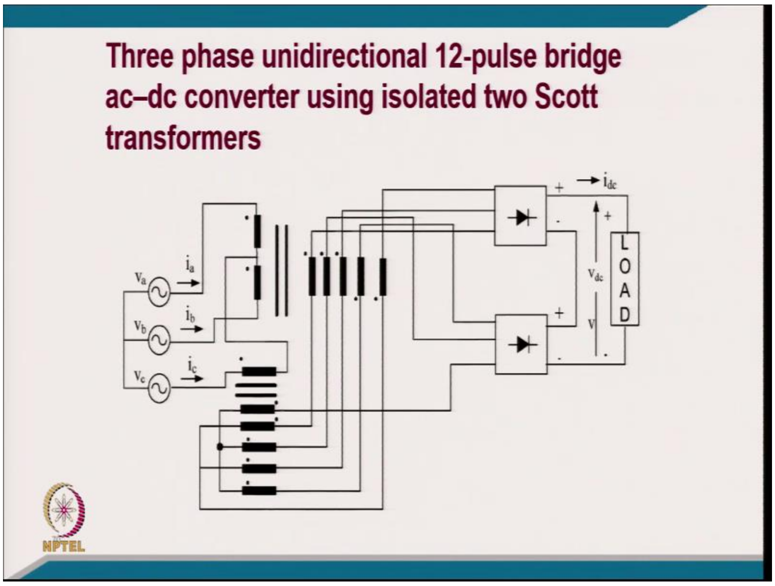

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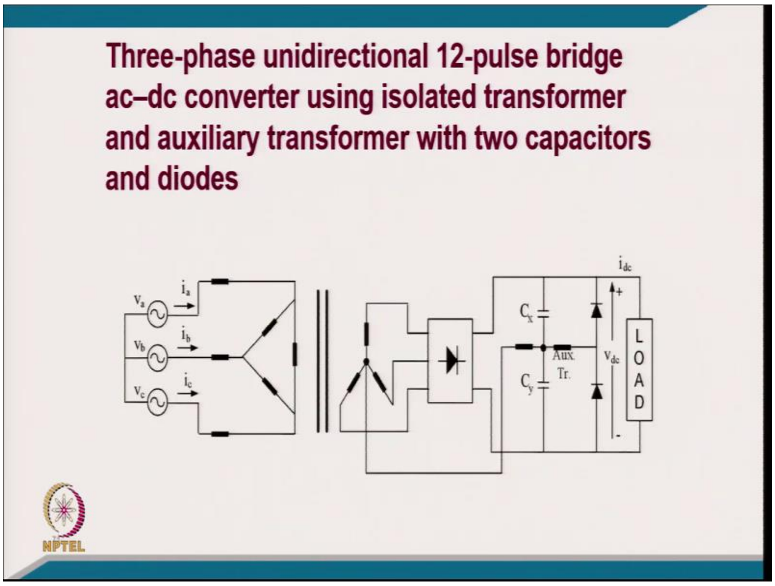

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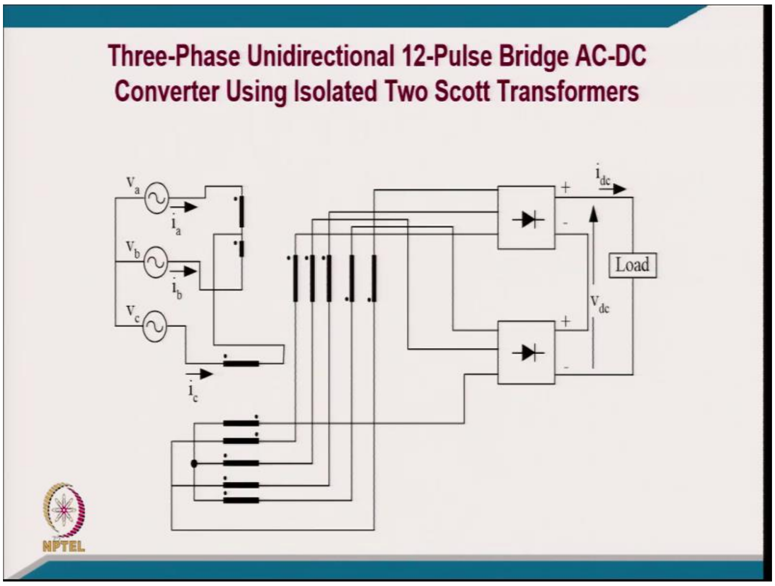

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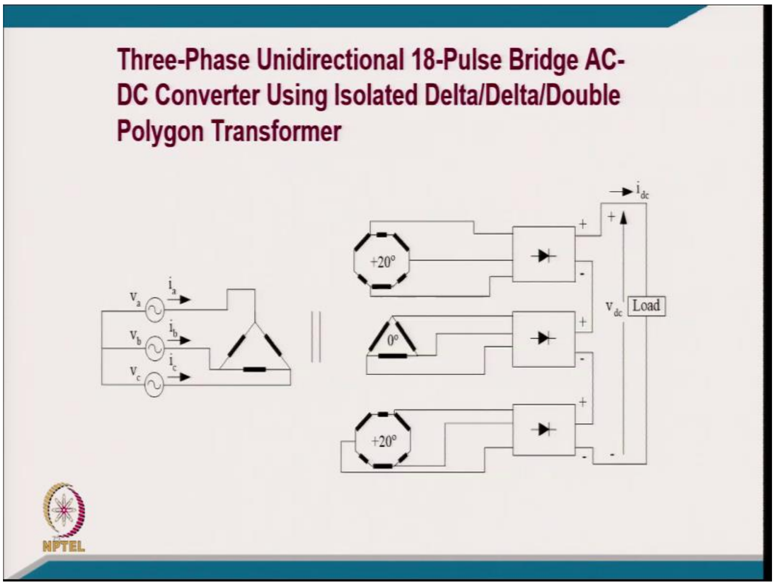

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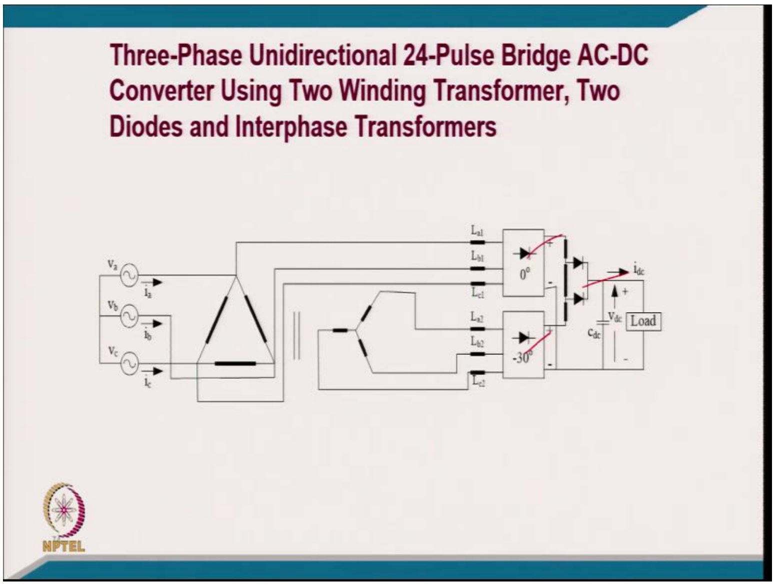

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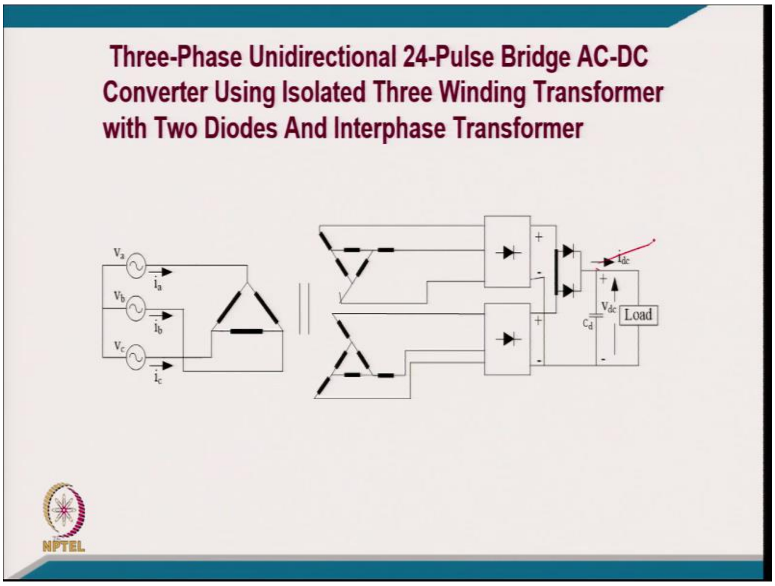

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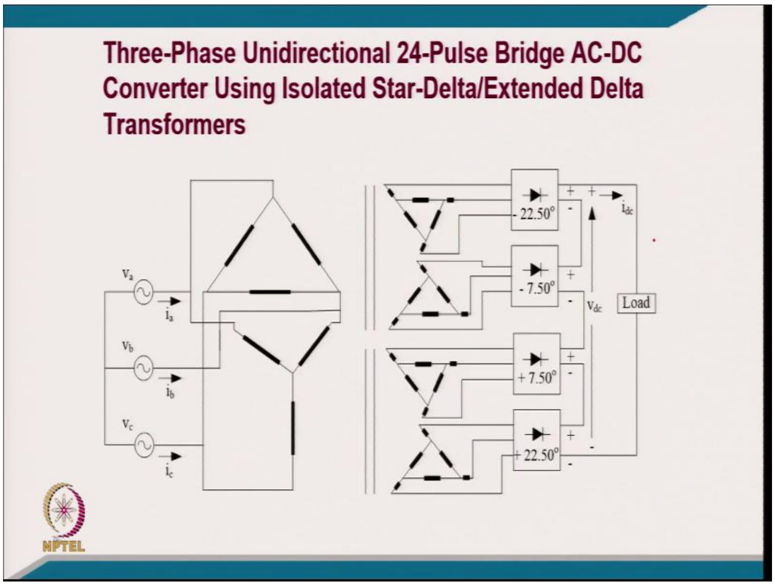

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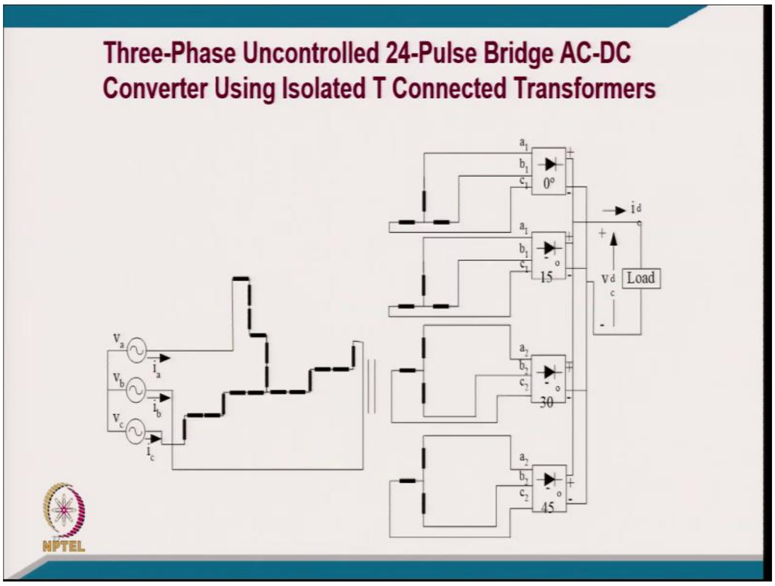

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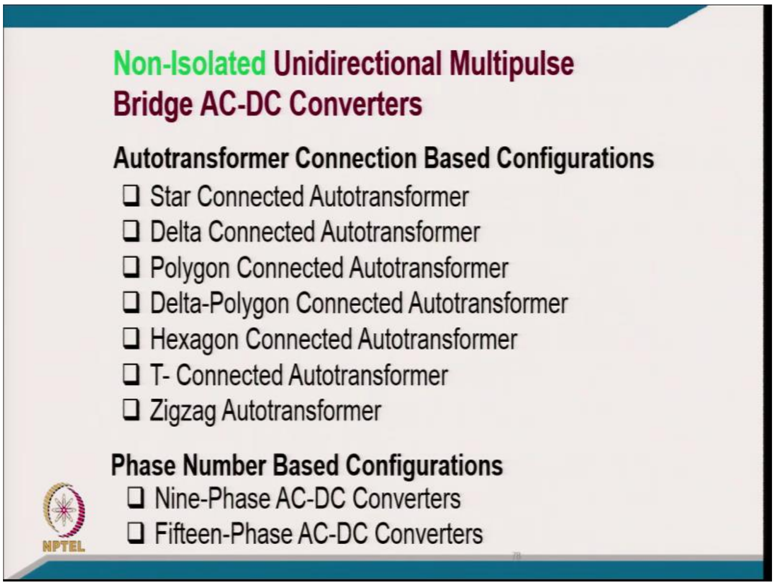

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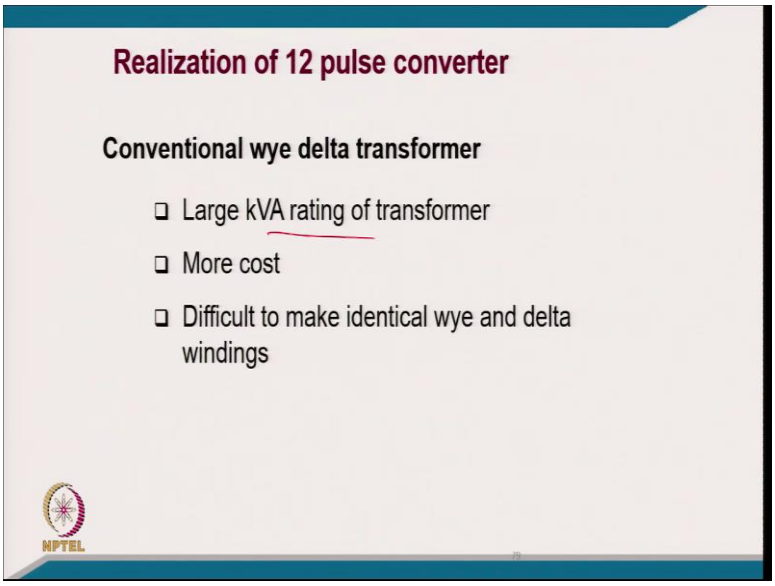

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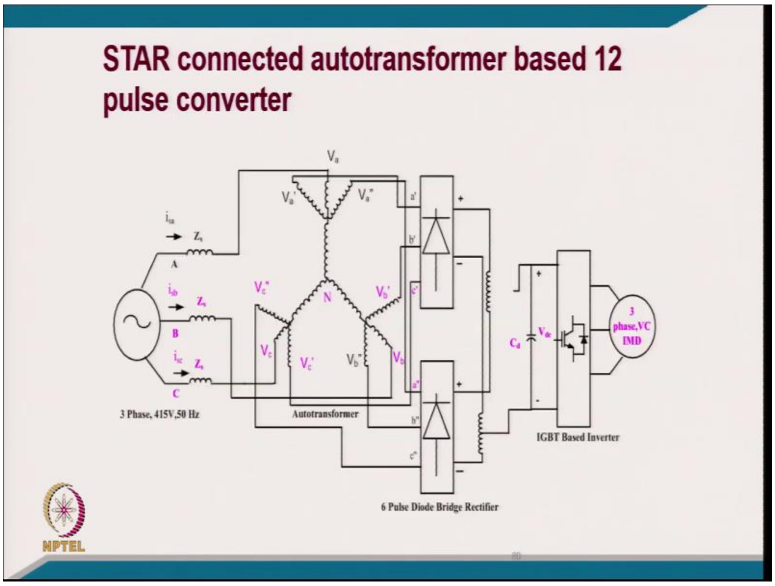

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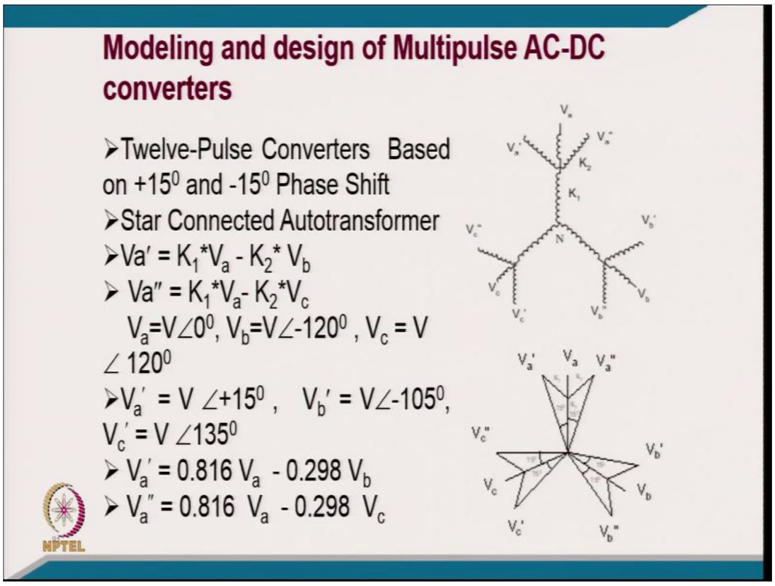

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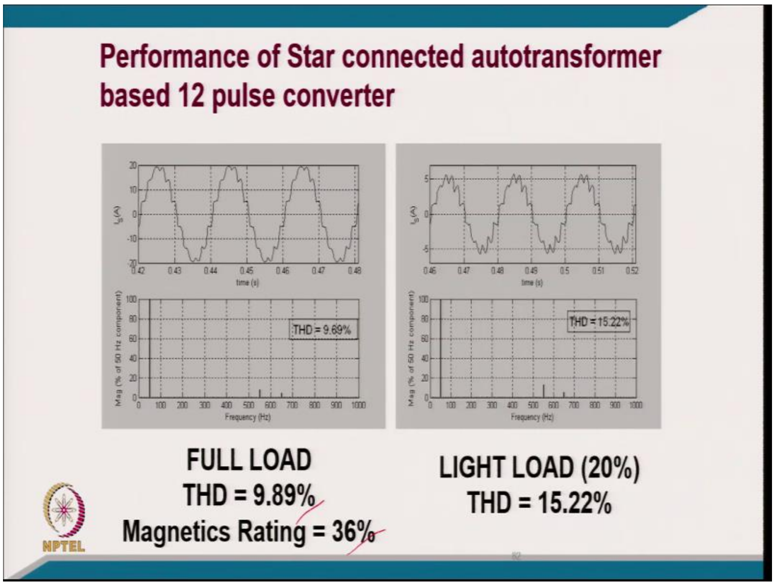

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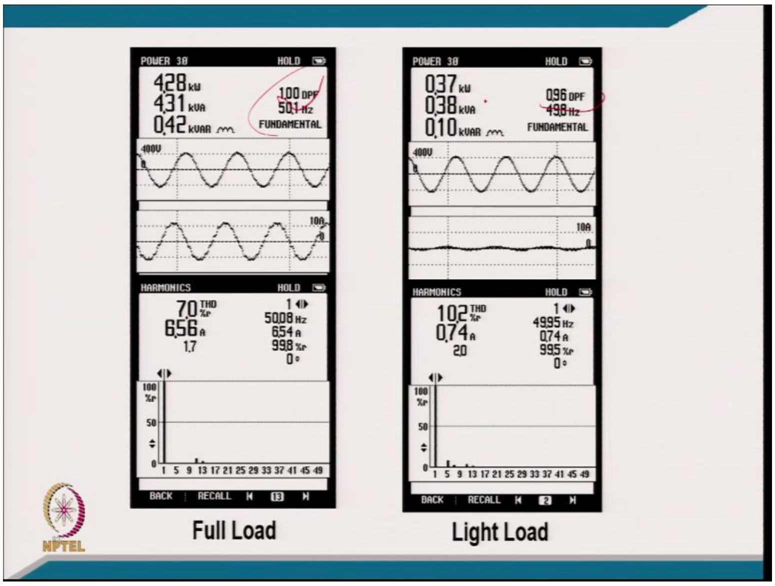

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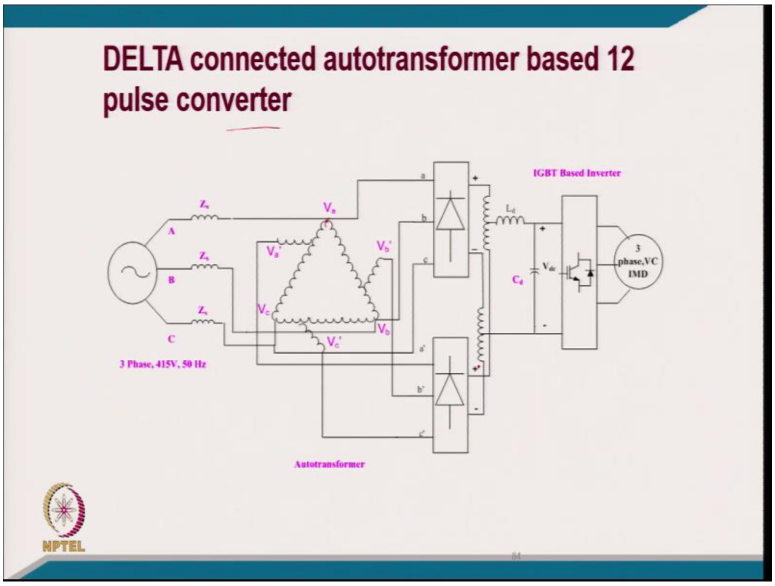

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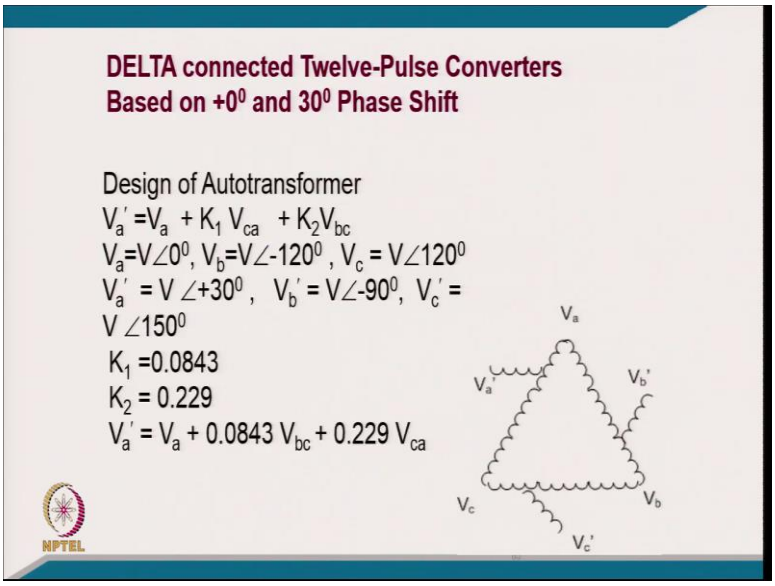

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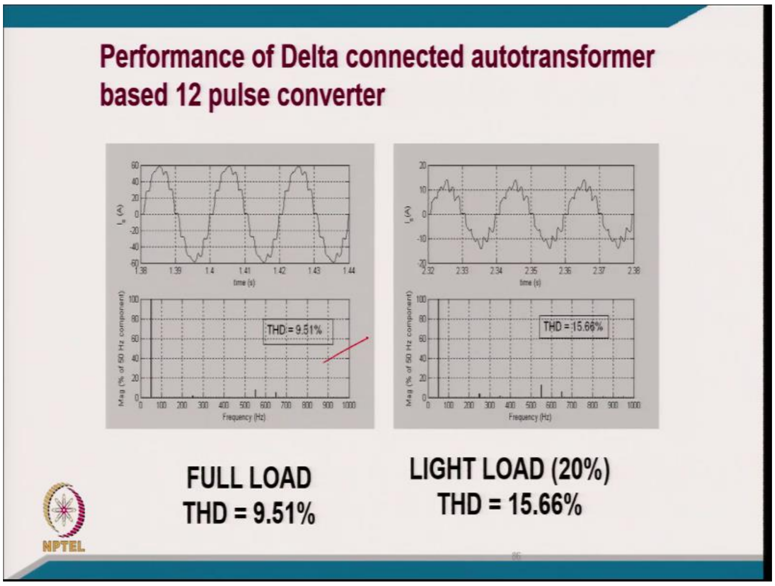

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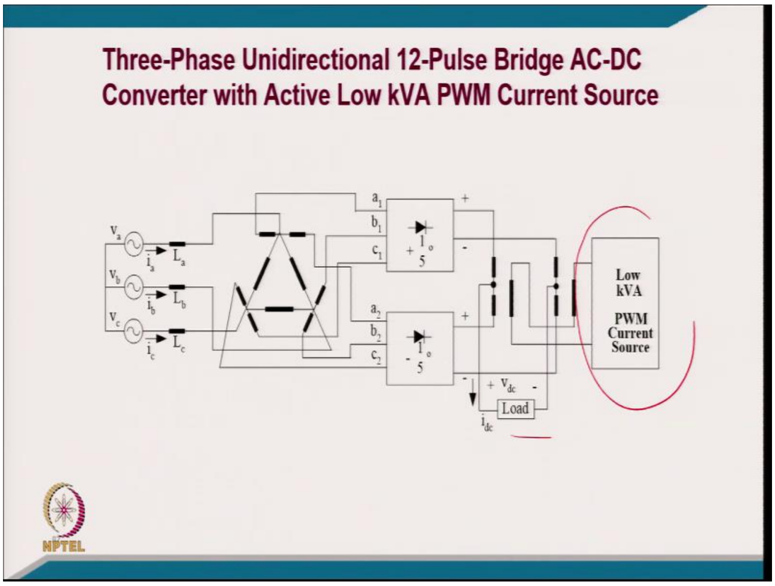

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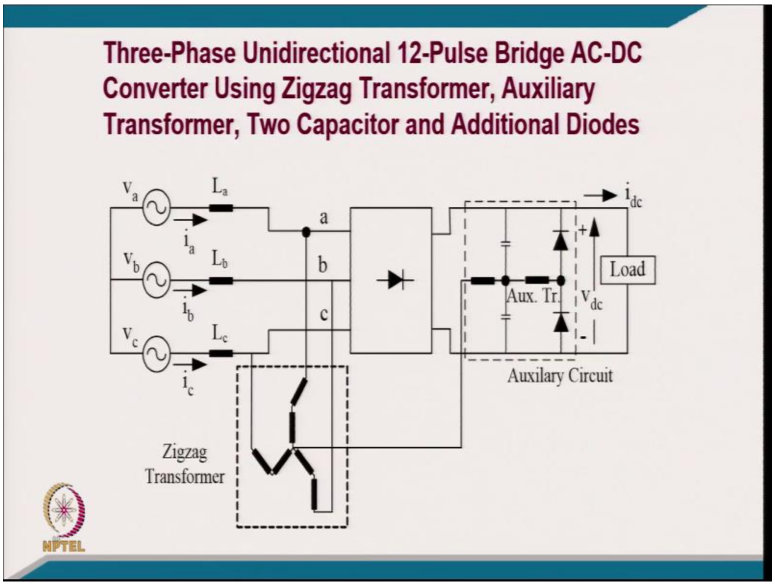

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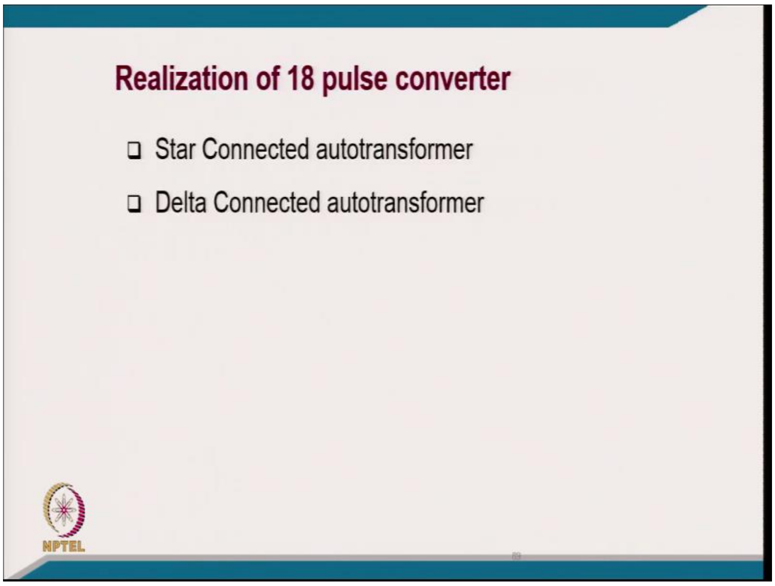

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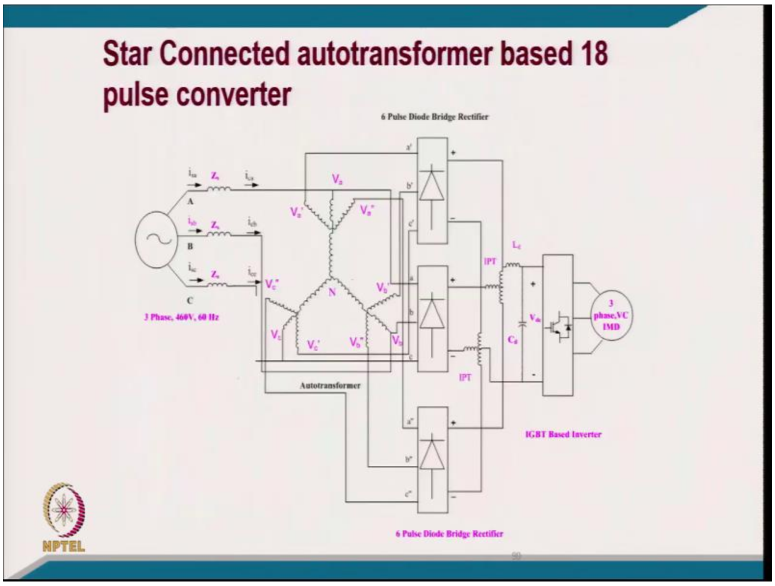

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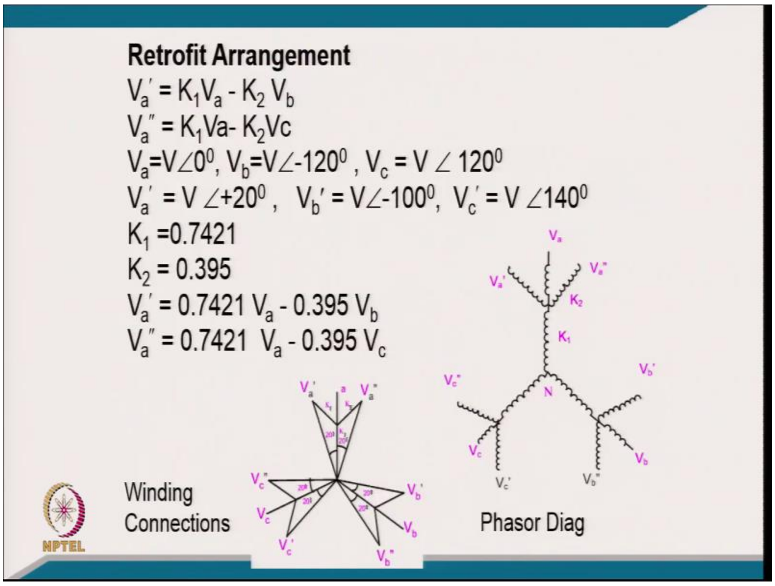
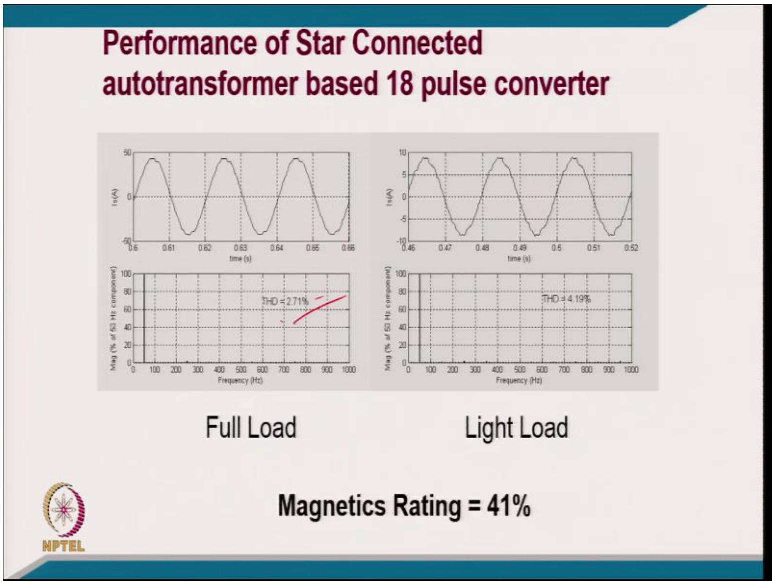


(Refer Slide Time: 51:01)



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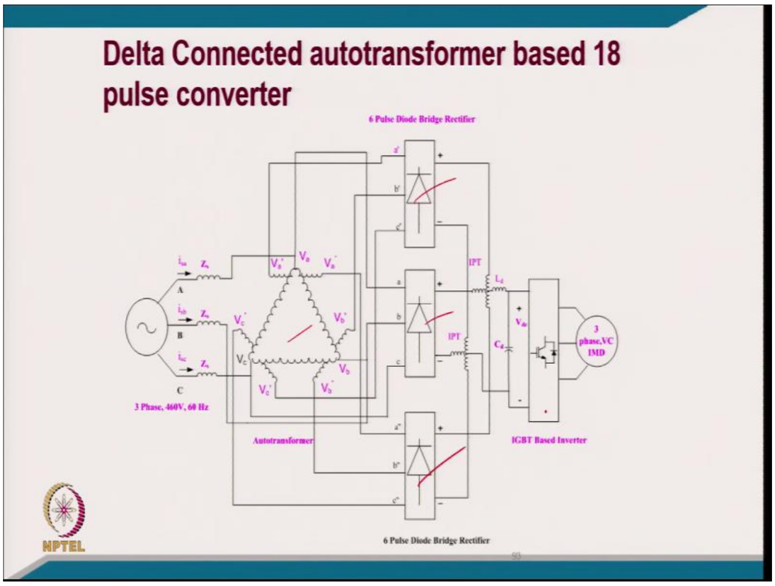

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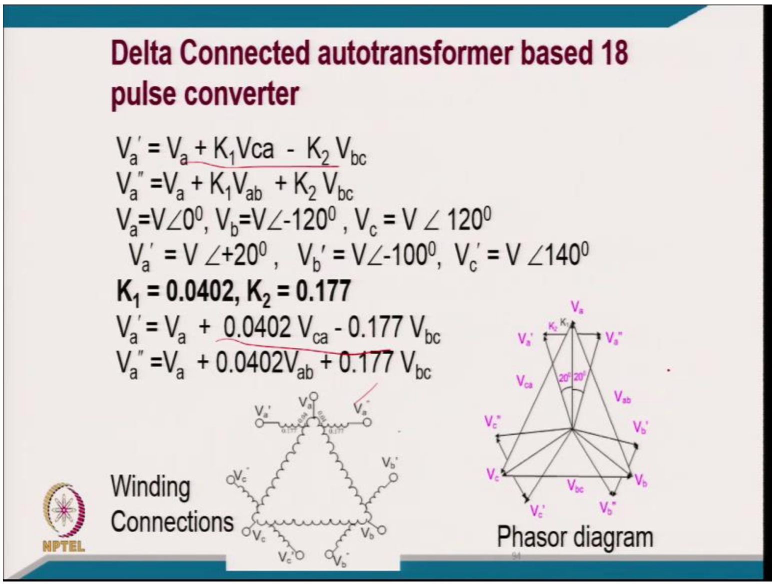

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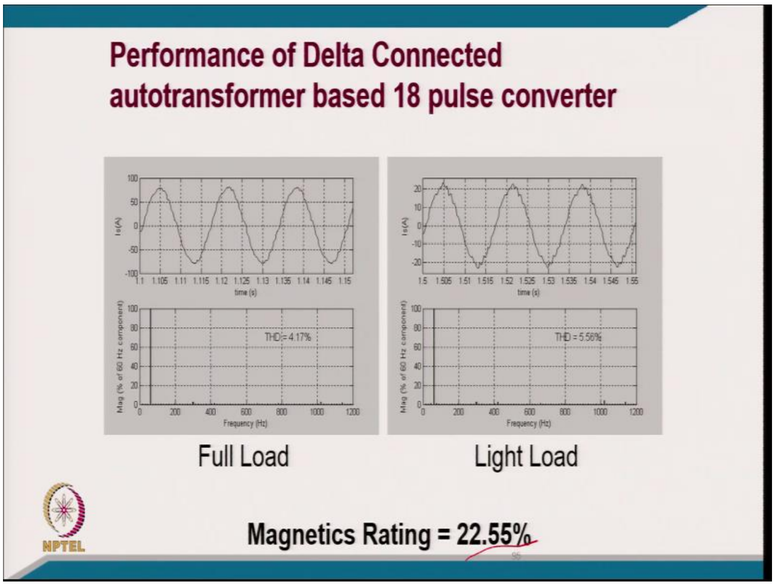

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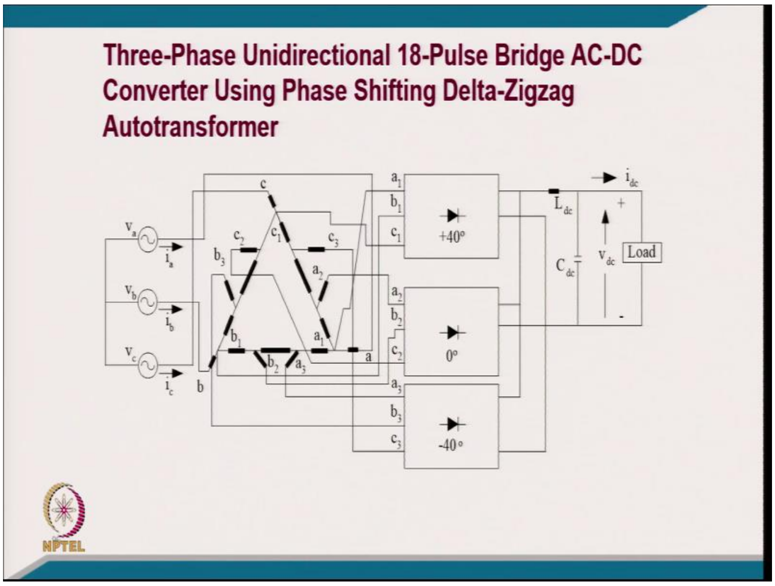

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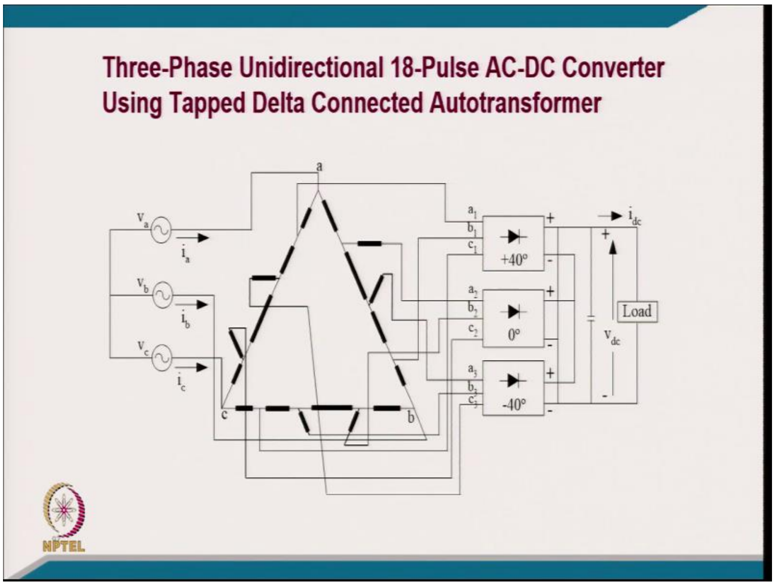

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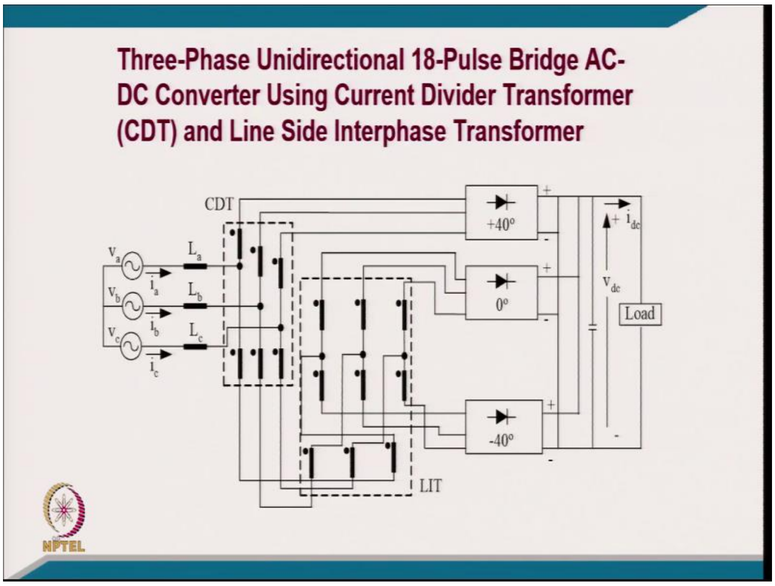

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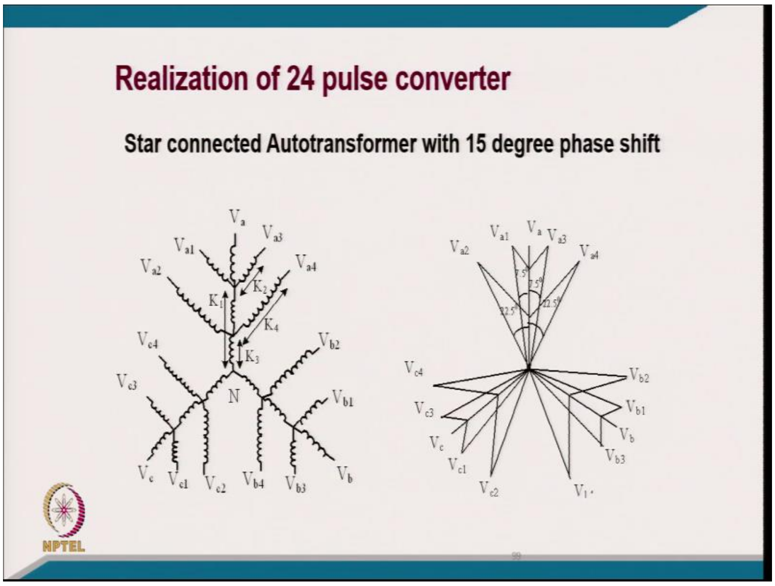

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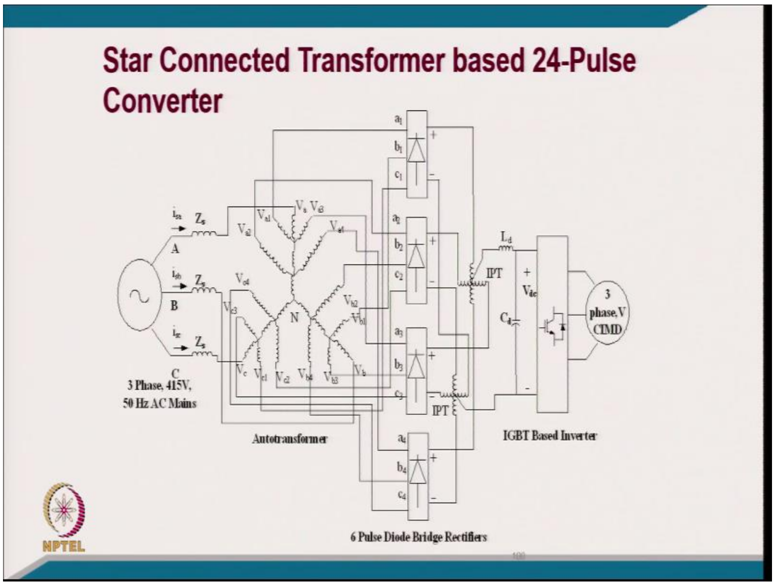

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$V_{a1} = K_1 V_a \angle 0^0 - K_2 V_b \angle -120^0$

$V_{a2} = K_3 V_a - K_4 V_b \angle -120^0$

$V_{a3} = K_1 V_a \angle 0^0 - K_2 V_c \angle 120^0$

$V_{a4} = K_3 V_a \angle 0^0 - K_4 V_c \angle 120^0$

$V_{a1} = V \angle 7.5^0$, $V_{b1} = V \angle -112.5^0$, $V_{c1} = V \angle 127.5^0$

$V_{a2} = V \angle 22.5^0$, $V_{b2} = V \angle -97.5^0$, $V_{c2} = V \angle 122.5^0$

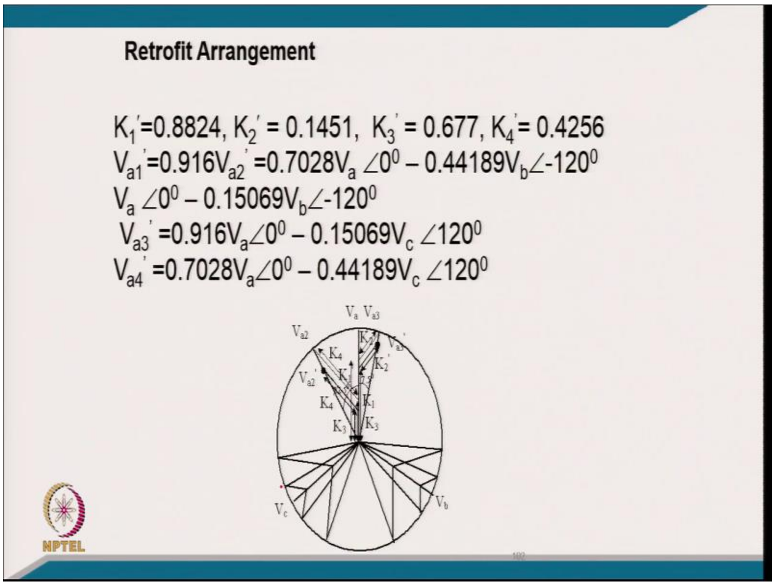
$V_{a3} = V \angle -7.5^0$, $V_{b3} = V \angle -127.5^0$, $V_{c3} = V \angle 112.5^0$

$V_{a4} = V \angle -22.5^0$, $V_{b4} = V \angle -142.5^0$, $V_{c4} = V \angle 97.5^0$

$K_1 = 0.916$, $K_2 = 0.15069$,

$K_3 = 0.7028$ and $K_4 = 0.44189$

(Refer Slide Time: 54:05)



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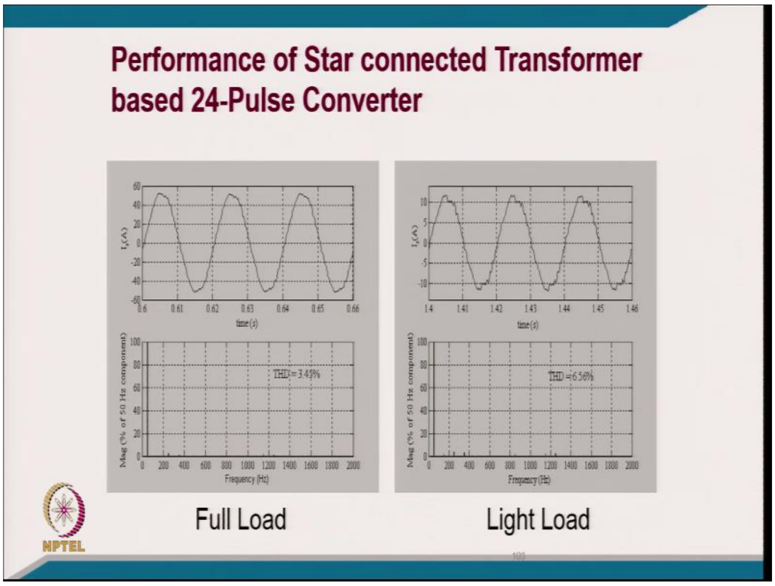

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Nine-Phase AC-DC Converters

Delta Connected Autotransformer

Phase shift = 360^0/ Number of output phases

$V_{a1} = V_a + K_1 V_{ca} - K_2 V_{bc}$

$V_{a2} = V_a + K_1 V_{ab} + K_2 V_{bc}$

$V_a = V\angle 0^0$, $V_b = V\angle -120^0$, $V_c = V\angle 120^0$

$V_{a1} = V\angle 40^0$, $V_{b1} = V\angle -80^0$, $V_{c1} = V\angle 160^0$

$V_{a2} = V\angle -40^0$, $V_{b2} = V\angle -160^0$, $V_{c2} = V\angle 80^0$

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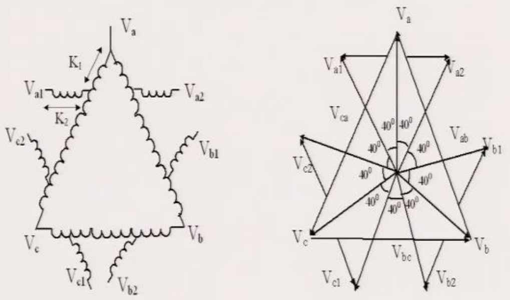
Nine-Phase AC-DC Converters

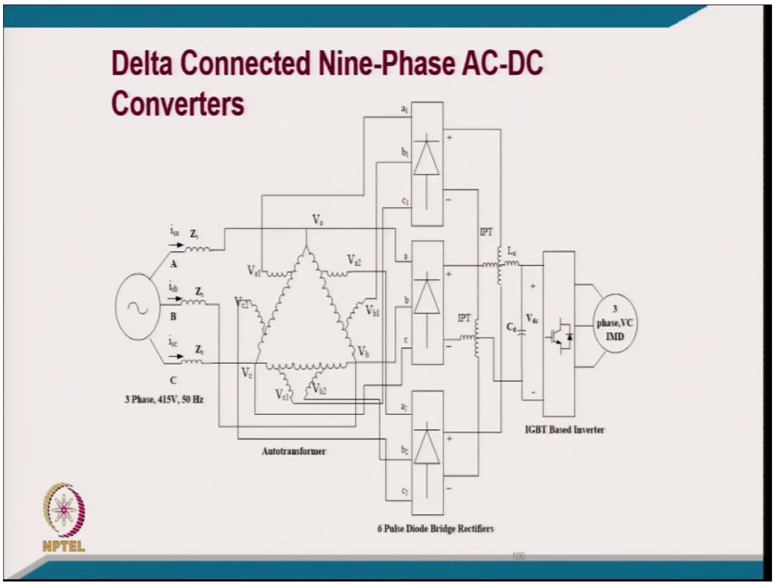


$K_1 = 0.156$, $K_2 = 0.293$

$V_{a1} = V_a + 0.156 V_{ca} - 0.293 V_{bc}$

$V_{a2} = V_a + 0.156 V_{ab} + 0.293 V_{bc}$

(Refer Slide Time: 55:39)



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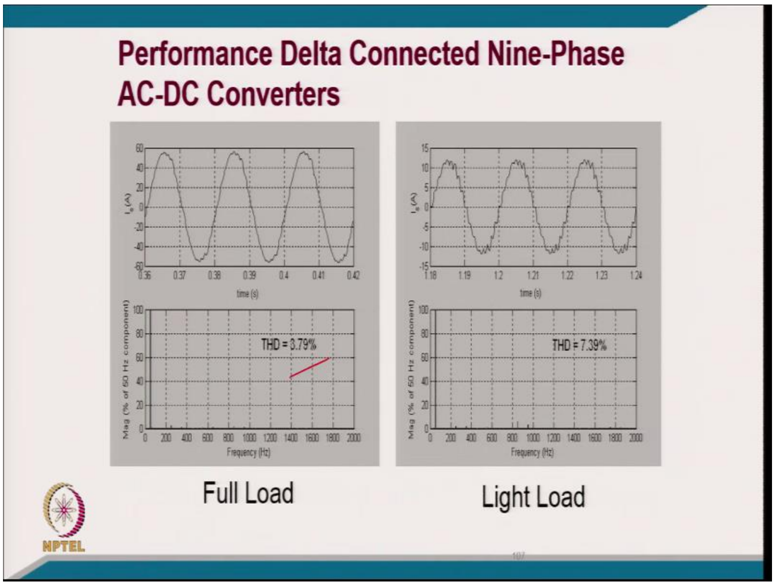

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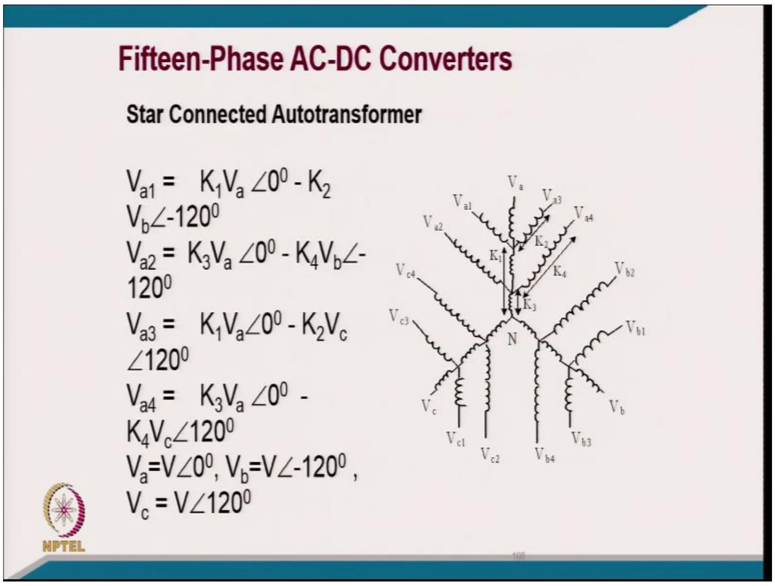

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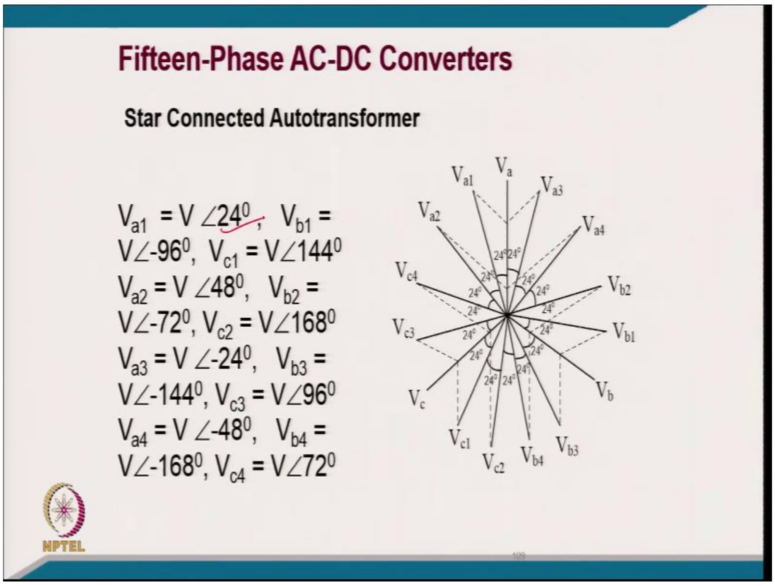

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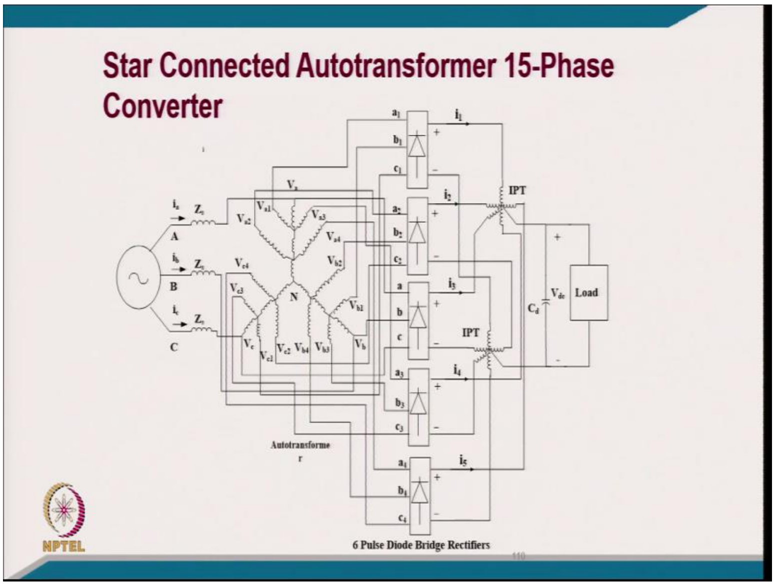

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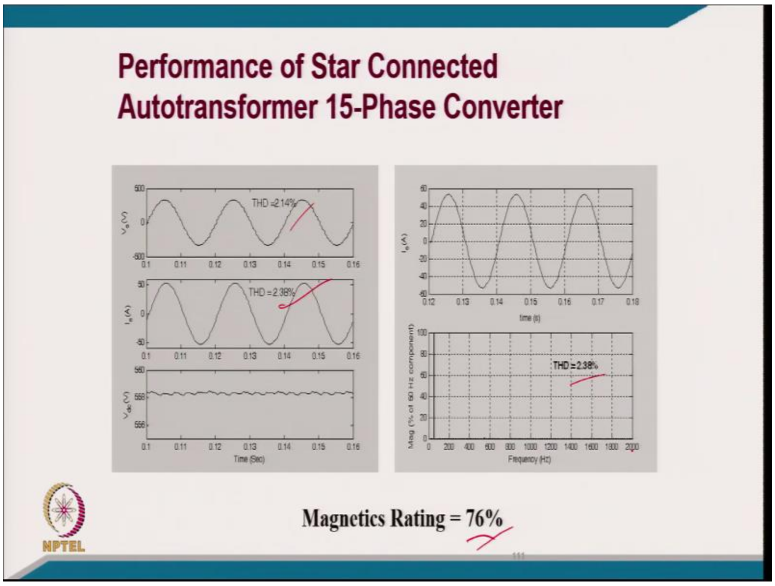

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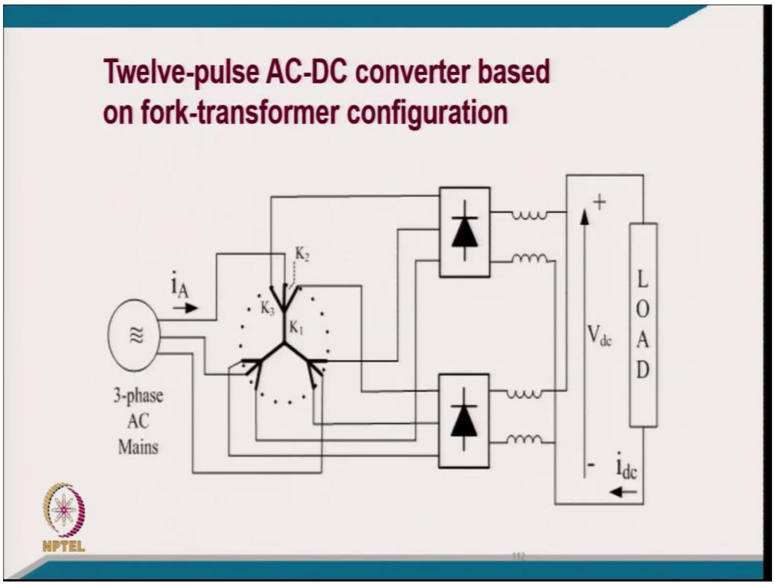

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Three-phase supply voltage applied to the input of autotransformer as

$$V_a = V_s\angle 0^0,\quad V_b = V_s\angle -120^0,\quad V_c = V_s\angle 120^0$$

$$K1 + K2 = 1$$

Output voltages of this configuration are expressed as

$$V_{a1} = K_1 V_a - K_3 V_b$$

$$V_{a2} = K_1 V_a - K_3 V_c$$

$$K1 = 0.8165,\ K2 = 0.1835,\ K3 = 0.2988$$

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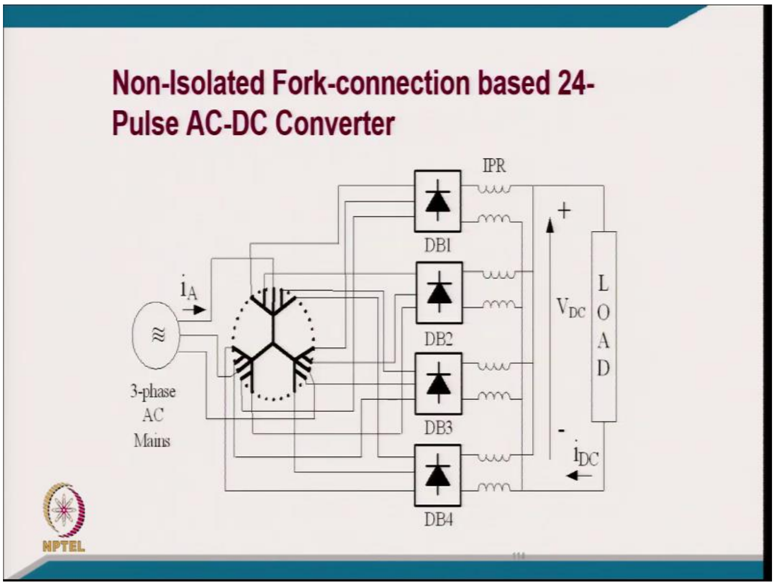
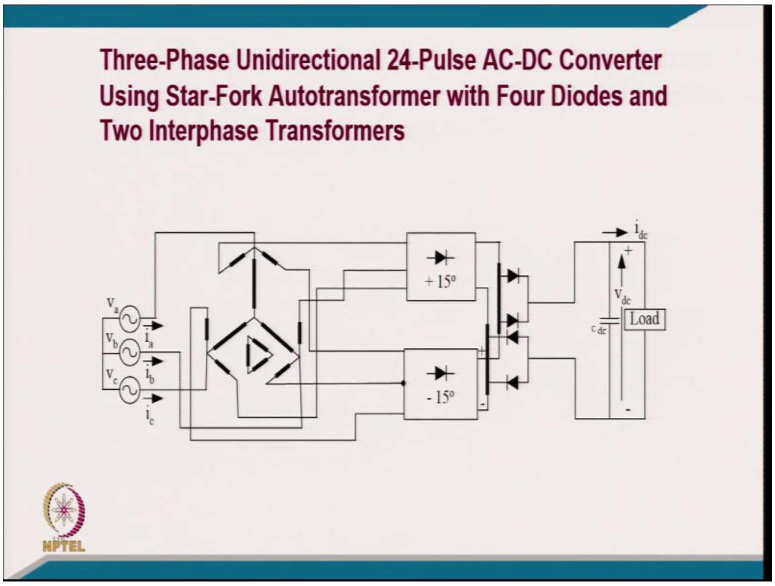
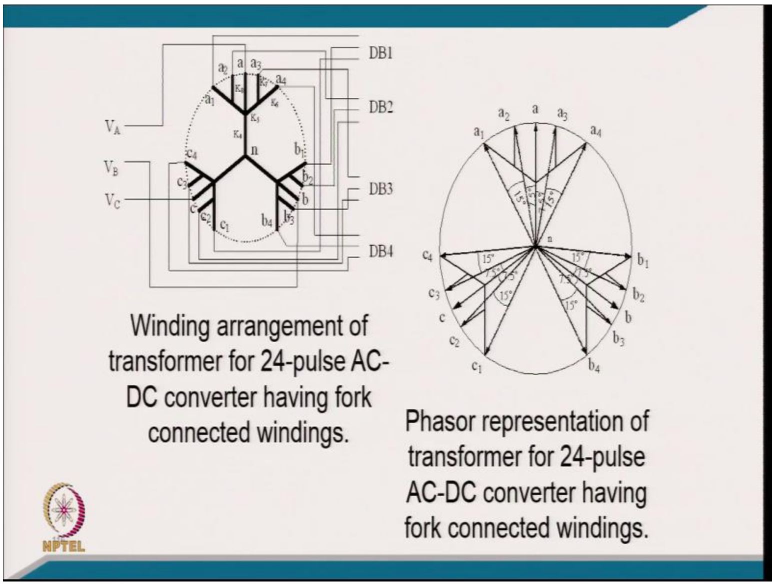


(Refer Slide Time: 58:16)



(Refer Slide Time: 58:30)



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The four sets of required voltages for the converters DB1 to DB4 are:

$$V_{a1} = V_s\angle 22.5^0,\ V_{b1} = V_s\angle -97.5^0,\ V_{c1} = V_s\angle -217.5^0$$

$$V_{a2} = V_s\angle 7.5^0,\ V_{b2} = V_s\angle -112.5^0,\ V_{c2} = V_s\angle -232.5^0$$

$$V_{a3} = V_s\angle -7.5^0,\ V_{b3} = V_s\angle -127.5^0,\ V_{c3} = V_s\angle -247.5^0$$

$$V_{a4} = V_s\angle -22.5^0,\ V_{b4} = V_s\angle -142.5^0,\ V_{c4} = V_s\angle -262.5^0$$

The output voltages can be expressed as follows:

$$V_{a1} = K_4V_a - K_5V_b - K_6V_b$$

$$V_{a2} = K_4V_a - K_5V_b + K_7V_a$$

$$V_{a3} = V_{a2}\angle -15^\circ$$

K8 = 1 − K4

K4 = 0.7029, K5 = 0.1507, K6 = 0.2912, K7 = 0.2132, K8 = 0.2971

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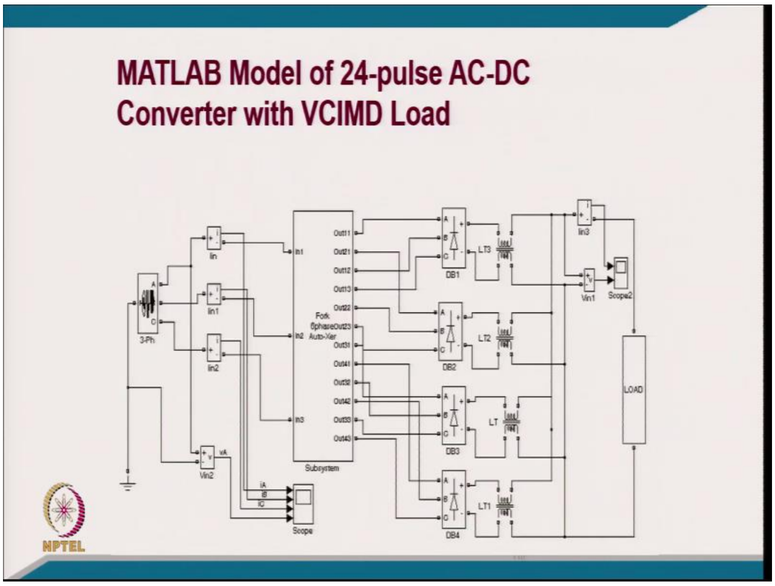
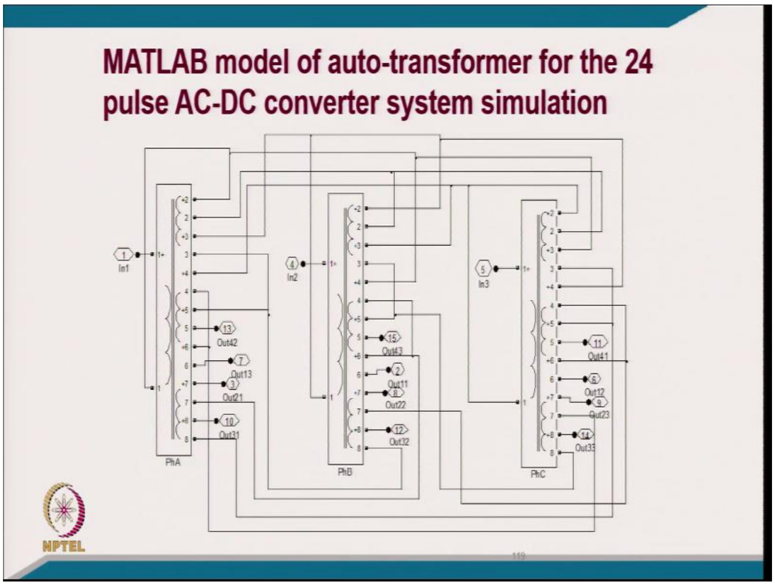
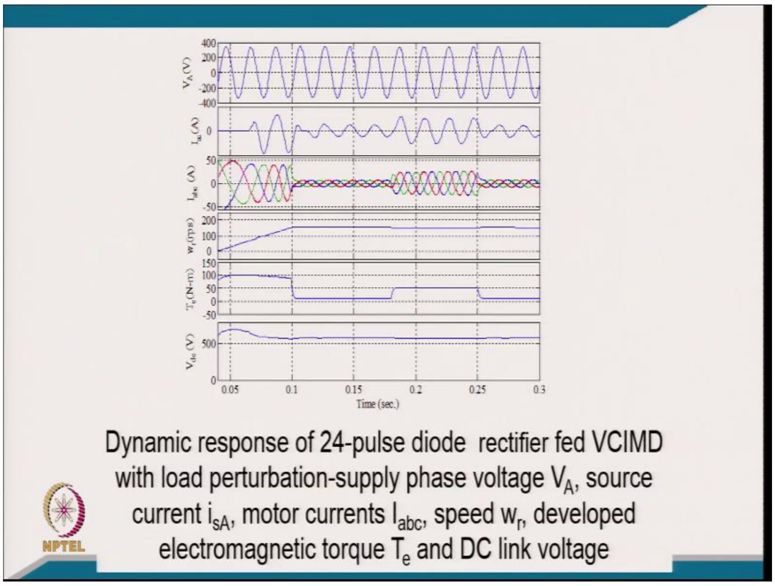


(Refer Slide Time: 59:01)



(Refer Slide Time: 59:02)



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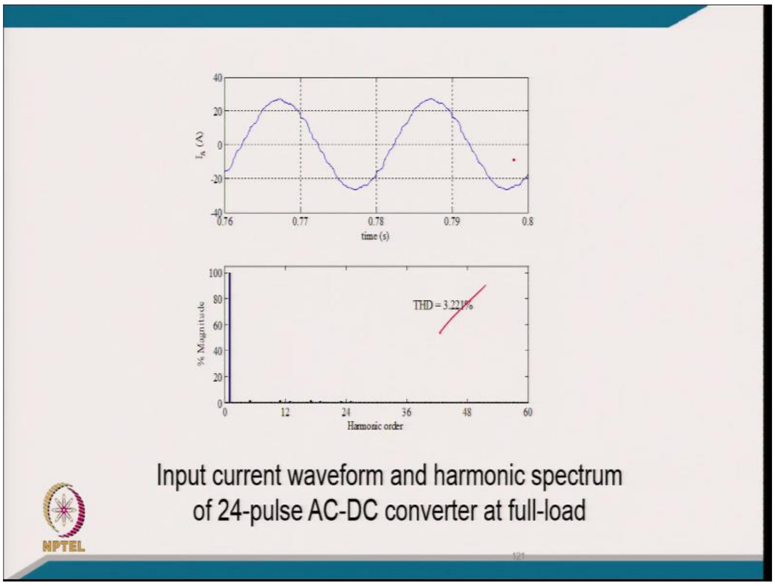

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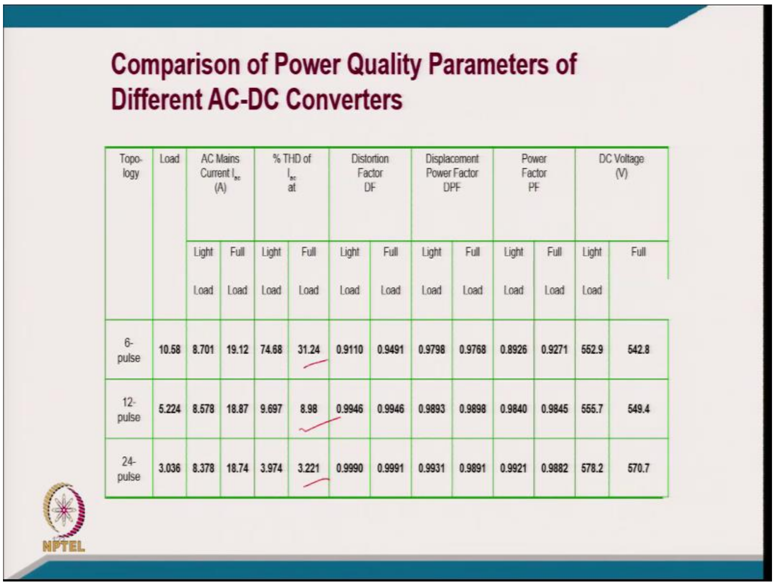
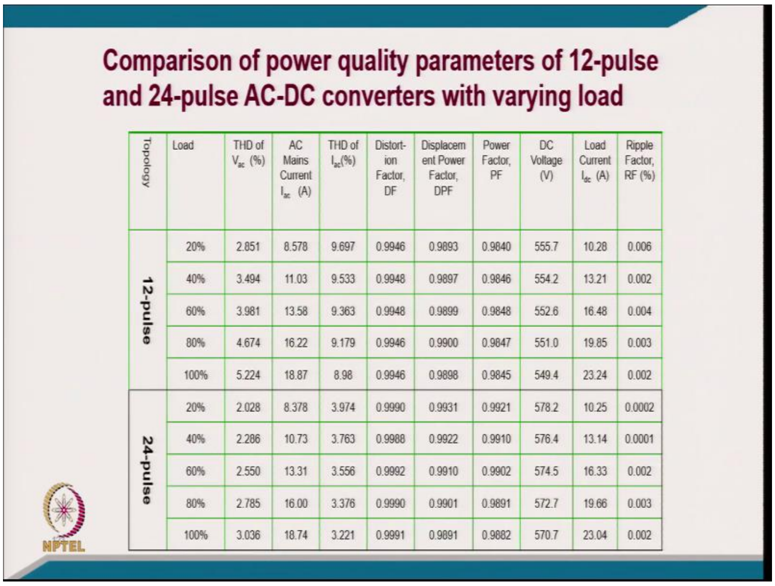


Comparison of Power Quality Parameters of Different AC-DC Converters

Topology	Load	AC Mains Current I_{ac} (A)		% THD of I_{ac} at		Distortion Factor DF		Displacement Power Factor DPF		Power Factor PF		DC Voltage (V)	
		Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full
6-pulse	10.58	8.701	19.12	74.68	31.24	0.9110	0.9491	0.9798	0.9768	0.8926	0.9271	552.9	542.8
12-pulse	5.224	8.578	18.87	9.697	8.98	0.9946	0.9946	0.9893	0.9898	0.9840	0.9845	555.7	549.4
24-pulse	3.036	8.378	18.74	3.974	3.221	0.9990	0.9991	0.9931	0.9891	0.9921	0.9882	578.2	570.7

(Refer Slide Time: 59:31)



Comparison of power quality parameters of 12-pulse and 24-pulse AC-DC converters with varying load

Topology	Load	THD of V_{ac} (%)	AC Mains Current I_{ac} (A)	THD of I_{ac}(%)	Distortion Factor, DF	Displacement Power Factor, DPF	Power Factor, PF	DC Voltage (V)	Load Current I_{dc} (A)	Ripple Factor, RF (%)
12-pulse	20%	2.851	8.578	9.697	0.9946	0.9893	0.9840	555.7	10.28	0.006
	40%	3.494	11.03	9.533	0.9948	0.9897	0.9846	554.2	13.21	0.002
	60%	3.981	13.58	9.363	0.9948	0.9899	0.9848	552.6	16.48	0.004
	80%	4.674	16.22	9.179	0.9946	0.9900	0.9847	551.0	19.85	0.003
	100%	5.224	18.87	8.98	0.9946	0.9898	0.9845	549.4	23.24	0.002
24-pulse	20%	2.028	8.378	3.974	0.9990	0.9931	0.9921	578.2	10.25	0.0002
	40%	2.286	10.73	3.763	0.9988	0.9922	0.9910	576.4	13.14	0.0001
	60%	2.550	13.31	3.556	0.9992	0.9910	0.9902	574.5	16.33	0.002
	80%	2.785	16.00	3.376	0.9990	0.9901	0.9891	572.7	19.66	0.003
	100%	3.036	18.74	3.221	0.9991	0.9891	0.9882	570.7	23.04	0.002

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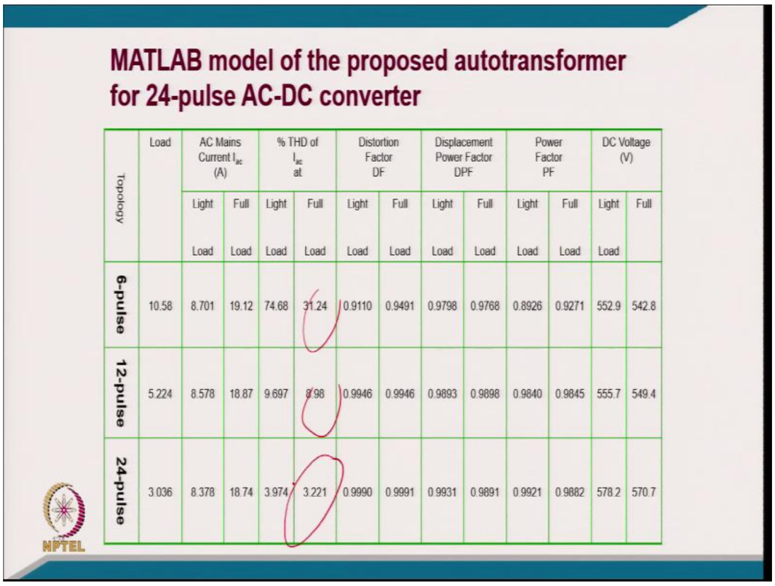

MATLAB model of the proposed autotransformer for 24-pulse AC-DC converter

Topology	Load	AC Mains Current I_{ac} (A)		% THD of I_{ac} at		Distortion Factor DF		Displacement Power Factor DPF		Power Factor PF		DC Voltage (V)	
		Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full Load	Light Load	Full
6-pulse	10.58	8.701	19.12	74.68	31.24	0.9110	0.9491	0.9798	0.9768	0.8926	0.9271	552.9	542.8
12-pulse	5.224	8.578	18.87	9.697	8.98	0.9946	0.9946	0.9893	0.9898	0.9840	0.9845	555.7	549.4
24-pulse	3.036	8.378	18.74	3.974	3.221	0.9990	0.9991	0.9931	0.9891	0.9921	0.9882	578.2	570.7

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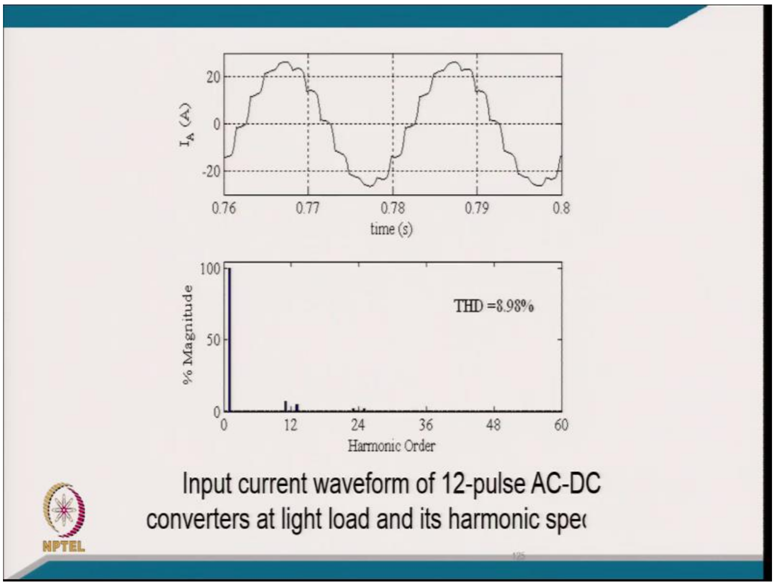

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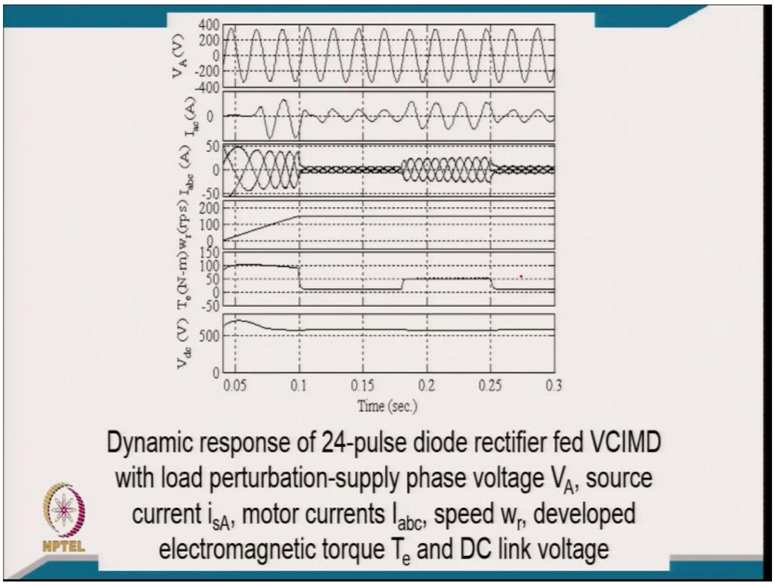

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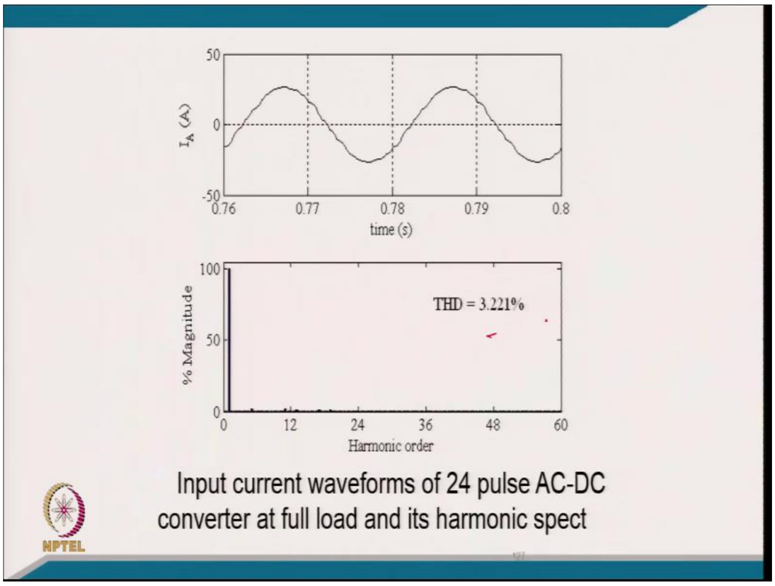

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Comparison of magnetic ratings in different AC-DC converters

Sr. No.	Topology	Main Transformer rating (% of load)	Interphase transformer rating (% of load)	Total magnetic rating (% of load)
1	12-pulse	28.68	7.50	36.18
2	24-pulse	49.2	7.36	56.56

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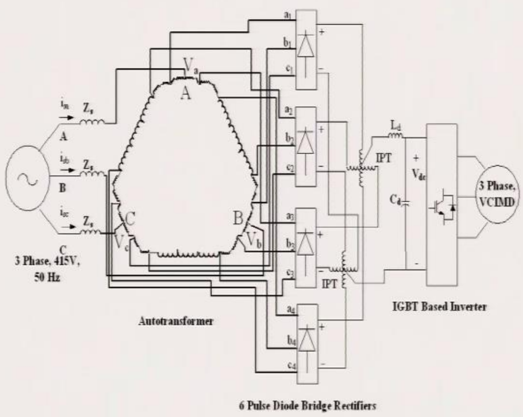
Polygon Autotransformer Based 24-pulse AC-DC Converter



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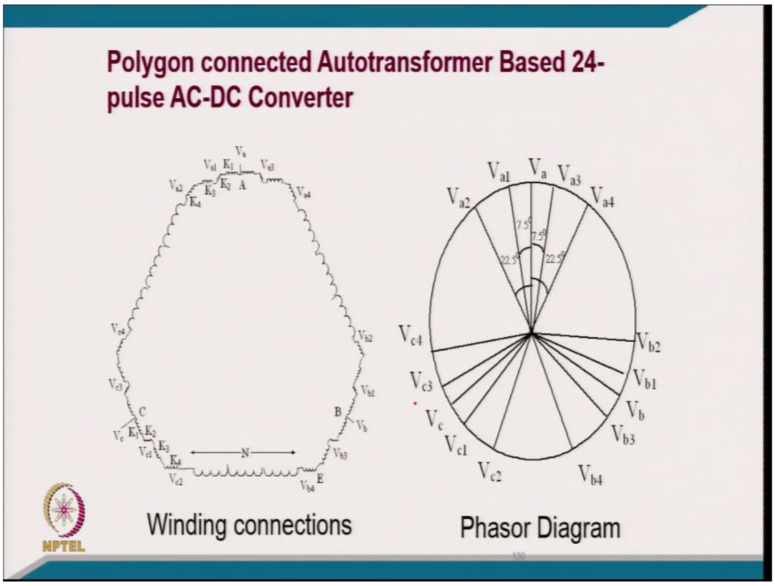

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Design

$V_{a1} = V_a - K_1 V_{bc} + K_2 V_{ca}$

$V_{a2} = V_{a1} - K_3 V_{bc} + K_4 V_{ca}$

$V_{a3} = V_a + K_1 V_{bc} - K_2 V_{ab}$

$V_{a4} = V_{a3} + K_3 V_{bc} - K_4 V_{ab}$

Assume the following set of voltages:

$V_a = V\angle 0^0$, $V_b = V\angle -120^0$, $V_c = V\angle 120^0$

$V_{a1} = V\angle 7.5^0$, $V_{b1} = V\angle -112.5^0$, $V_{c1} = V\angle 127.5^0$

$V_{a2} = V\angle 22.5^0$, $V_{b2} = V\angle -97.5^0$, $V_{c2} = V\angle 122.5^0$

$V_{a3} = V\angle -7.5^0$, $V_{b3} = V\angle -127.5^0$, $V_{c3} = V\angle 112.5^0$

$V_{a4} = V\angle -22.5^0$, $V_{b4} = V\angle -142.5^0$, $V_{c4} = V\angle 97.5^0$

$K_1 = 0.07249$, $K_2 = 0.00576$, $K_3 = 0.123$, $K_4 = 0.04509$

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Load (%)	THD (%)		CF of I_s	DF	DPF	PF	V_{dc} (V)
	I_s	V_t					
20	5.22	1.76	1.43	.998	.989	.988	557
40	4.65	1.90	1.43	.999	.990	.989	553
60	4.41	2.31	1.43	.999	.989	.989	551
80	4.05	2.51	1.44	.999	.988	.988	547
100	3.20	2.73	1.44	.999	.988	.988	546

Power Quality Indices under varying Loads for 24-pulse AC-DC converter (Polygon)

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Multipulse AC-DC Converters for Bidirectional Power Flow

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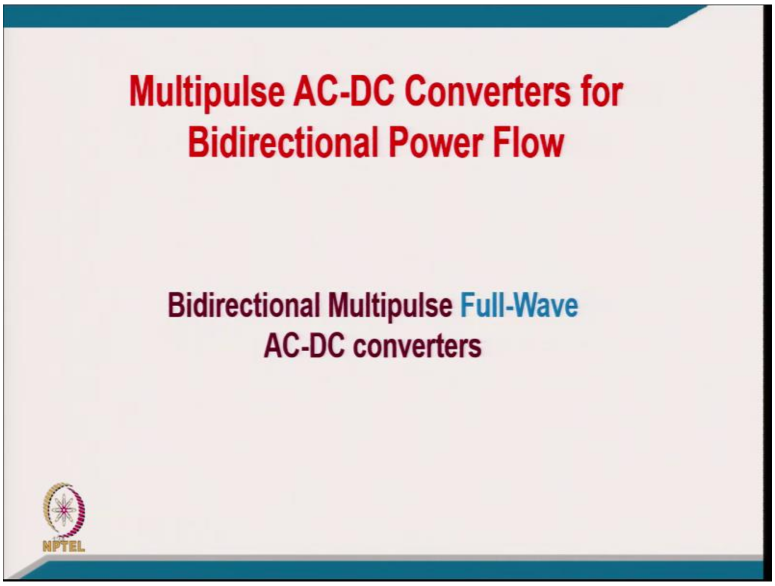

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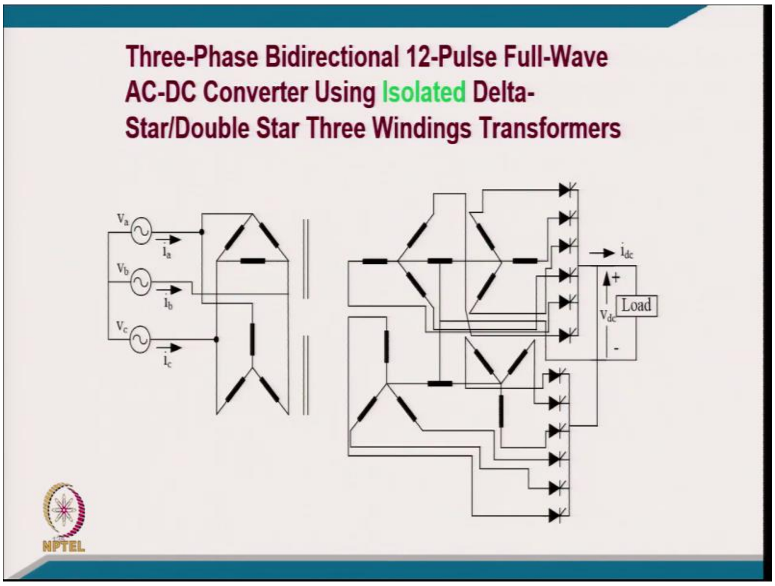

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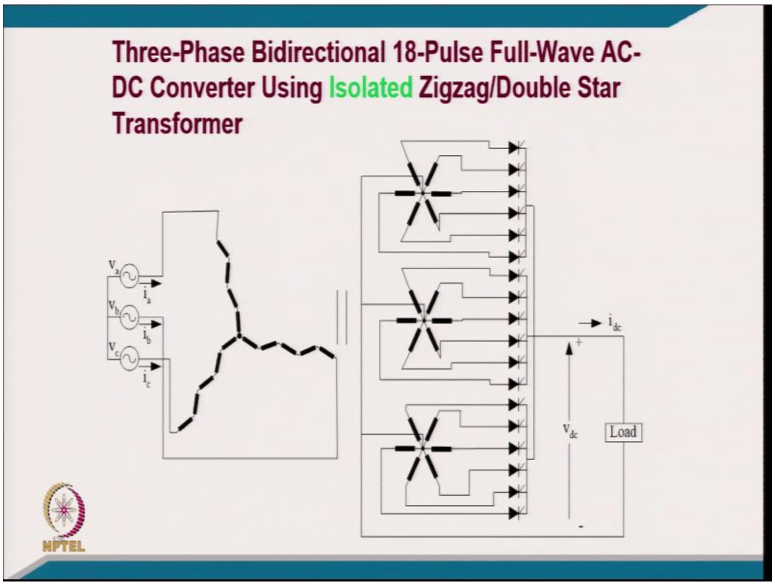

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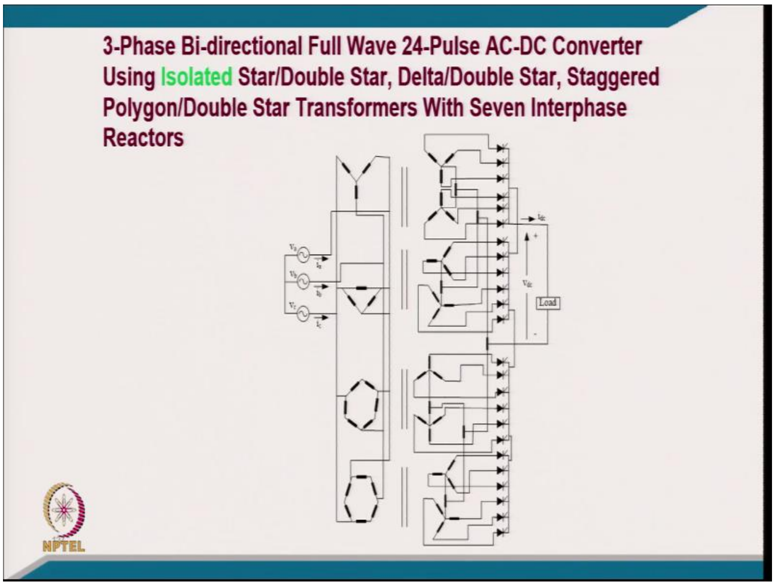

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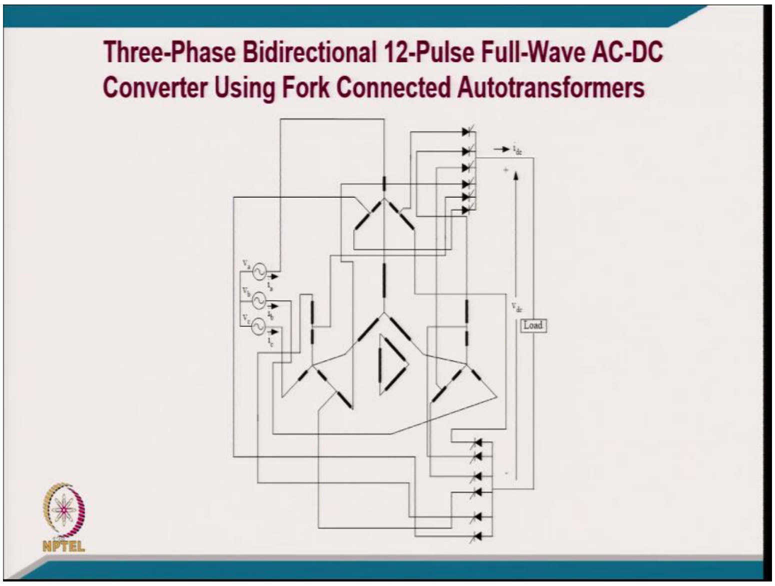

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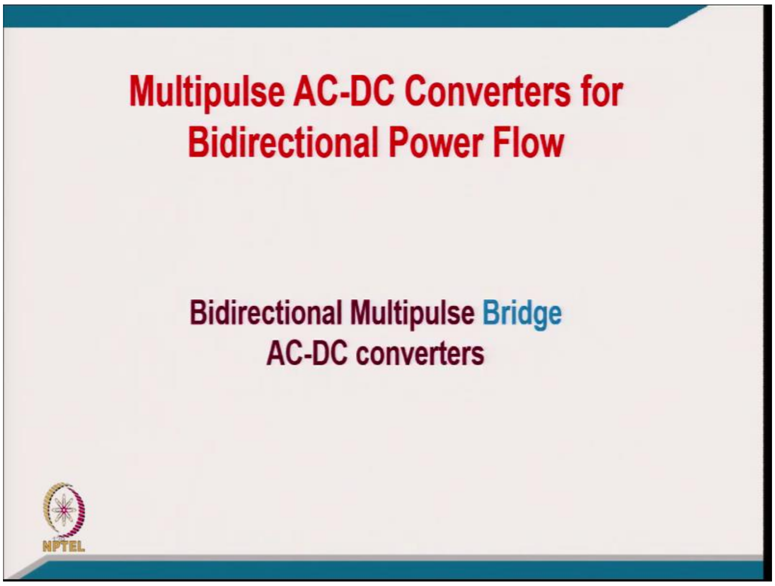

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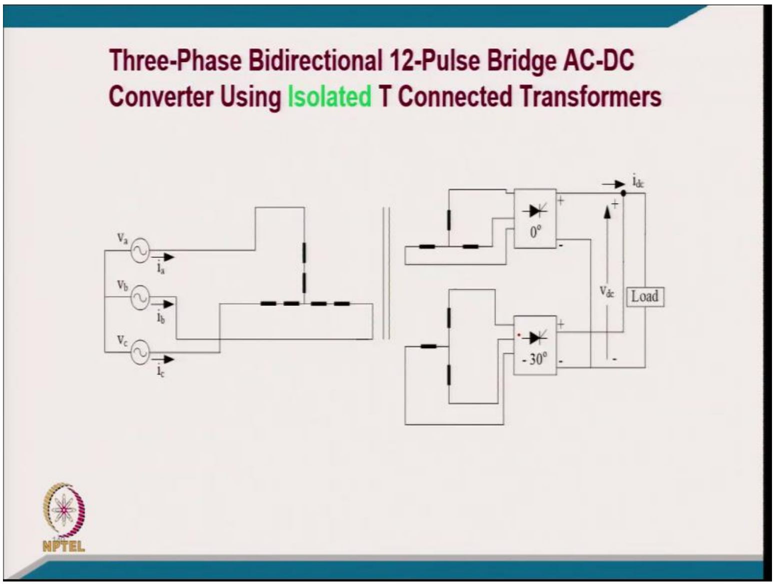

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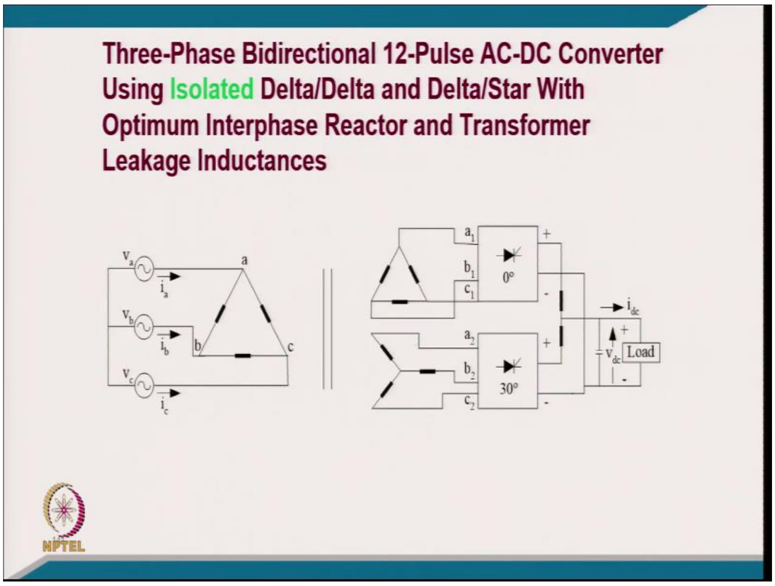

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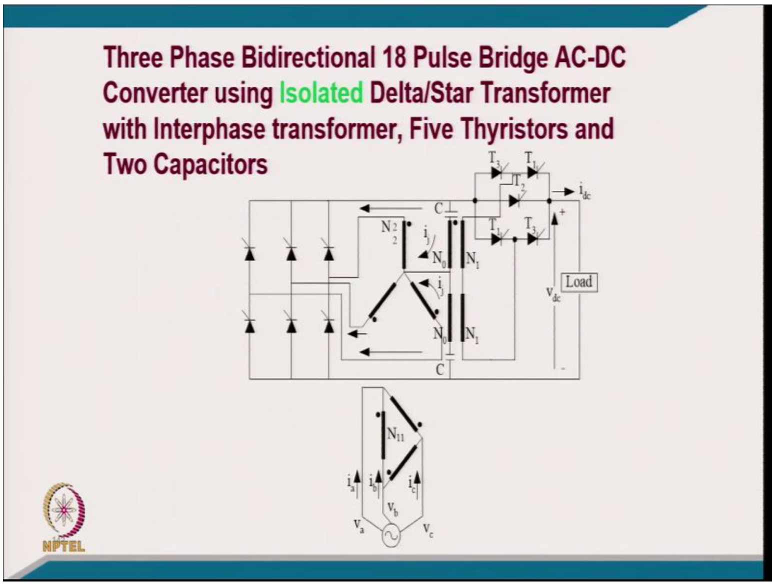

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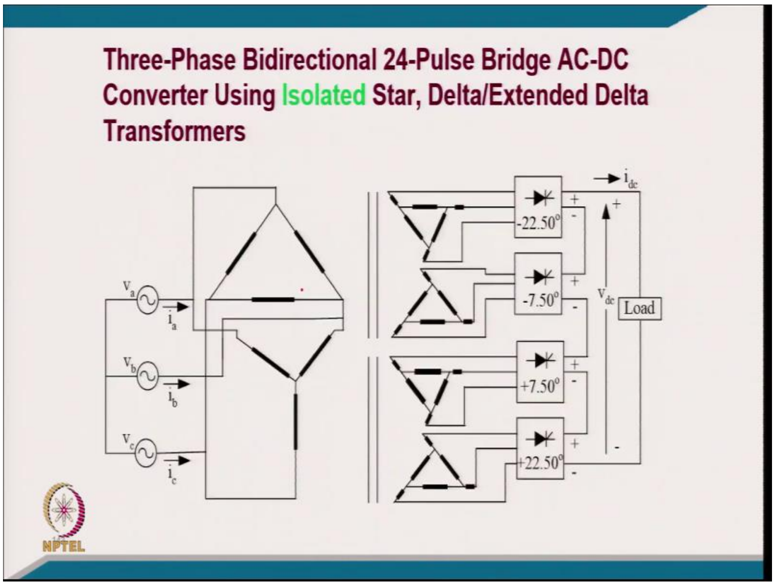

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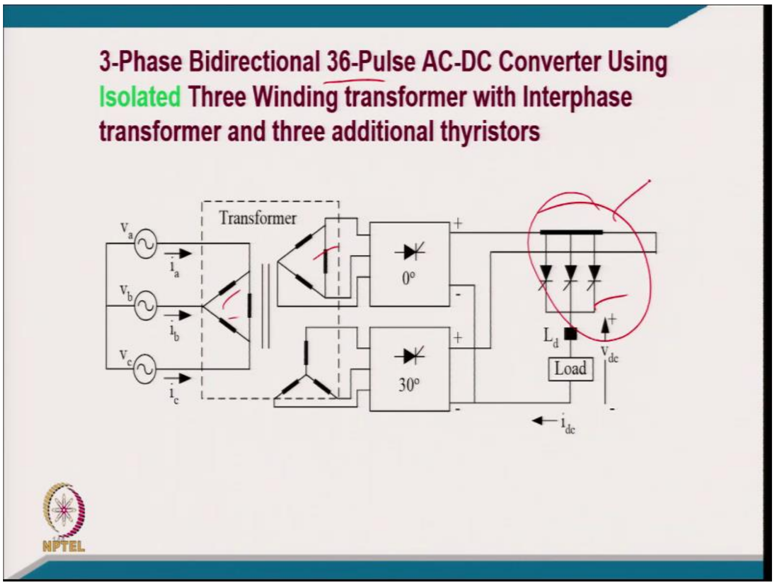

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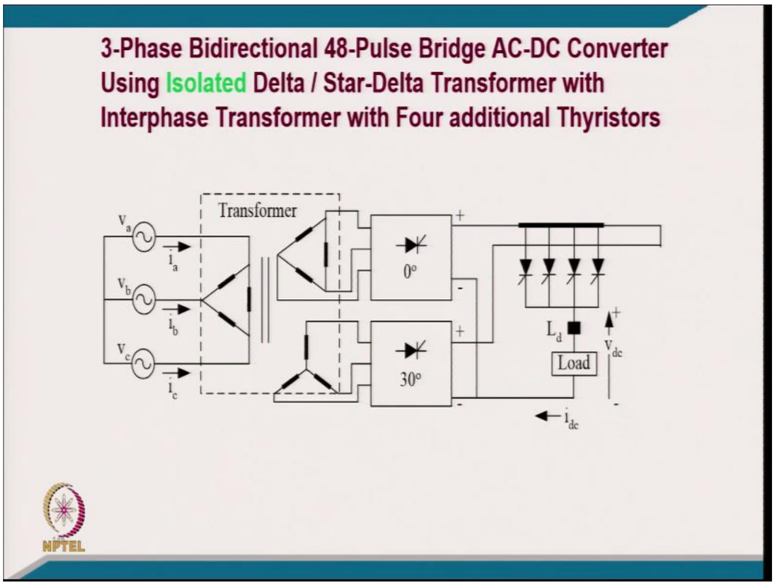

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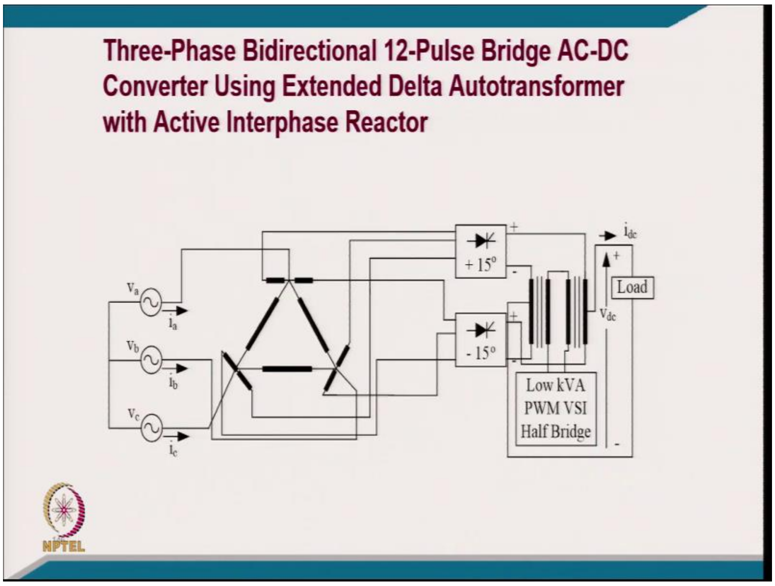

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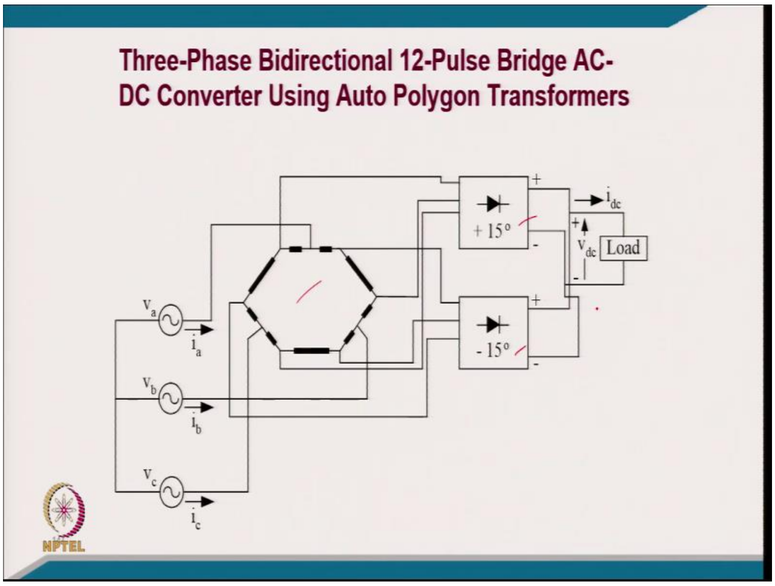

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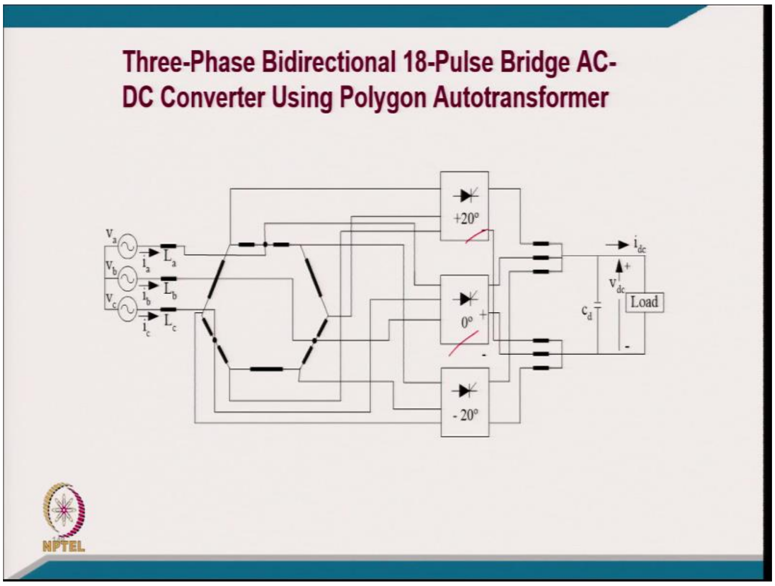

Thank you.