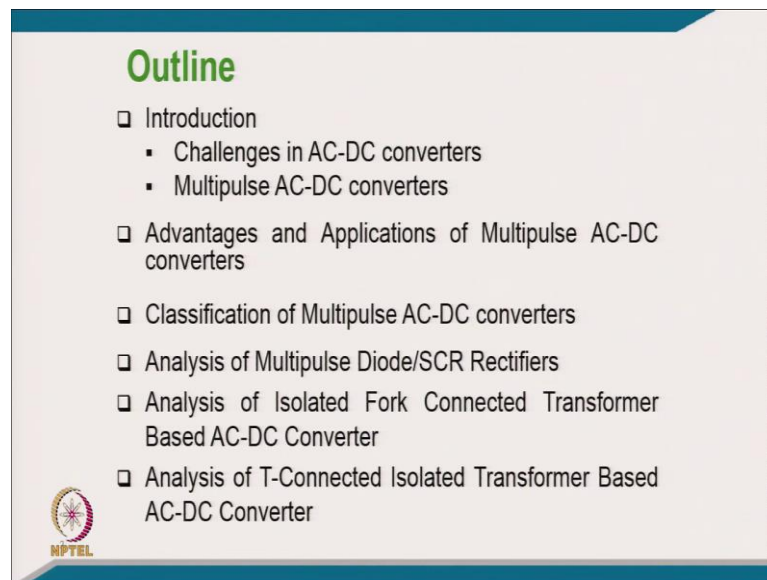


**Power Quality**  
**Prof. Bhim Singh**  
**Department of Electrical Engineering**  
**Indian Institute of Technology, Delhi**

**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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**Outline**

- Introduction
  - Challenges in AC-DC converters
  - Multipulse AC-DC converters
- Advantages and Applications of Multipulse AC-DC converters
- Classification of Multipulse AC-DC converters
- Analysis of Multipulse Diode/SCR Rectifiers
- Analysis of Isolated Fork Connected Transformer Based AC-DC Converter
- Analysis of T-Connected Isolated Transformer Based AC-DC Converter

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These are the outlines of this lecture.

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## Introduction

### Challenges in AC-DC Converters


- ❑ The major problems in AC-DC converters are injection of harmonics at input and output.
- ❑ Harmonics cause dielectric, thermal or voltage stress, which cause premature ageing of electrical insulation.
- ❑ Voltage distortion at point of common coupling takes place due to the voltage drop of harmonic currents flowing through system impedances.



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### Challenges in AC-DC Converters


- ❑ Capacitor bank overloading due to system resonance.
- ❑ Interference on telephone and communication lines due to noise induced from the power conductors.
- ❑ Poor power factor.
- ❑ Equipment damage from voltage spikes created by high frequency resonance resulting from notching.



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### Multi Pulse AC-DC Converters

- ❑ **Multi pulse Converters:** Defined as diode/thyristor converters where the pulse number is  $> 6$ .)
- ❑ Generally the pulse number is a multiple of 6 (assuming 3-phase system), so 12, 18, 24-pulse circuits etc are possible
- ❑ A 12-pulse converter, for example, consists of two 6-pulse converters fed from a 6-phase supply and connected in series or parallel on the DC side (18-pulse has three 6-pulse circuits and so on)



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Pulse Number	Harmonics in input current ( $K=1,2,3,4\dots$ )	Ripple frequency on DC side
6	$6K\pm 1$	$6*\text{supply}$
12	$12K\pm 1$	$12*\text{supply}$
18	$18K\pm 1$	$18*\text{supply}$
24	$24K\pm 1$	$24*\text{supply}$



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**Advantages of Multi-pulse AC-DC Converters**

- ❑ The performance parameters such as total-harmonic-distortion (THD) of AC mains current and ripple factor of output DC voltage improve, simultaneously.
- ❑ The improvement is independent of supply frequency variation, unlike passive filters.
- ❑ Minimal or no control required as Diodes and/or thyristors are mainly used.




These are the advantages of multipulse AC-DC Converters

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**Advantages of Multi-pulse AC-DC Converters**

- ❑ Economic, maintenance free and efficient.
- ❑ Phase shifting transformers are used to derive multiple phase supply from three-phase AC mains using different combinations of transformer windings such as star, delta, zigzag, fork, polygon, etc.



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**Application Potential**

**Non-Isolated Uncontrolled Rectifiers :**

- Front end of Switched mode powers like- SMPS, UPS, AC-DC motor drives, dc servo drives.
- aircraft VSCF (Variable Speed Constant frequency) systems and aircraft maintenance systems using 60Hz/400Hz converter systems.

**Isolated Uncontrolled Rectifiers :**

- The railways working on DC.
- The welding equipment working on high frequency.



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**Application Potential**

**Non-Isolated Controlled Rectifiers:**

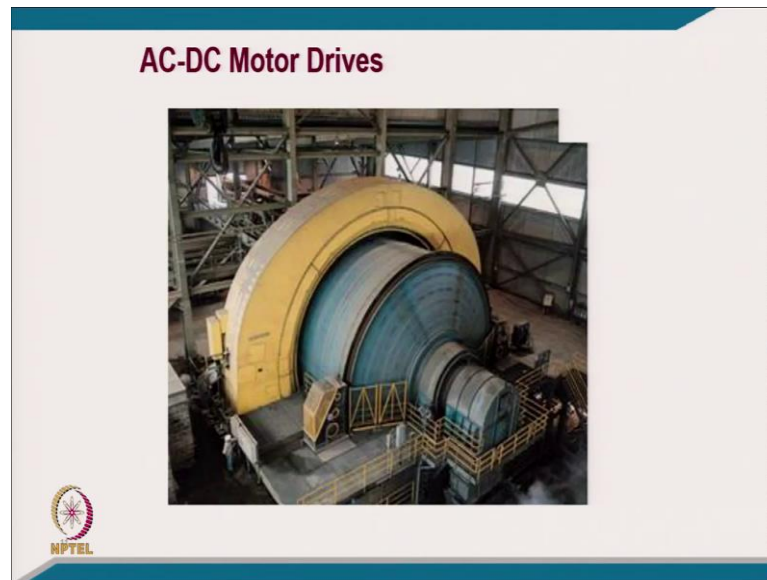
- DC motor drive system with regenerative capacity.
- Some power supplies of large rating also use non-isolated dual converters

**Isolated Controlled Rectifiers :**

- HVDC systems.
- Battery energy storage systems.
- Adjustable speed synchronous motor drive of large power ratings for applications such as mining.
- Arc furnaces



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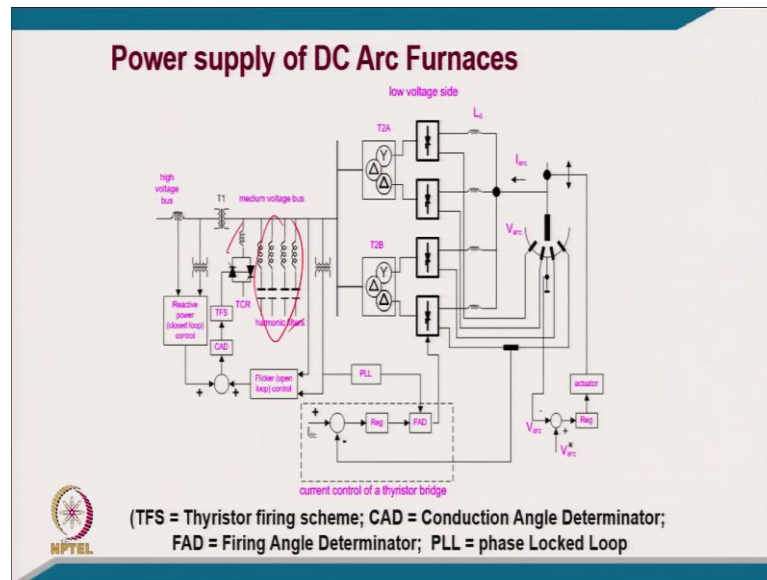
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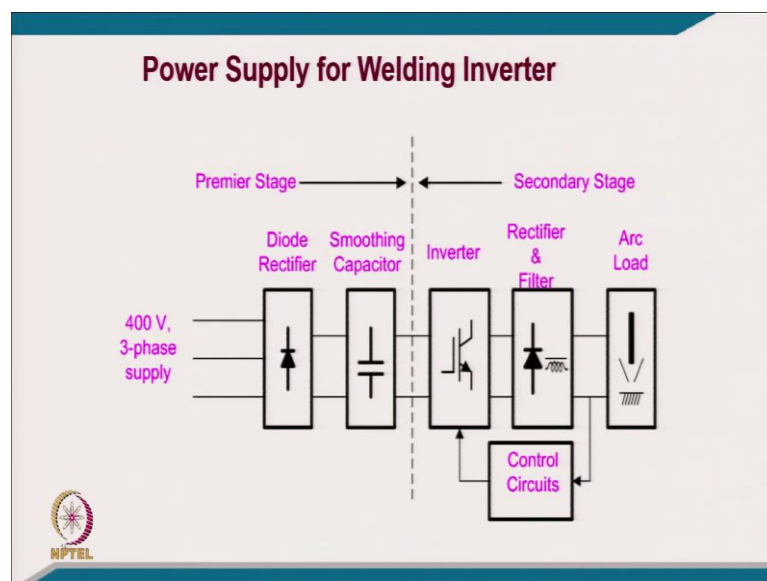
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## Configurations of Multipulse AC-DC Converters

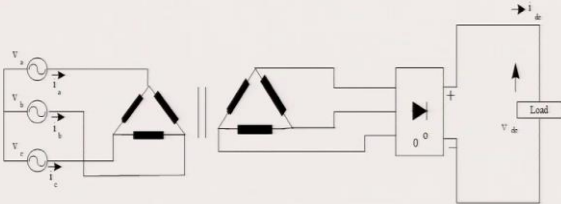
**Phase Shift =  $60^\circ$  / Number of Six-Pulse Converters**



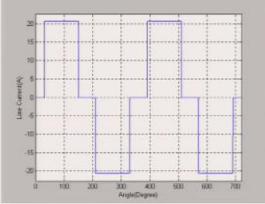
The slide features a title in green text and a formula in maroon text. The NPTEL logo is located in the bottom-left corner.

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### 6-pulse AC-DC Converter



The circuit diagram shows a three-phase AC source with voltages  $V_a$ ,  $V_b$ , and  $V_c$  and currents  $I_a$ ,  $I_b$ , and  $I_c$ . The source is connected to a bridge rectifier. The output of the bridge rectifier is connected to a diode bridge rectifier, which is then connected to a load. The load current is  $i_d$  and the load voltage is  $V_d$ .

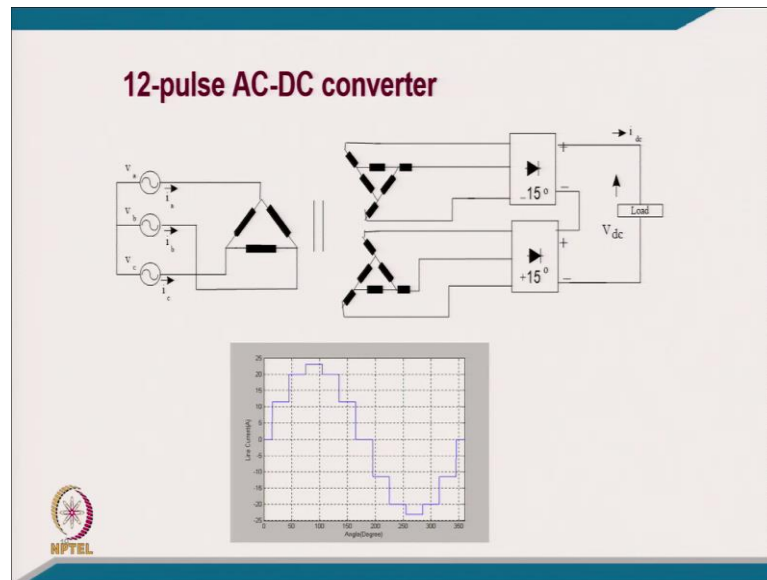


The graph shows the load current  $i_d$  in Amperes (A) versus the angle in degrees. The current is a six-pulse waveform with a peak value of 20 A and a trough value of -20 A. The x-axis ranges from 0 to 720 degrees, and the y-axis ranges from -20 to 20 A.



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### 12-pulse AC-DC converter

#### Current Expressions (Fundamental and RMS):

The expression for current using  $t=0$  is is and odd and quarter wave symmetric,  $a_n = 0$  for all  $n$ , and  $b_n = 0$  for all even  $n$  for

$0^\circ < t < 30^\circ$ ,  $i_{pa} = 0.577 I_d$   
 $30^\circ < t < 60^\circ$ ,  $i_{pa} = 1.577 I_d$   
 $60^\circ < t < 90^\circ$ ,  $i_{pa} = 2.155 I_d$

$$b_n = \frac{4}{\pi} \int_0^{\pi/2} i_{pa}(t) \sin(n\omega t) d(\omega t)$$

$$b_n = \frac{4I_d}{n\pi} \left[ \int_0^{\pi/6} 0.577 \sin(n\omega t) d(\omega t) + \int_{\pi/6}^{\pi/3} 1.577 \sin(n\omega t) d(\omega t) + \int_{\pi/3}^{\pi/2} 2.155 \sin(n\omega t) d(\omega t) \right]$$

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$$b_n = 4I_d / h\pi \left\{ \begin{array}{l} 0.577 [\cos(0^\circ) - \cos(h30^\circ)] + 1.577 [\cos(h30^\circ) - \cos(h60^\circ)] \\ + 2.155 [\cos(h60^\circ) - \cos(h90^\circ)] \end{array} \right\}$$

Substituting the above values for h = 1, 3, 5, 7, 9, 11, 13,

$$b_1 = 4I_d / \pi \{ 0.577 * 0.1339 + 1.577 * 0.366 + 2.155 * 0.5 \} = 2.205 I_d$$

$$b_3 = 0$$

$$b_5 = 4I_d / 5\pi \{ 0.577 * 1.866 + 1.577 * (-0.366) + 2.155 * 0.5 \} = 0$$


$$b_7 = 4I_d / 7\pi \{ 0.577 * 1.866 + 1.577 * (-0.366) + 2.155 * 0.5 \} = 0$$

$$b_9 = 0$$

$$b_{11} = 4I_d / h\pi \{ 0.577 * 0.1339 + 1.577 * 0.366 + 2.155 * 0.5 \} = 2.205/h I_d$$

$$b_{13} = 4I_d / h\pi \{ 0.577 * 0.1339 + 1.577 * 0.366 + 2.155 * 0.5 \} = 2.205/h I_d$$

Therefore,  $b_1 = 2.205 I_d$ ,  $b_3 = b_7 = 0$ ,  $b_{11} = 0.2 I_d$  and  $b_{13} = 0.1696 I_d$



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Fundamental current  $i(t) = 2.205 I_d \sinh(\omega t)$

$$I_{s1}(\text{RMS}) = (2.205 / \sqrt{2}) * I_d = 1.559 I_d$$

$$\text{RMS current } (I_s) = \sqrt{(I_1^2 + I_{11}^2 + I_{13}^2)} = (1/\sqrt{2}) \sqrt{2.205^2 + 0.2^2 + 0.1696^2}$$

$$I_s = 1.577 I_d$$

expression for 12-pulse current is given as

$$i_{pa}(t) = I_d [2.205 \sin \alpha t + 0.2 \sin 11 \alpha t + 0.1696 \sin 13 \alpha t + \dots]$$


$$\text{THD} = [(I_s^2 - I_{s1}^2) / I_{s1}^2]^{1/2}$$

In 12 - pulse LCI

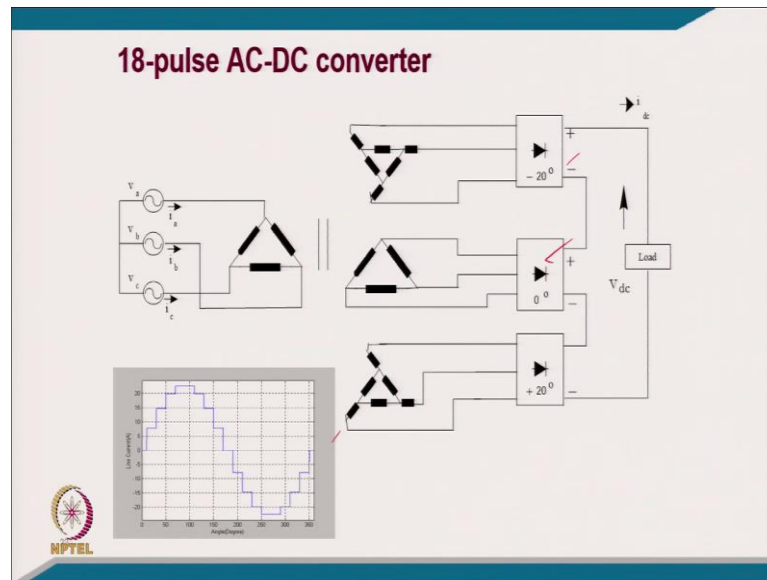
$$I_s = 1.577 * I_d \text{ (This is sum of } 0.816 I_d \angle 30^\circ + 0.816 I_d \angle 0^\circ)$$

$$I_{s1} = \sqrt{6/\pi} * I_d = 1.559 * I_d$$

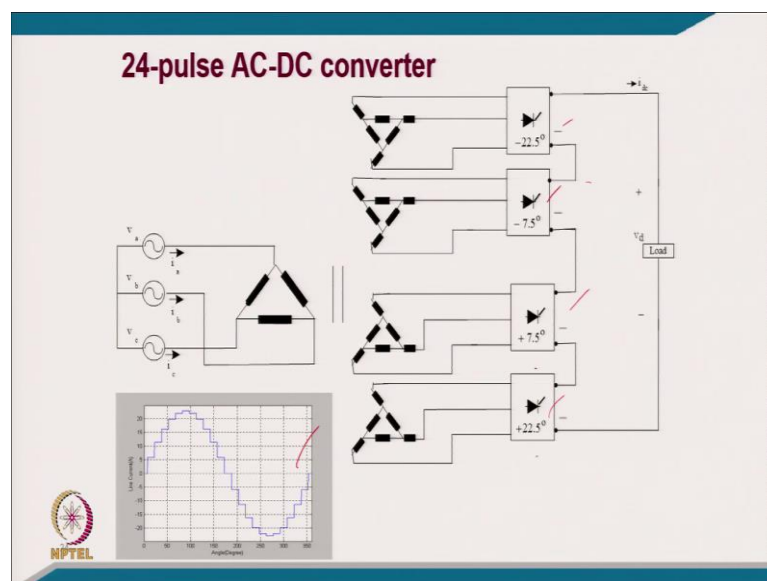
$$\text{THD} = [(1.577 I_d^2 - 1.559 I_d^2) / 1.559 I_d^2]^{1/2} * 100$$

$$\text{THD} = 15.08\%$$


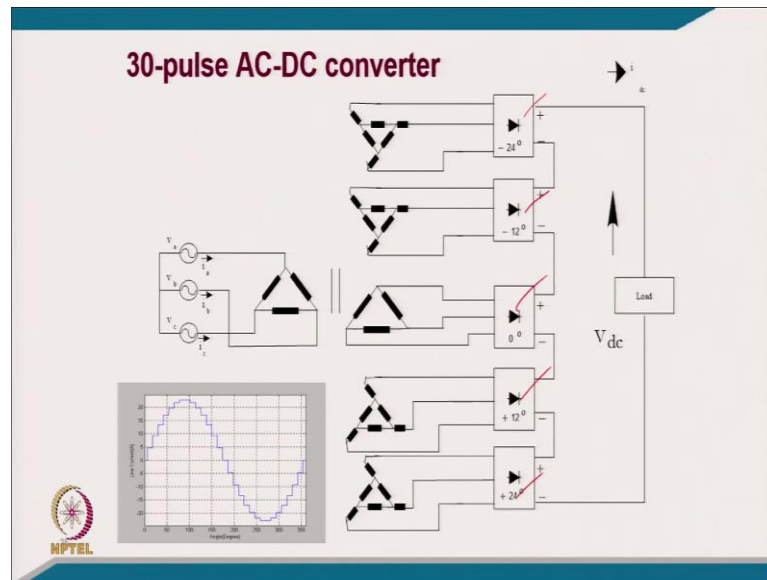
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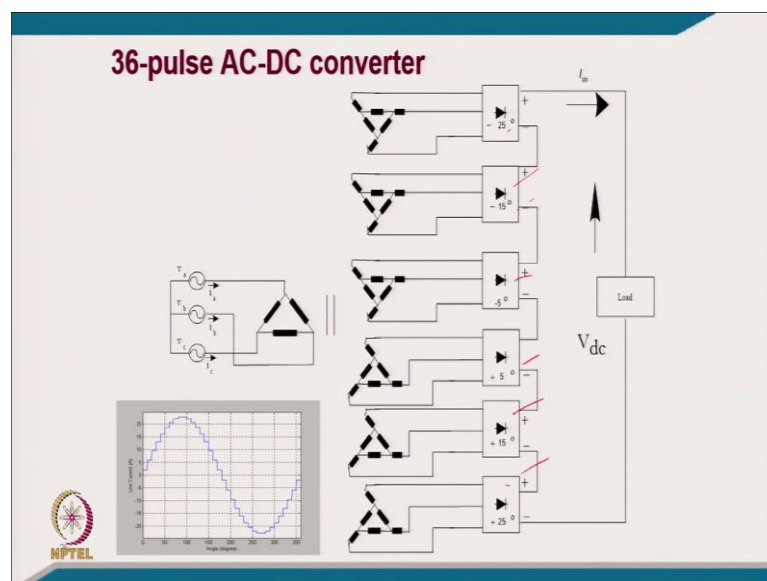
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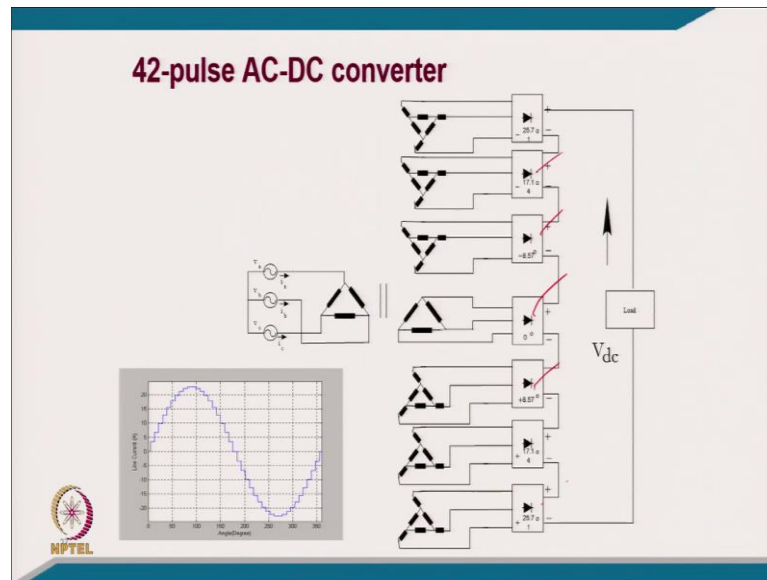
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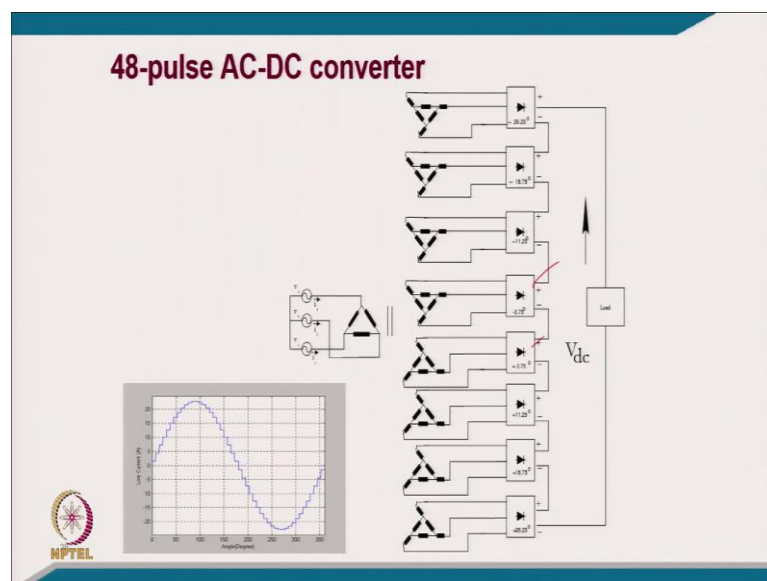
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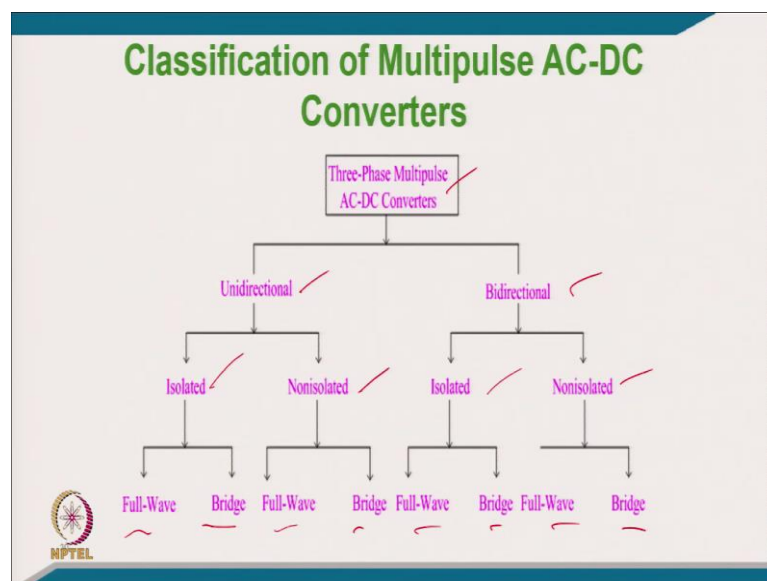
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### Performance Comparison of Different Multipulse AC-DC Converters at DC Load Current of 35.78 A

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

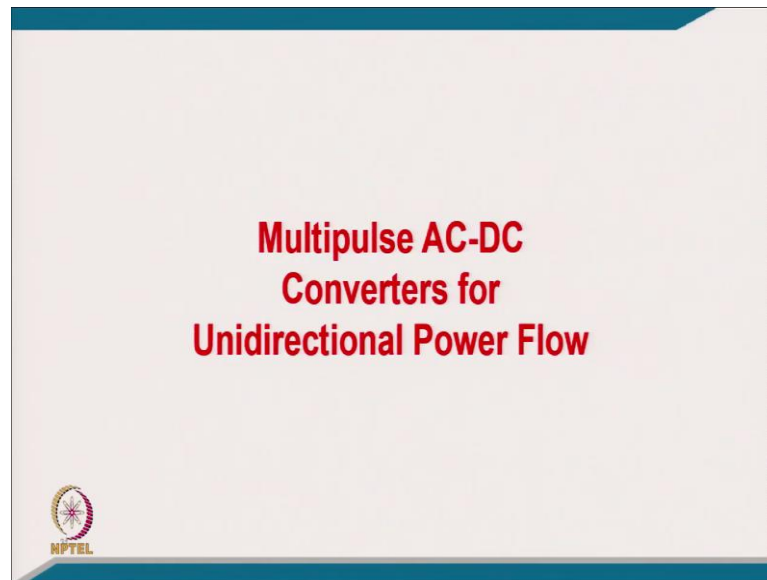


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This is the classification of multipulse AC-DC Converters.

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### Isolated Unidirectional Multipulse Full-Wave AC-DC Converters


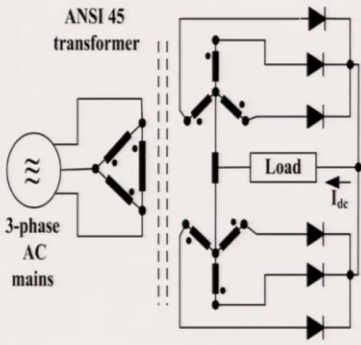
These are possible with different transformers connections as,

- Star Connection
- Zig-zag Connection
- T-Connection

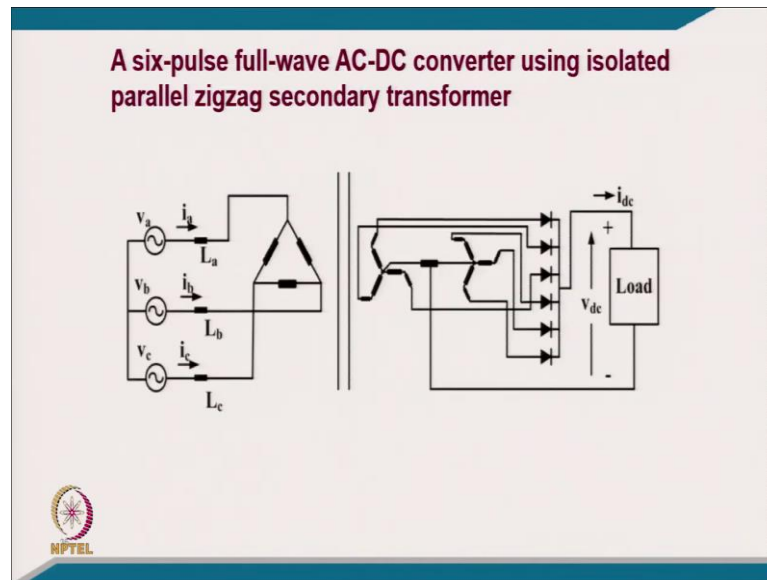


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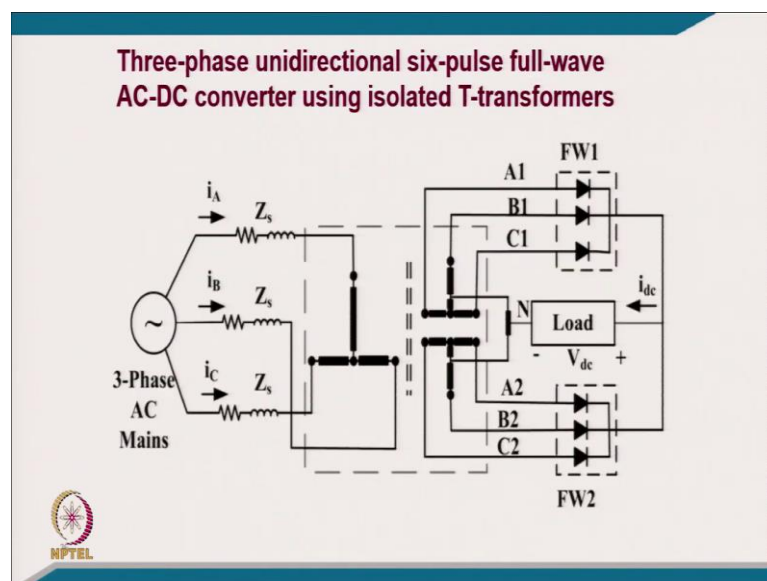
### An isolated six-pulse full-wave AC-DC converter employing delta/double-star transformer



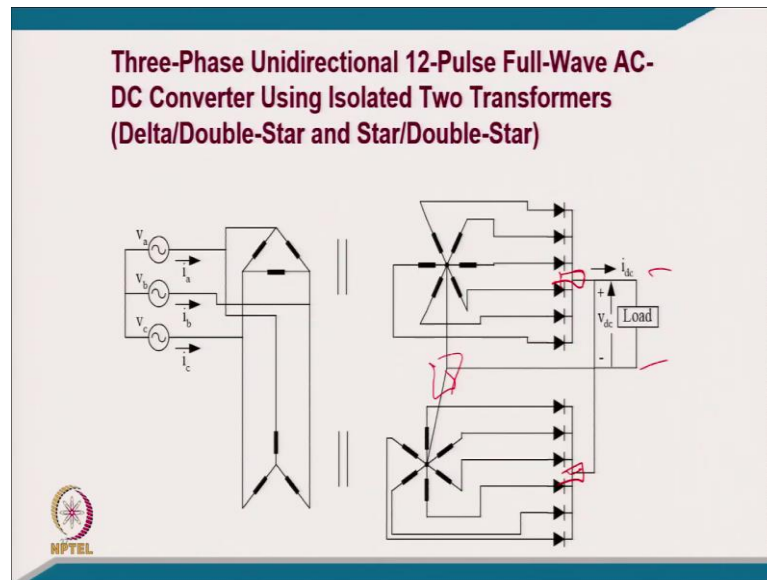
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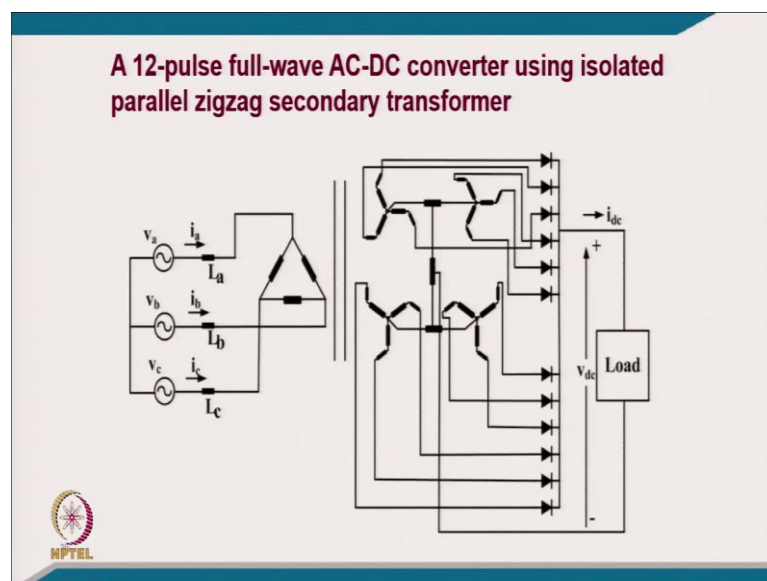
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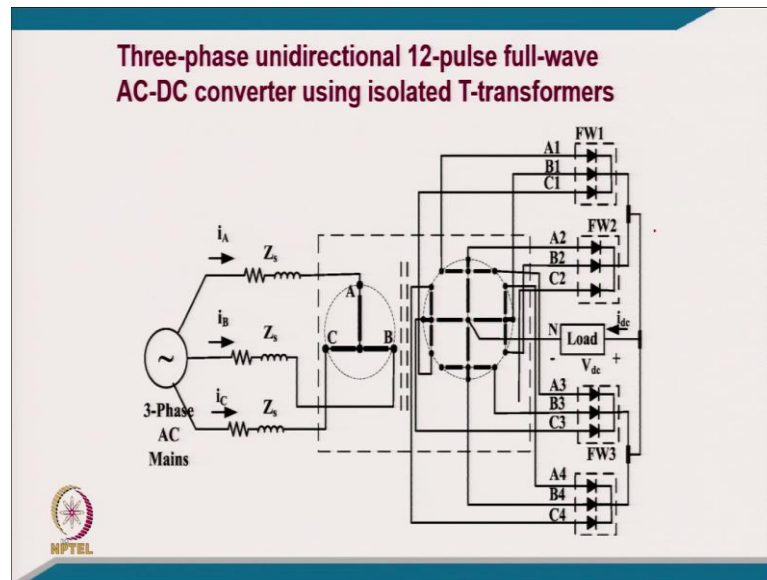
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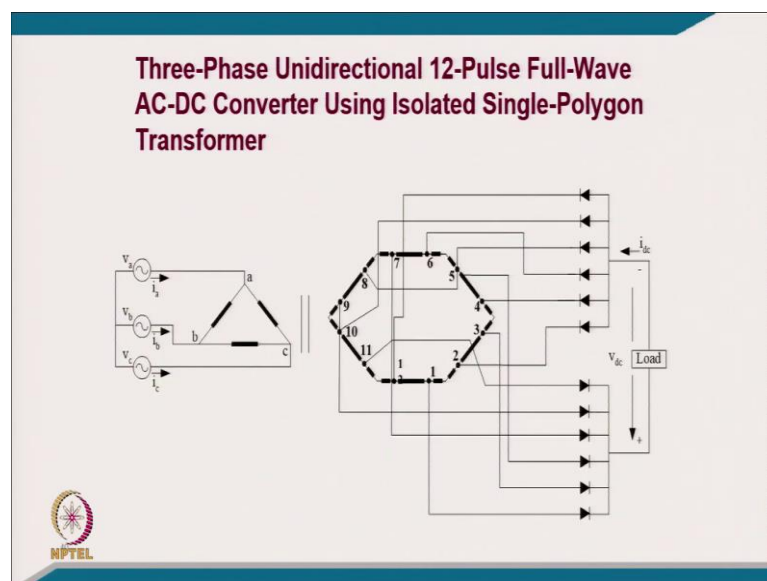
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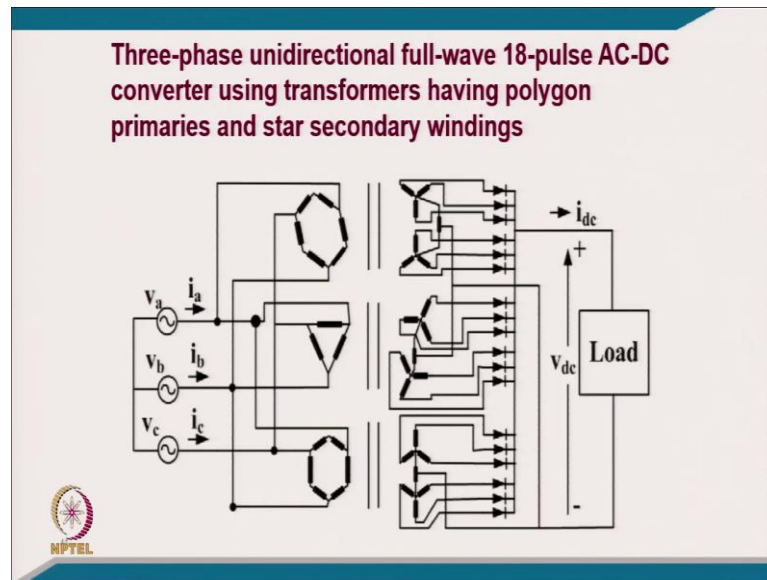
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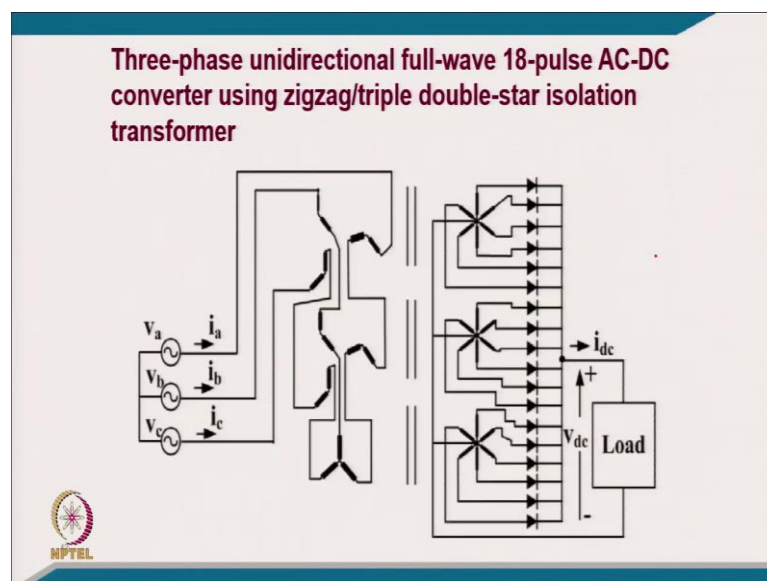
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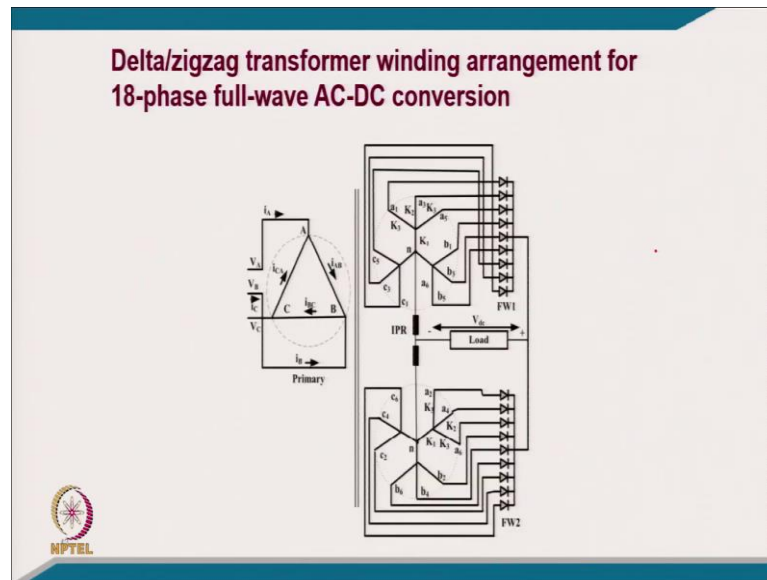
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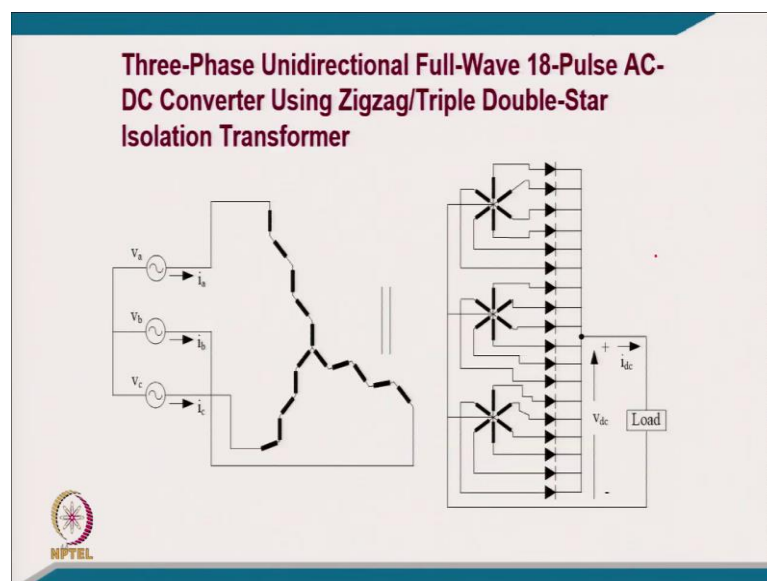
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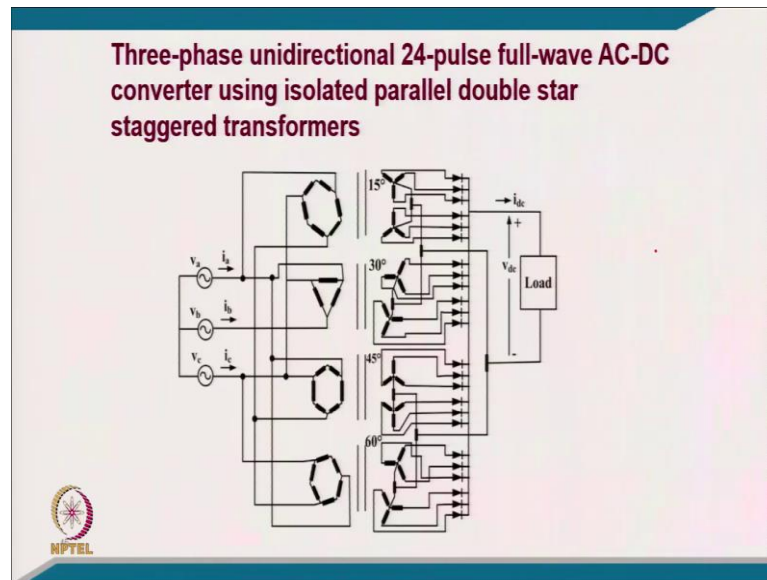
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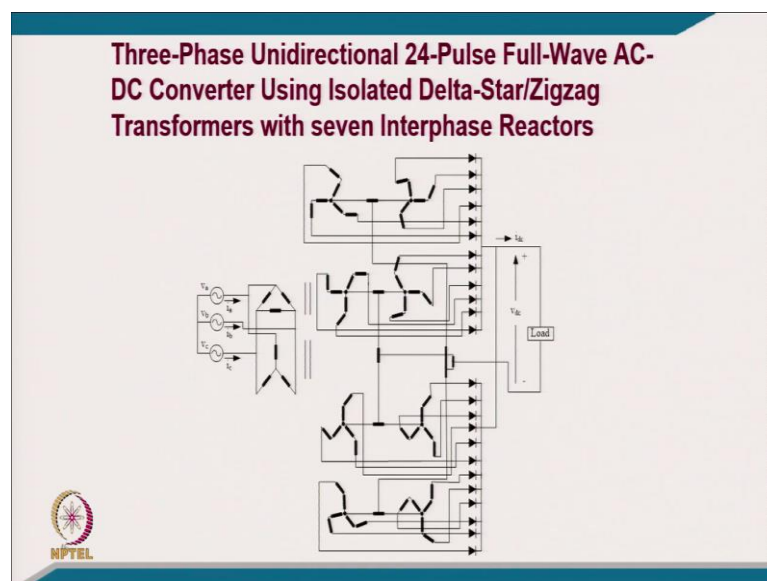
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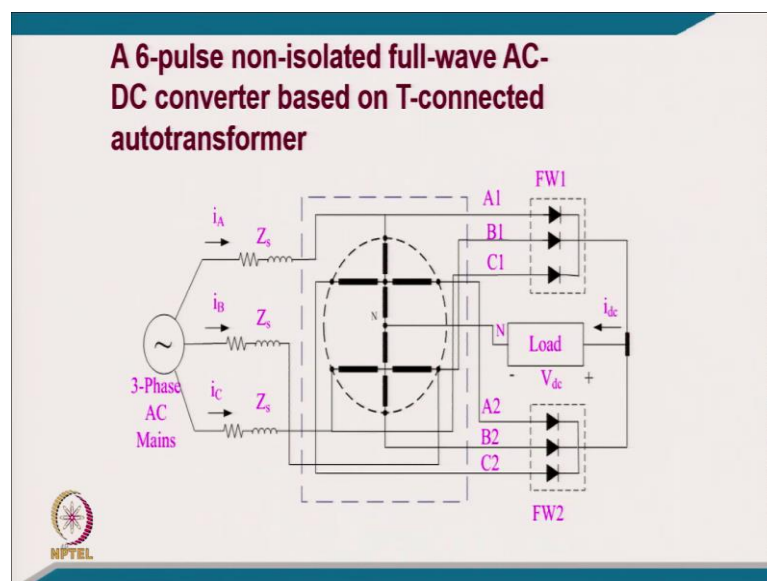
### Non-Isolated Unidirectional Multipulse Full-Wave AC-DC Converters

These are possible with the transformers connections with neutral terminal as,

- Star Connection
- Zig-zag Connection
- T-Connection
- Scott Connection

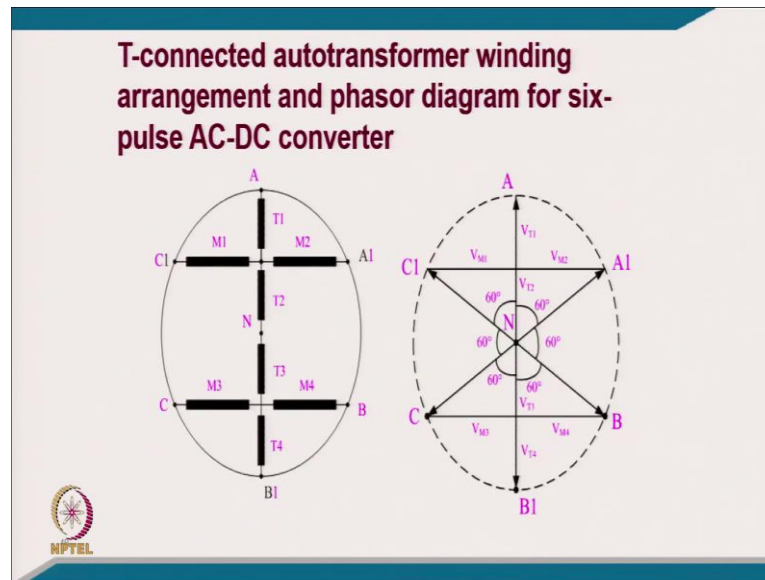


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### Design of T-connected transformer for six-pulse AC-DC converter

- The T-connected transformer for six-pulse AC-DC converter is made up of two single-phase transformers, M (main) and T (teaser) connected orthogonally on primary and provides a neutral point.
- The transformer T has four windings (connected vertically) while the transformer M has four windings (connected horizontally).
- The voltages of these windings in terms of the supply phase voltage  $V_A$  can be determined as:  
$$V_{T1} = V_A (1 - \cos 60^\circ) = 0.5 V_A$$
$$V_{T2} = V_A \cos 60^\circ = 0.5 V_A$$

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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:

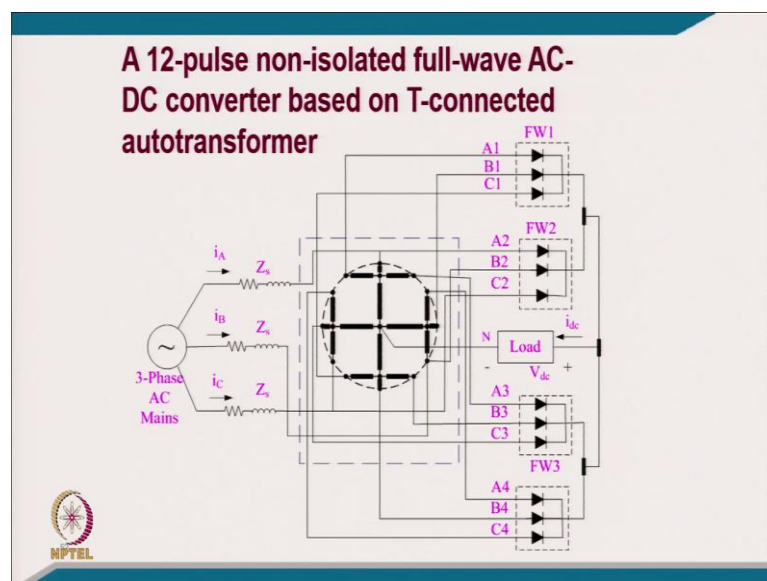
**12-Pulse converter:**  $K_1=0.07735$ ;  $K_2=0.5$ ;  $K_3=0.2886$ ;

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

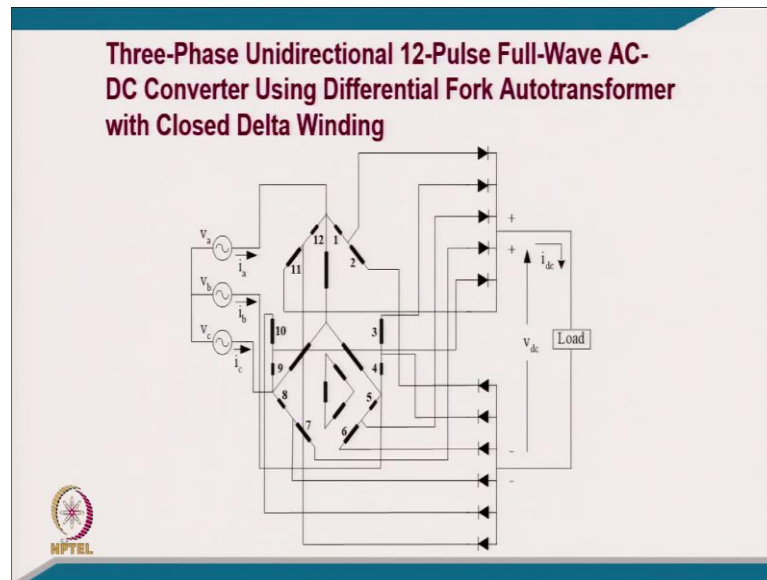
**24-Pulse converter:**  $K_{31}=0.0114$ ;  $K_{32}=0.0333$ ;  
 $K_{33}=0.0529$ ;  $K_{34}=0.2356$ ;  $K_{35}=0.1666$ ;  $K_{36}=0.0863$ ;  
 $K_{37}=0.2357$ ;  $K_{38}=0.2886$



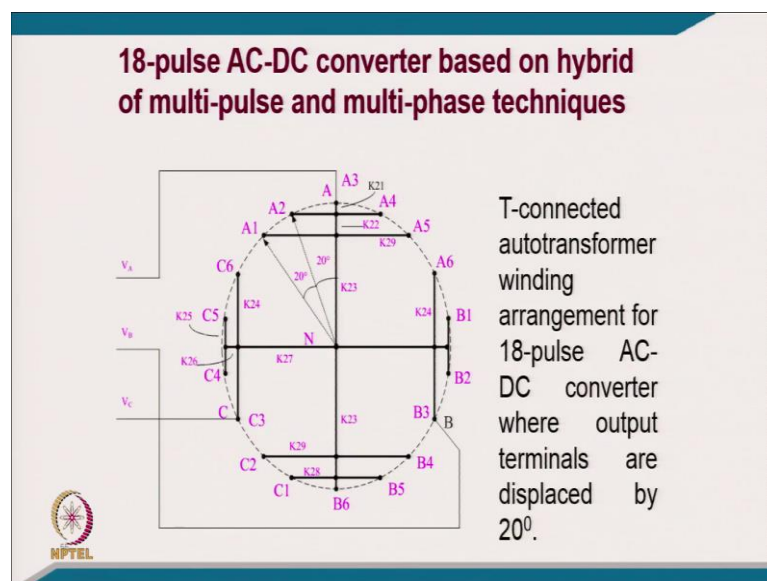
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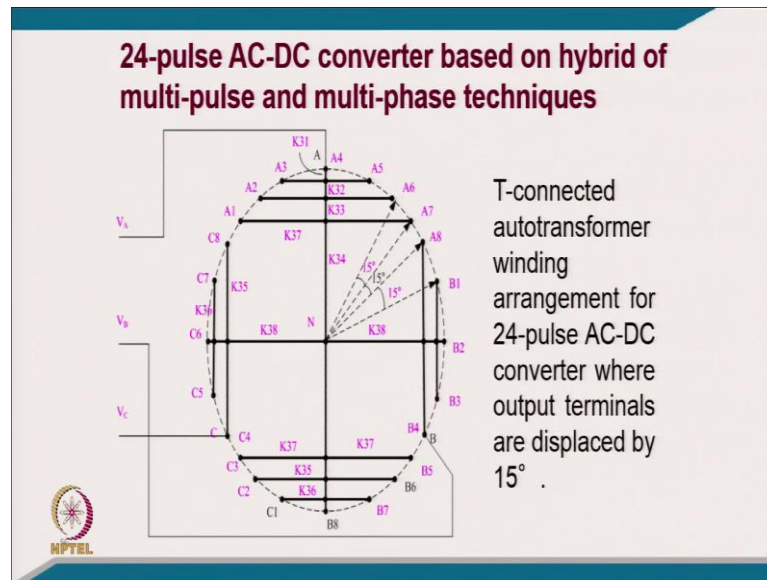
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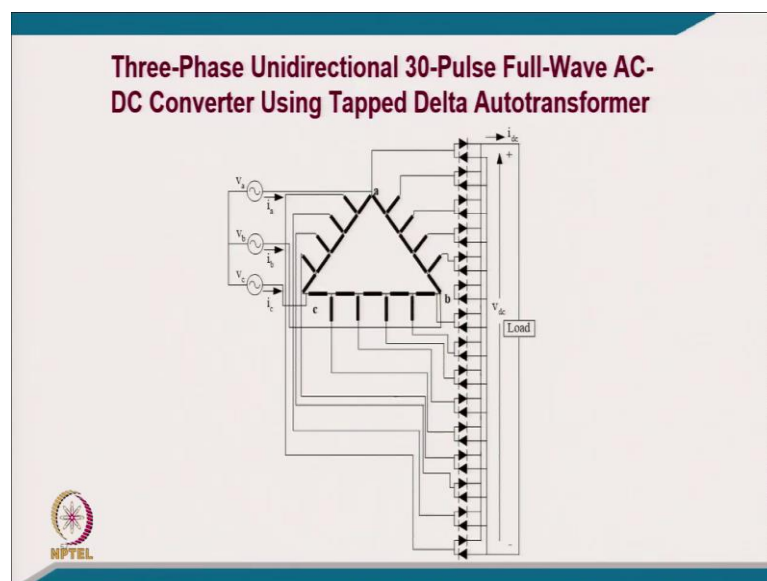
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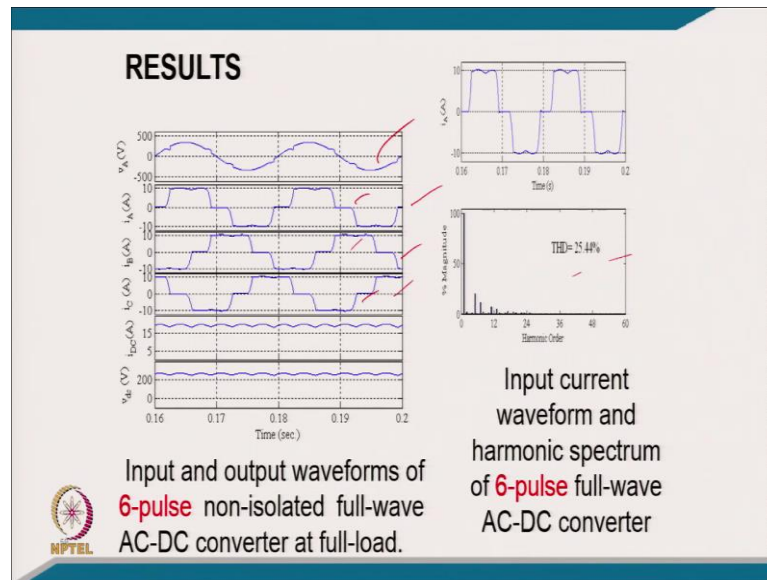
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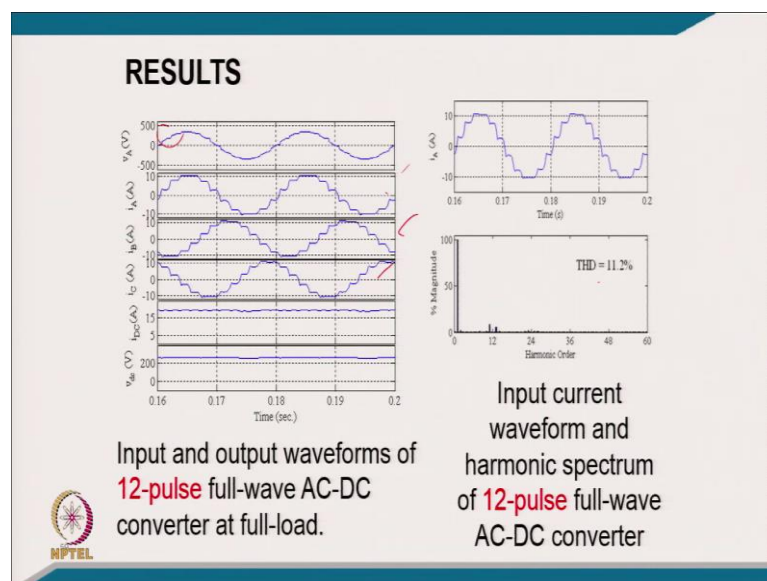
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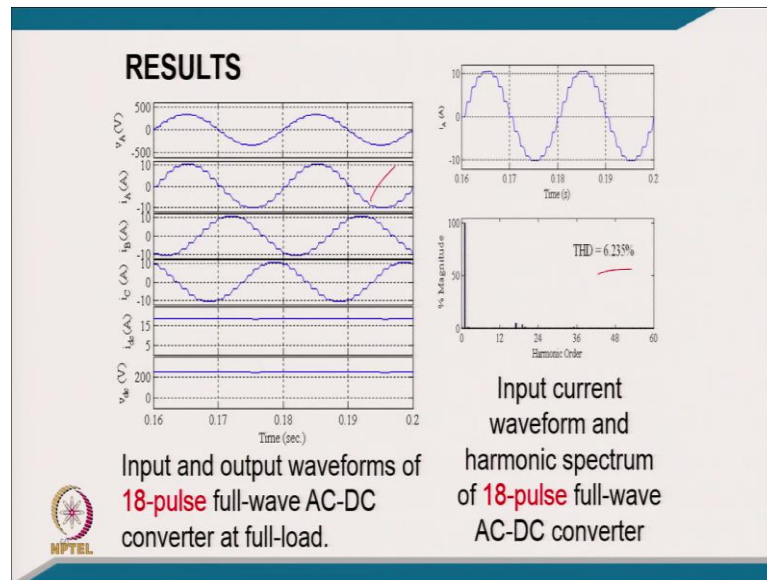
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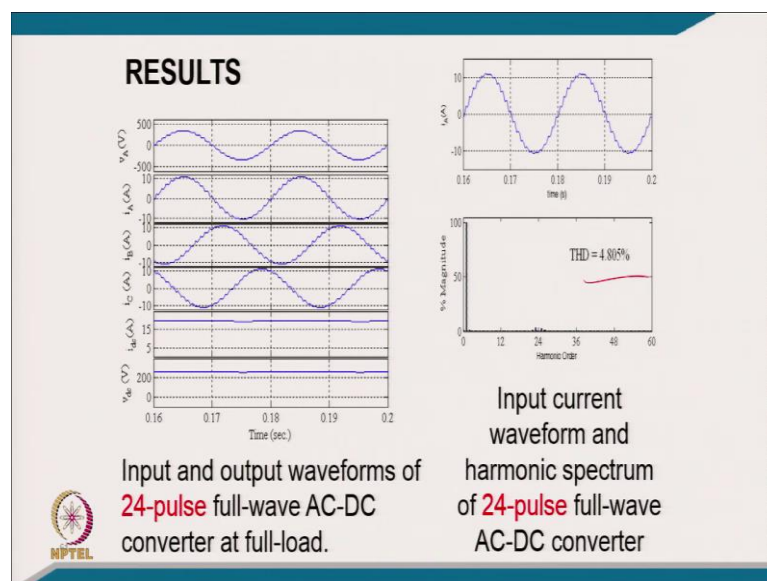
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### Power quality parameters of T-connected non-isolated six-pulse full-wave AC-DC converters

Topology	Input Power, % Full-Load	%THD of $V_s$	AC Mains Current $I_k$ (A)	% THD of $I_o$	Distortion Factor, DF	Displacement Factor DPF	Power Factor, PF	DC Voltage ( $V_{dc}$ )	Load Current $I_o$ (A)	RF
6-pulse	20	<b>2.05</b>	1.675	28.67	0.9611	0.9989	0.960	278.5	4.09	4.43
	40	<b>3.42</b>	3.288	27.68	0.9632	0.9958	0.959	273.4	8.09	4.00
	50	<b>4.01</b>	4.077	27.24	0.964	0.9943	0.958	271.9	10.06	3.74
	60	<b>4.57</b>	4.857	26.83	0.9648	0.9929	0.958	270.5	12.0	3.49
	80	<b>5.58</b>	6.387	26.09	0.9661	0.9904	0.956	267.5	15.83	3.04
	100	<b>6.49</b>	7.879	25.44	0.9671	0.9881	0.955	264.7	19.58	2.69




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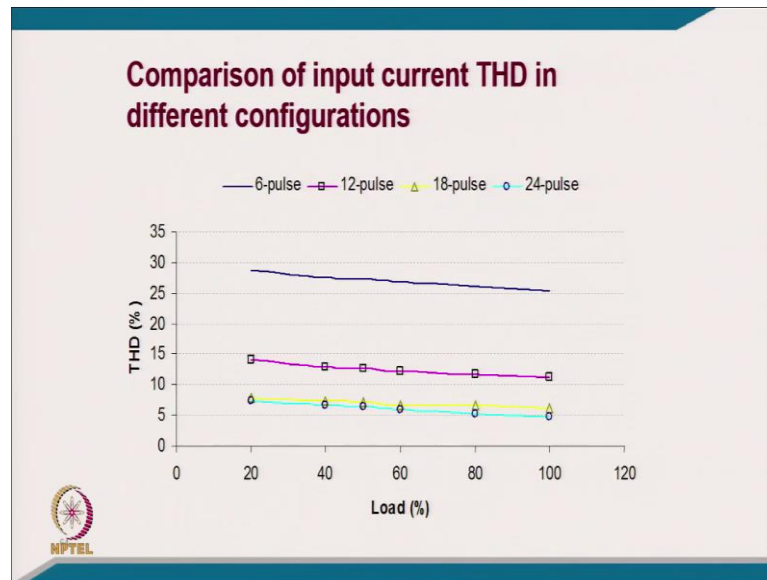
### Comparison of power quality parameters of the T-connected non-isolated full-wave AC-DC converters

Sr. No.	Topology	% THD of $V_s$		AC Mains Current $I_k$ (A)		% THD of $I_o$		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	Light Load	Full Load
		1	A*	4.24	1.647	7.815	7.815	27.58	24.09	0.9825	0.9712	0.9945	0.9771	0.9586	0.949
2	6-pulse	6.49	1.675	7.879	7.879	28.67	25.44	0.9611	0.9671	0.9689	0.9881	0.9601	0.9556	276.5	264.7
3	12-pulse	4.97	1.621	7.55	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	7.394	8.235	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	7.605	7.458	4.805	0.9971	0.9982	0.9938	0.9968	0.991	0.988	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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## Multipulse AC-DC Converters for Unidirectional Power Flow

Unidirectional Multipulse Bridge AC-DC converters




(Refer Slide Time: 42:59)

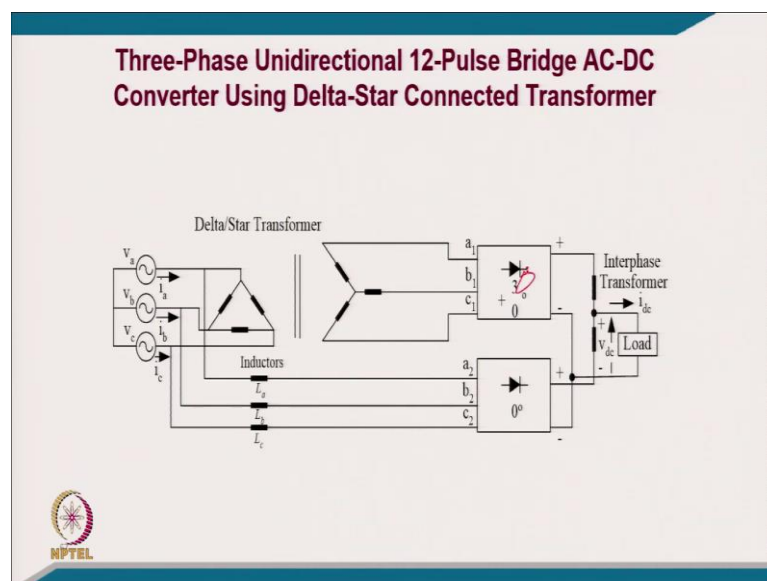
### Isolated Unidirectional Multipulse Bridge AC-DC Converters

These are possible with different transformers connections as,

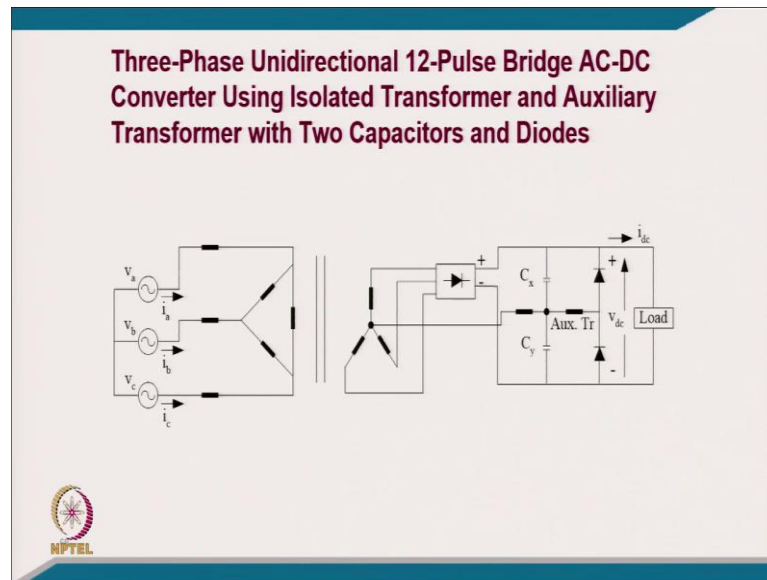
- Delta Star Connection
- Scott Connection
- Polygon



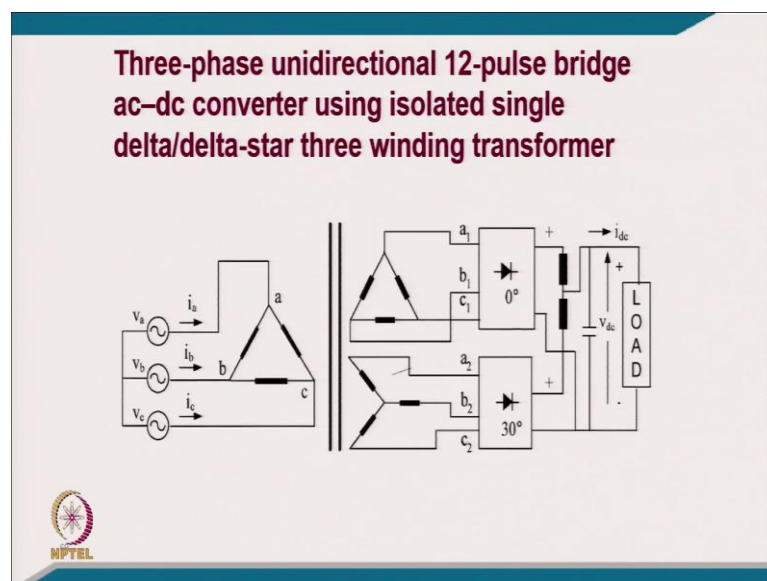
(Refer Slide Time: 43:09)



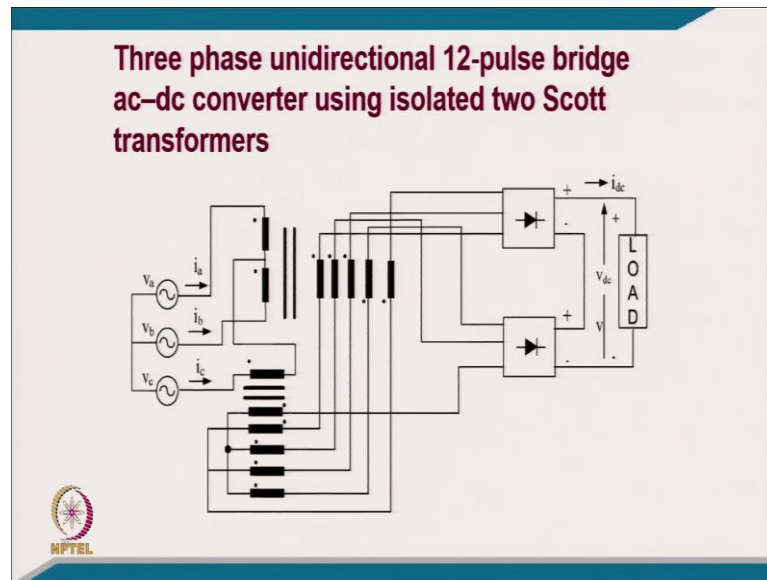
(Refer Slide Time: 43:25)



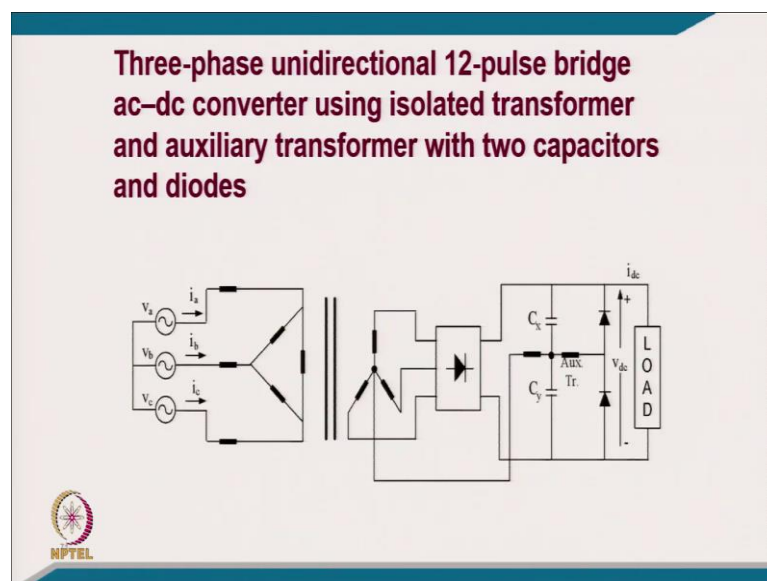
(Refer Slide Time: 43:35)



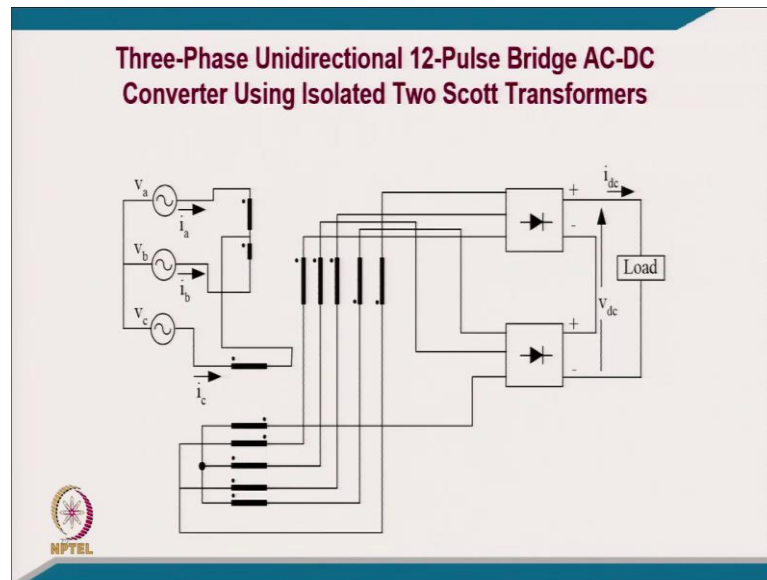
(Refer Slide Time: 44:01)



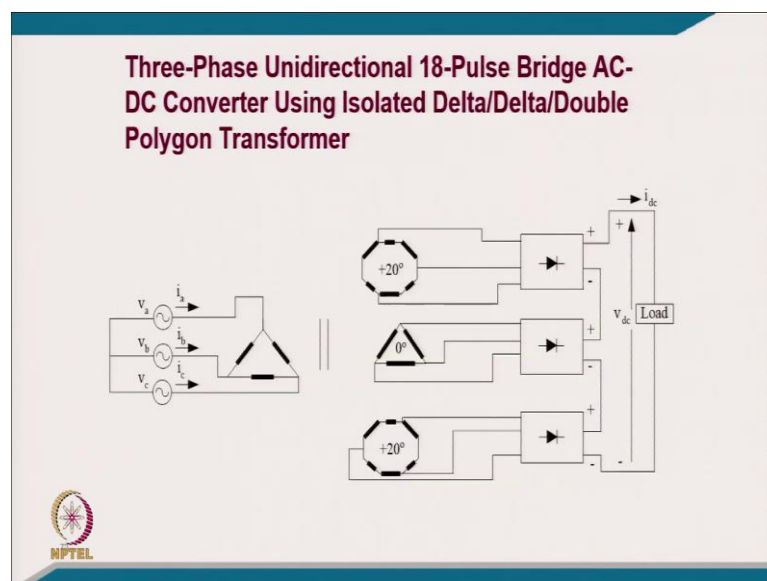
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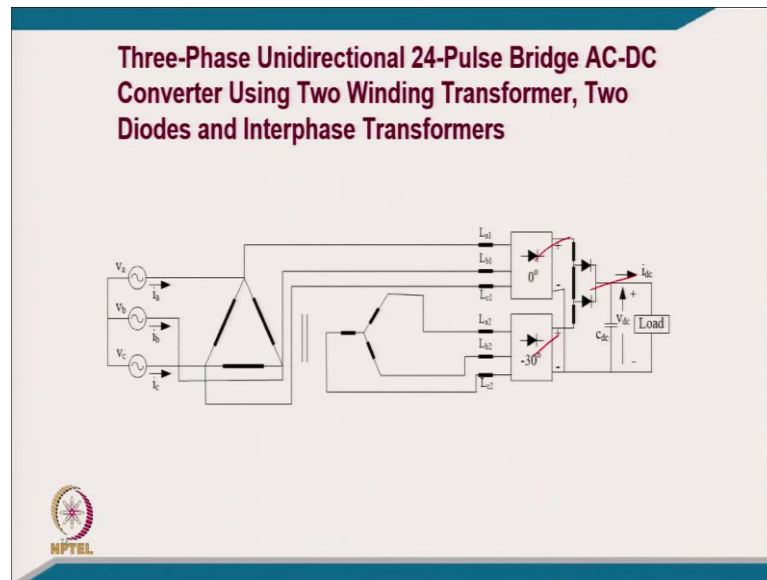
(Refer Slide Time: 44:20)



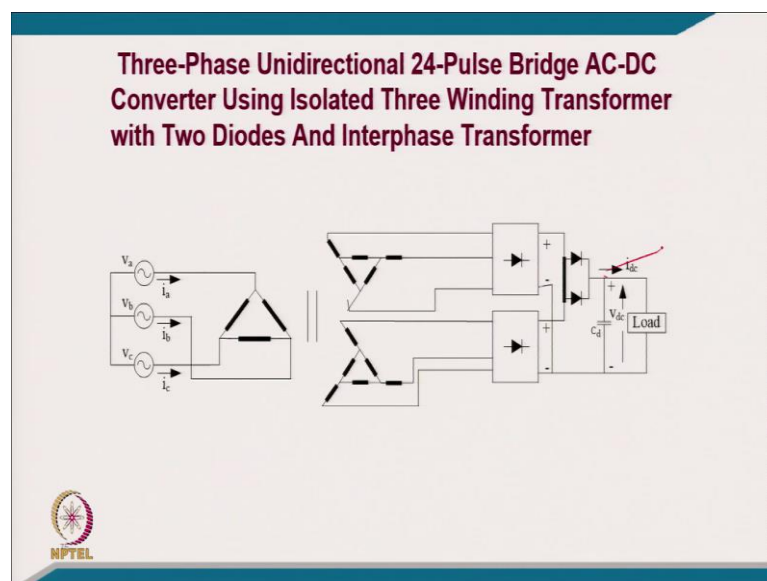
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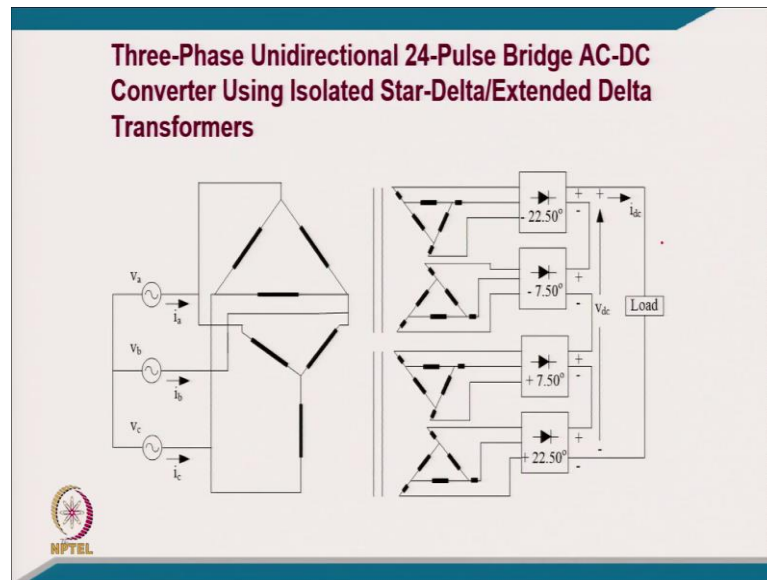
(Refer Slide Time: 44:48)



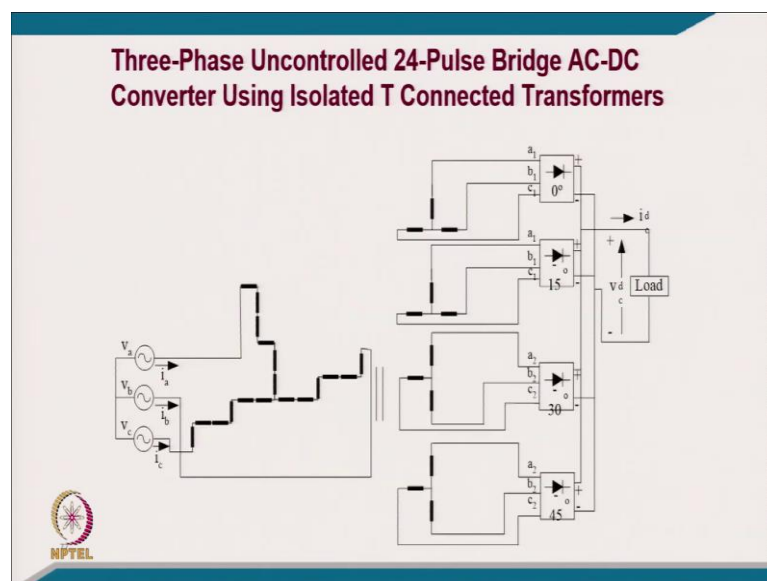
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(Refer Slide Time: 46:07)



**Non-Isolated Unidirectional Multipulse Bridge AC-DC Converters**


**Autotransformer Connection Based Configurations**

- Star Connected Autotransformer
- Delta Connected Autotransformer
- Polygon Connected Autotransformer
- Delta-Polygon Connected Autotransformer
- Hexagon Connected Autotransformer
- T- Connected Autotransformer
- Zigzag Autotransformer

**Phase Number Based Configurations**

- Nine-Phase AC-DC Converters
- Fifteen-Phase AC-DC Converters

(Refer Slide Time: 46:59)

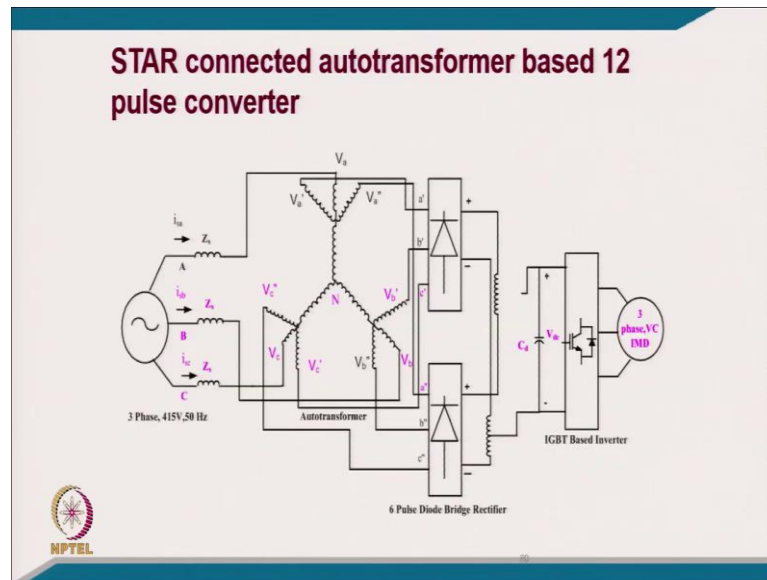


**Realization of 12 pulse converter**

**Conventional wye delta transformer**

- Large kVA rating of transformer
- More cost
- Difficult to make identical wye and delta windings

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(Refer Slide Time: 48:02)

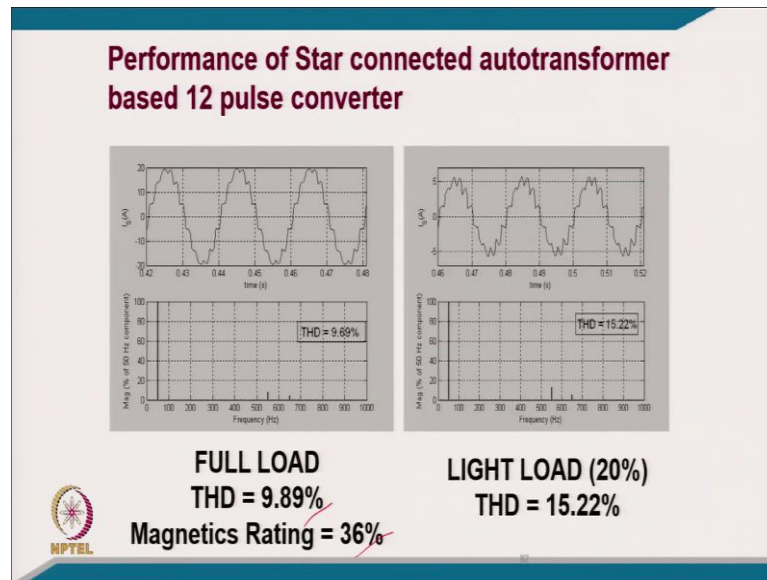
### Modeling and design of Multipulse AC-DC converters

- Twelve-Pulse Converters Based on  $+15^\circ$  and  $-15^\circ$  Phase Shift
- Star Connected Autotransformer
- $V_{a'} = K_1 * V_a - K_2 * V_b$
- $V_{a''} = K_1 * V_a - K_2 * V_c$
- $V_a = V \angle 0^\circ, V_b = V \angle -120^\circ, V_c = V \angle 120^\circ$
- $V_{a'} = V \angle +15^\circ, V_{b'} = V \angle -105^\circ, V_{c'} = V \angle 135^\circ$
- $V_{a''} = 0.816 V_a - 0.298 V_b$
- $V_{a''} = 0.816 V_a - 0.298 V_c$

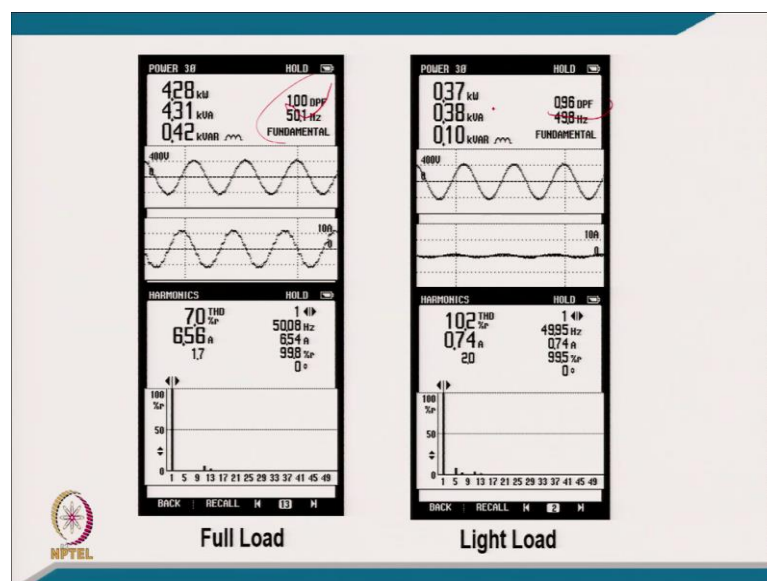
NPTEL



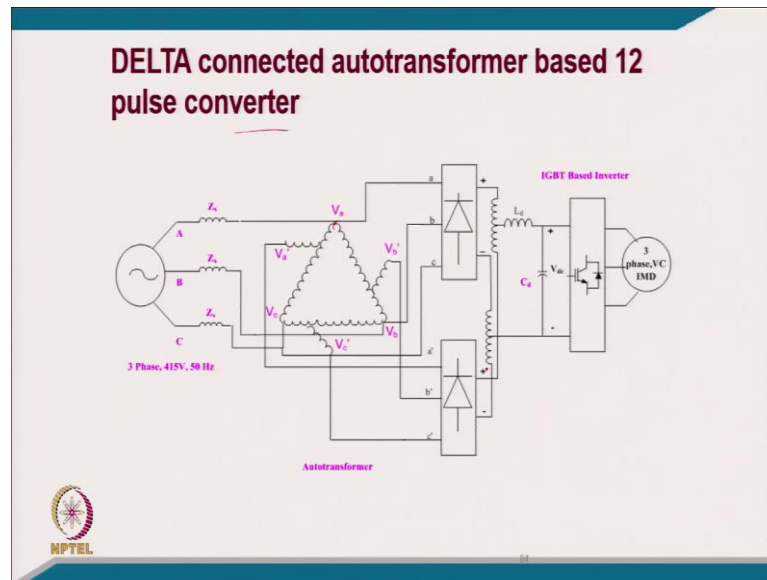
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(Refer Slide Time: 49:17)



(Refer Slide Time: 49:31)

### DELTA connected Twelve-Pulse Converters Based on $+0^\circ$ and $30^\circ$ Phase Shift

Design of Autotransformer

$$V_a' = V_a + K_1 V_{ca} + K_2 V_{bc}$$

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

$$V_a' = V \angle +30^\circ, V_b' = V \angle -90^\circ, V_c' = V \angle 150^\circ$$

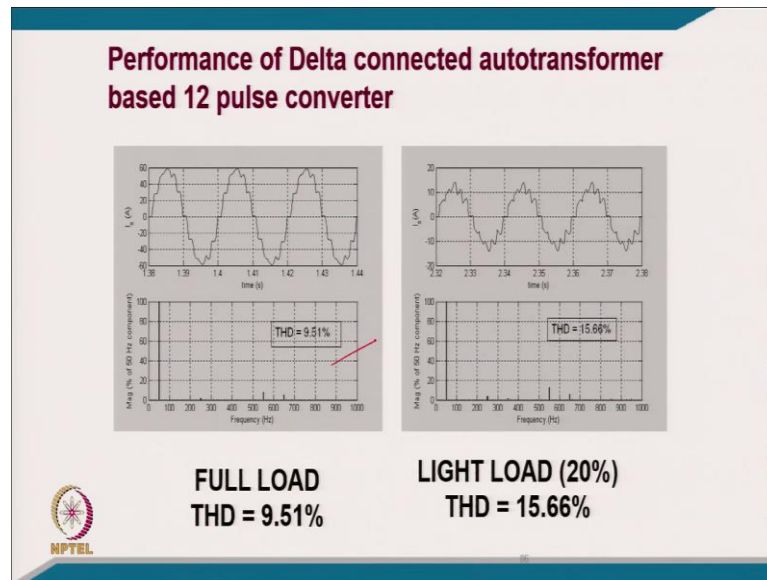
$$K_1 = 0.0843$$

$$K_2 = 0.229$$

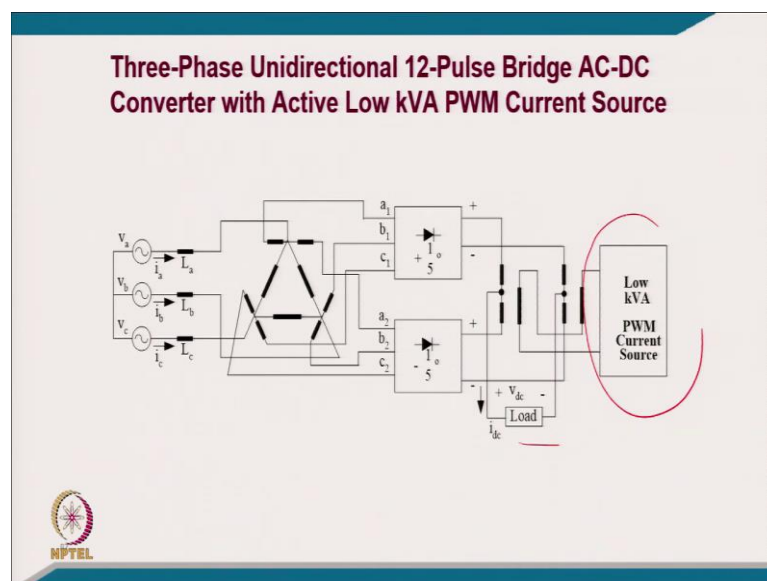
$$V_a' = V_a + 0.0843 V_{bc} + 0.229 V_{ca}$$

NPTEL

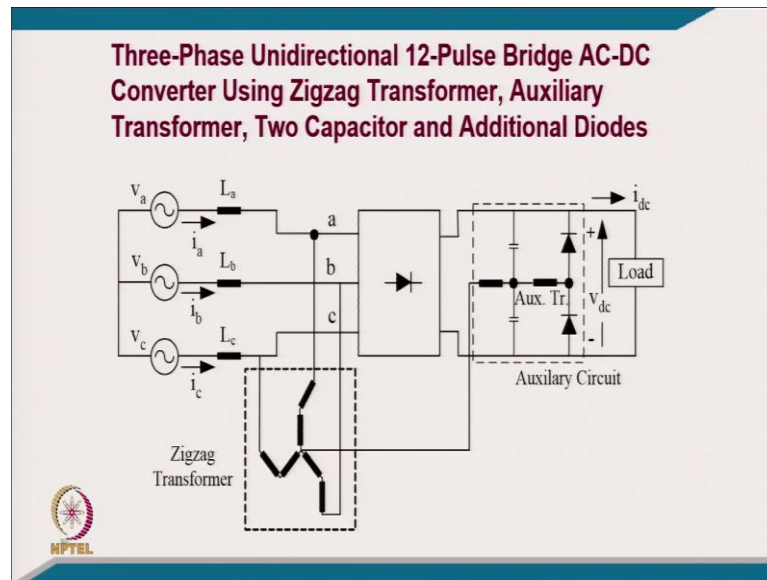
(Refer Slide Time: 49:41)



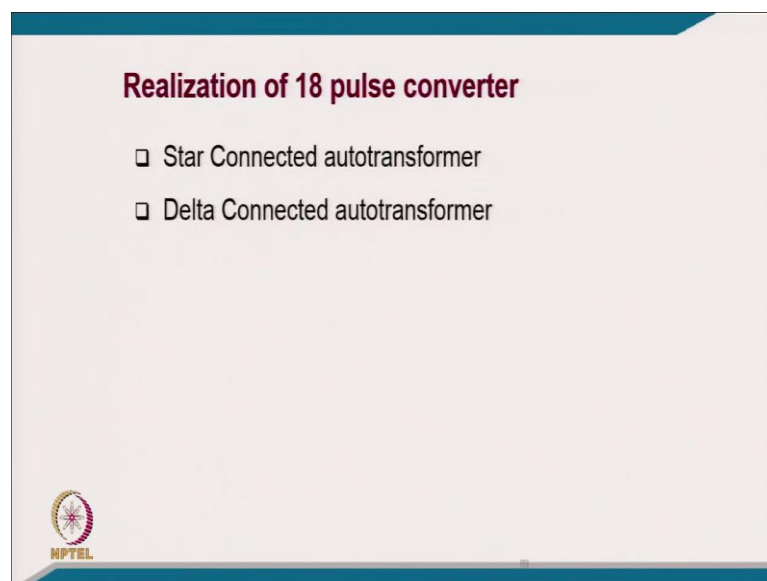
(Refer Slide Time: 49:49)



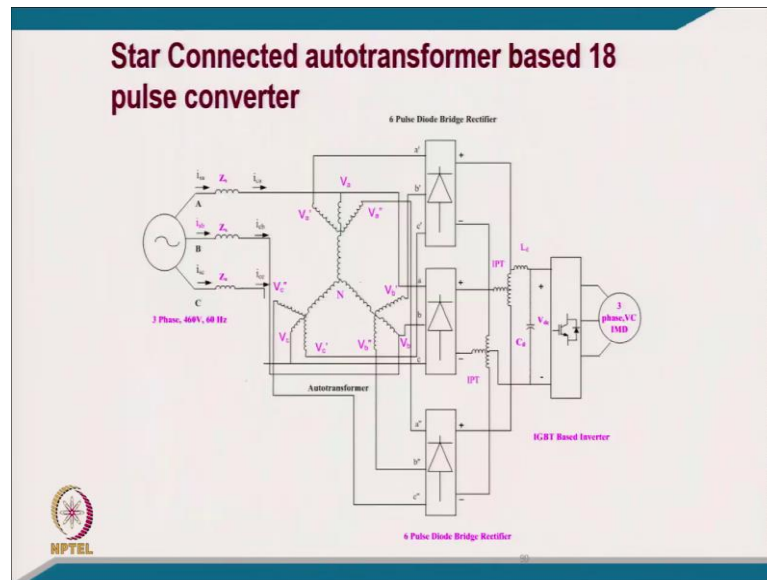
(Refer Slide Time: 50:05)



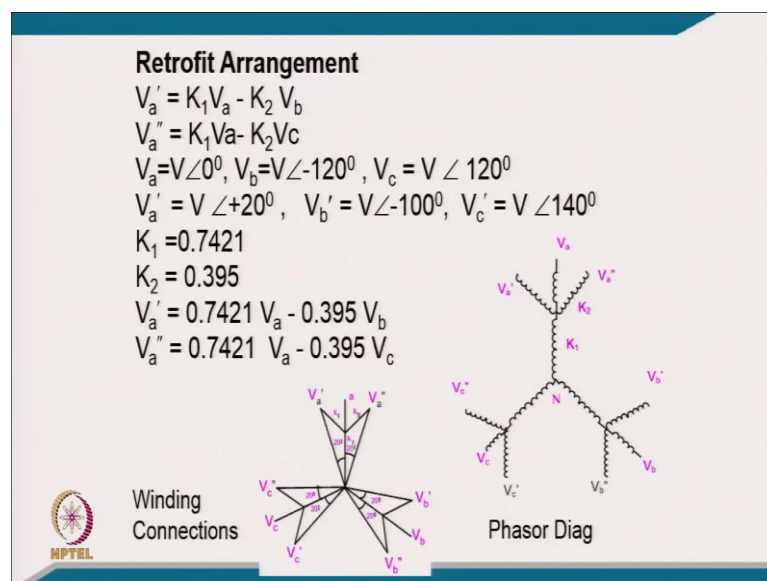
(Refer Slide Time: 50:19)



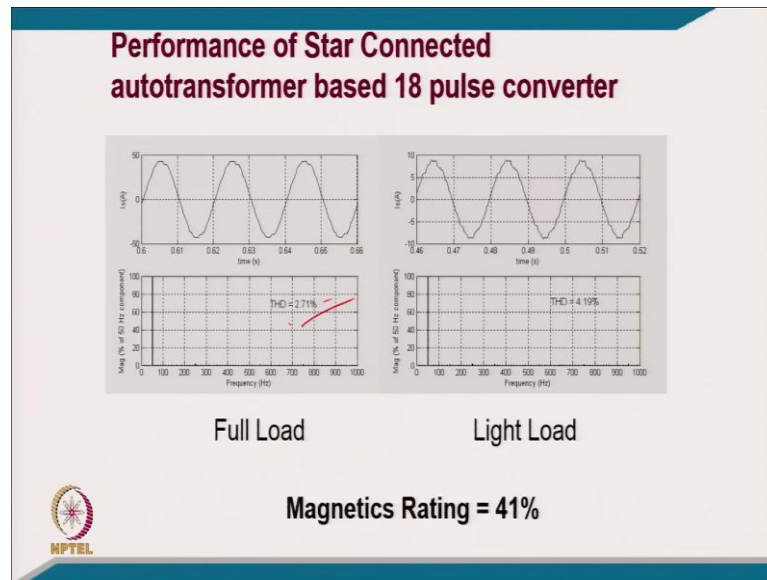
(Refer Slide Time: 50:21)



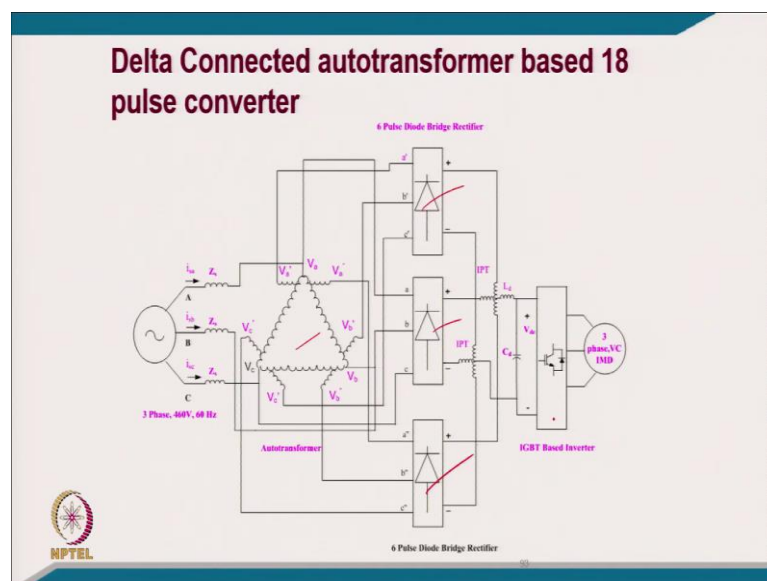
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(Refer Slide Time: 51:01)



(Refer Slide Time: 51:22)



(Refer Slide Time: 51:44)

### Delta Connected autotransformer based 18 pulse converter

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

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

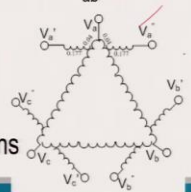
$$V_a = V \angle 0^\circ, V_b = V \angle -120^\circ, V_c = V \angle 120^\circ$$

$$V_a' = V \angle +20^\circ, V_b' = V \angle -100^\circ, V_c' = V \angle 140^\circ$$

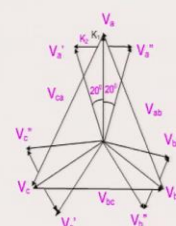
$$K_1 = 0.0402, K_2 = 0.177$$

$$V_a' = V_a + 0.0402 V_{ca} - 0.177 V_{bc}$$

$$V_a'' = V_a + 0.0402 V_{ab} + 0.177 V_{bc}$$



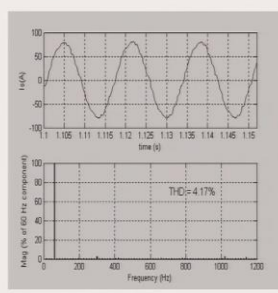
Winding Connections



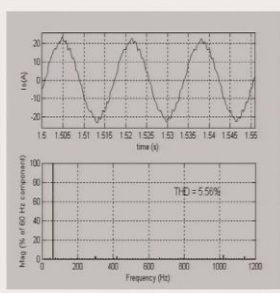
Phasor diagram

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### Performance of Delta Connected autotransformer based 18 pulse converter



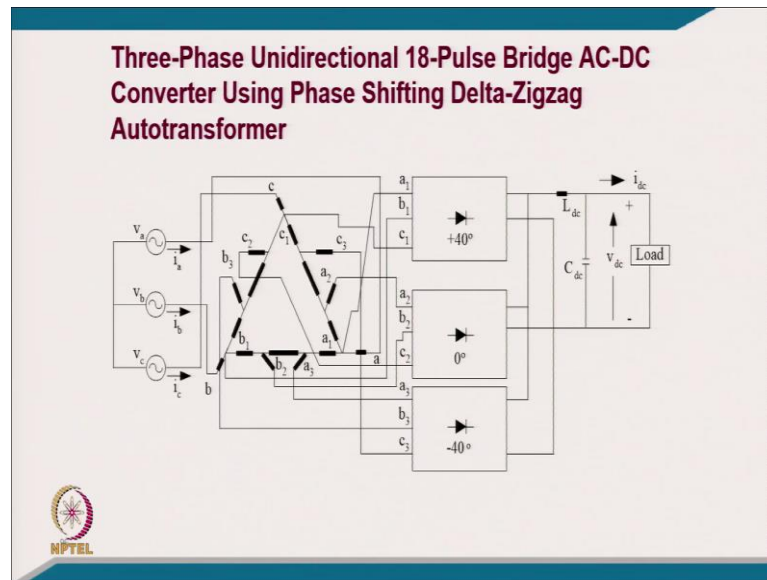
Full Load



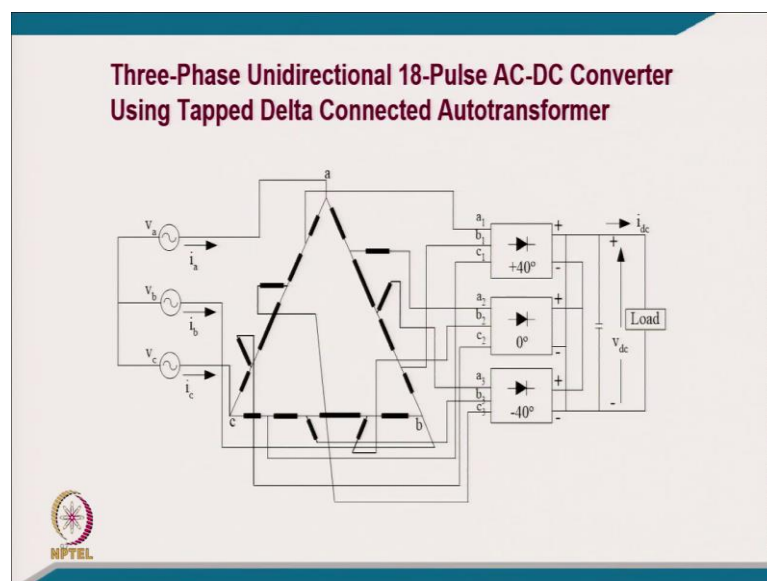
Light Load

Magnetics Rating = 22.55%

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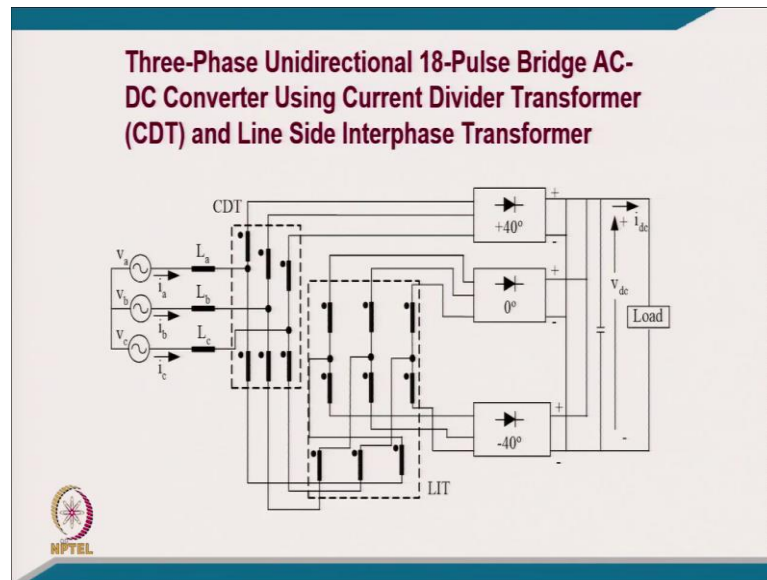


(Refer Slide Time: 53:05)

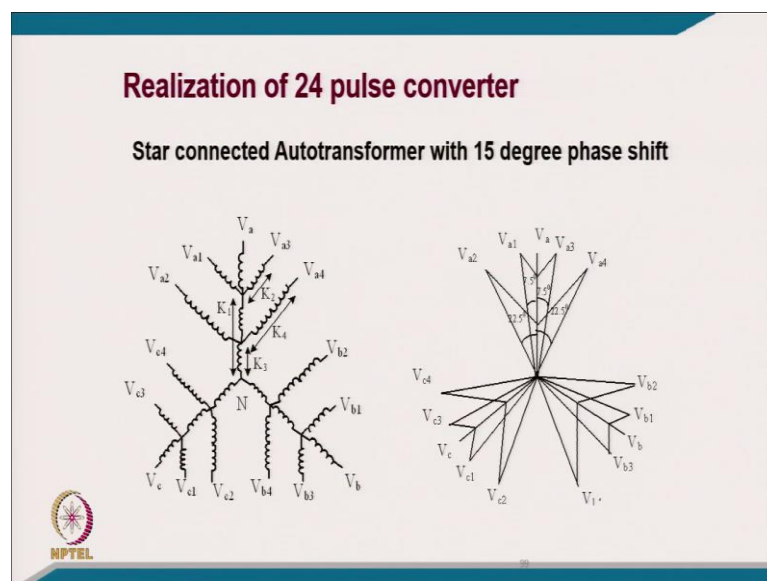




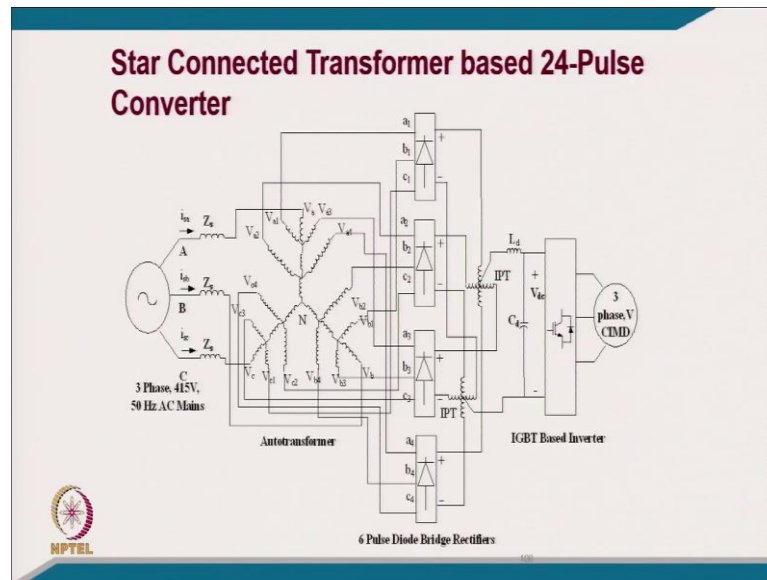
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$$\begin{aligned}
 V_{a1} &= K_1 V_a \angle 0^\circ - K_2 V_b \angle -120^\circ \\
 V_{a2} &= K_3 V_a - K_4 V_b \angle -120^\circ \\
 V_{a3} &= K_1 V_a \angle 0^\circ - K_2 V_c \angle 120^\circ \\
 V_{a4} &= K_3 V_a \angle 0^\circ - K_4 V_c \angle 120^\circ \\
 V_{a1} &= V \angle 7.5^\circ, \quad V_{b1} = V \angle -112.5^\circ, \quad V_{c1} = V \angle 127.5^\circ \\
 V_{a2} &= V \angle 22.5^\circ, \quad V_{b2} = V \angle -97.5^\circ, \quad V_{c2} = V \angle 122.5^\circ \\
 V_{a3} &= V \angle -7.5^\circ, \quad V_{b3} = V \angle -127.5^\circ, \quad V_{c3} = V \angle 112.5^\circ \\
 V_{a4} &= V \angle -22.5^\circ, \quad V_{b4} = V \angle -142.5^\circ, \quad V_{c4} = V \angle 97.5^\circ \\
 K_1 &= 0.916, \quad K_2 = 0.15069, \\
 K_3 &= 0.7028 \text{ and } K_4 = 0.44189
 \end{aligned}$$

NPTEL

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### Retrofit Arrangement

$$K_1' = 0.8824, K_2' = 0.1451, K_3' = 0.677, K_4' = 0.4256$$

$$V_{a1}' = 0.916V_{a2}' = 0.7028V_a \angle 0^\circ - 0.44189V_b \angle -120^\circ$$

$$V_a \angle 0^\circ - 0.15069V_b \angle -120^\circ$$

$$V_{a3}' = 0.916V_a \angle 0^\circ - 0.15069V_c \angle 120^\circ$$

$$V_{a4}' = 0.7028V_a \angle 0^\circ - 0.44189V_c \angle 120^\circ$$

NPTEL

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### Performance of Star connected Transformer based 24-Pulse Converter

**Full Load**

**Light Load**

NPTEL

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### Nine-Phase AC-DC Converters


Delta Connected Autotransformer  
Phase shift =  $360^\circ / \text{Number of output phases}$

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

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

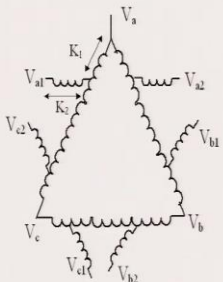
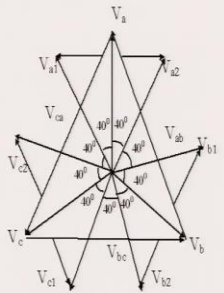
$$V_a = V \angle 0^\circ, V_b = V \angle -120^\circ, V_c = V \angle 120^\circ$$

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

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



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### Nine-Phase AC-DC Converters

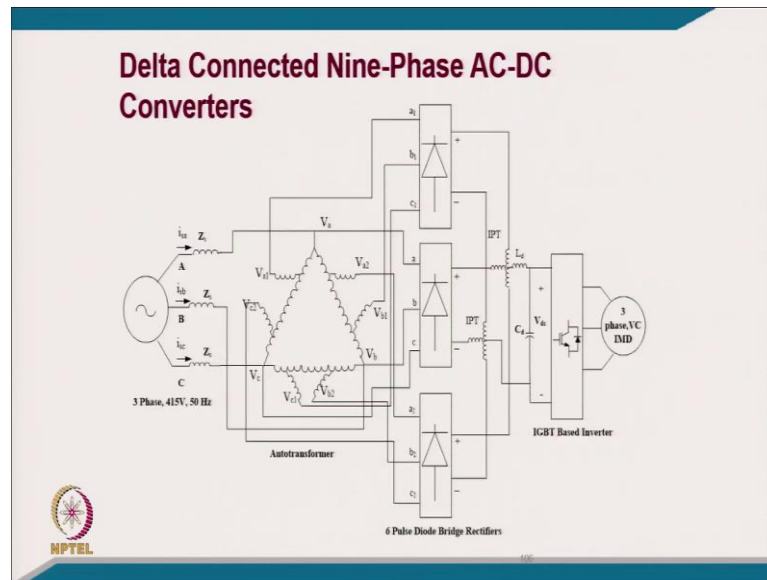



**$K_1 = 0.156, K_2 = 0.293$**

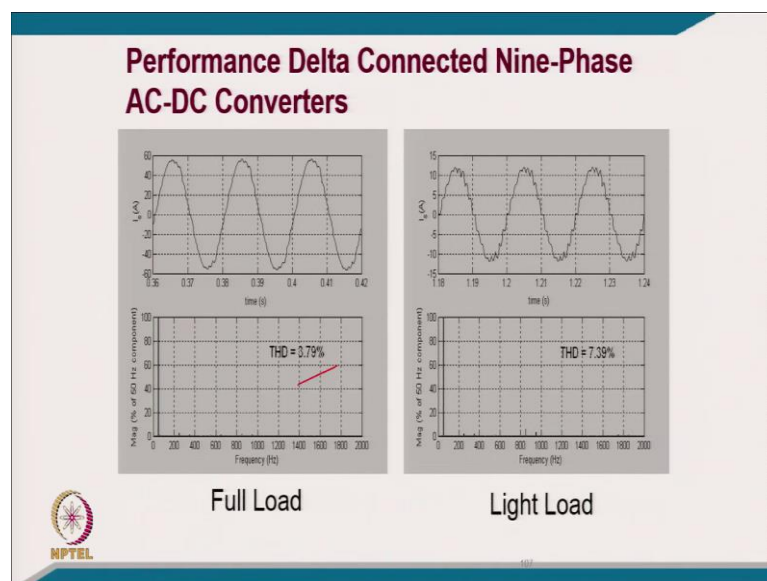
$$V_{a1} = V_a + 0.156 V_{ca} - 0.293 V_{bc}$$

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


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(Refer Slide Time: 55:55)



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### Fifteen-Phase AC-DC Converters

**Star Connected Autotransformer**

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

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

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

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

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

NPTEL

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### Fifteen-Phase AC-DC Converters

**Star Connected Autotransformer**

$$V_{a1} = V \angle 24^\circ, V_{b1} = V \angle -96^\circ, V_{c1} = V \angle 144^\circ$$

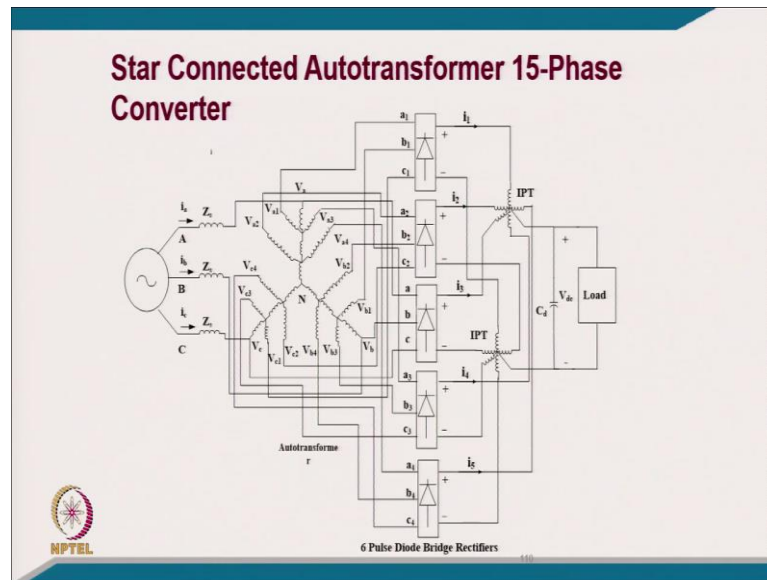
$$V_{a2} = V \angle 48^\circ, V_{b2} = V \angle -72^\circ, V_{c2} = V \angle 168^\circ$$

$$V_{a3} = V \angle -24^\circ, V_{b3} = V \angle -144^\circ, V_{c3} = V \angle 96^\circ$$

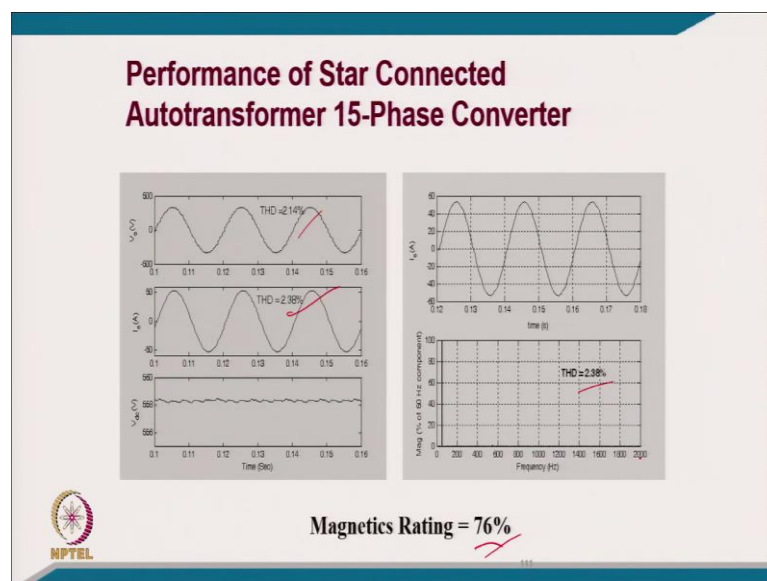
$$V_{a4} = V \angle -48^\circ, V_{b4} = V \angle -168^\circ, V_{c4} = V \angle 72^\circ$$

NPTEL

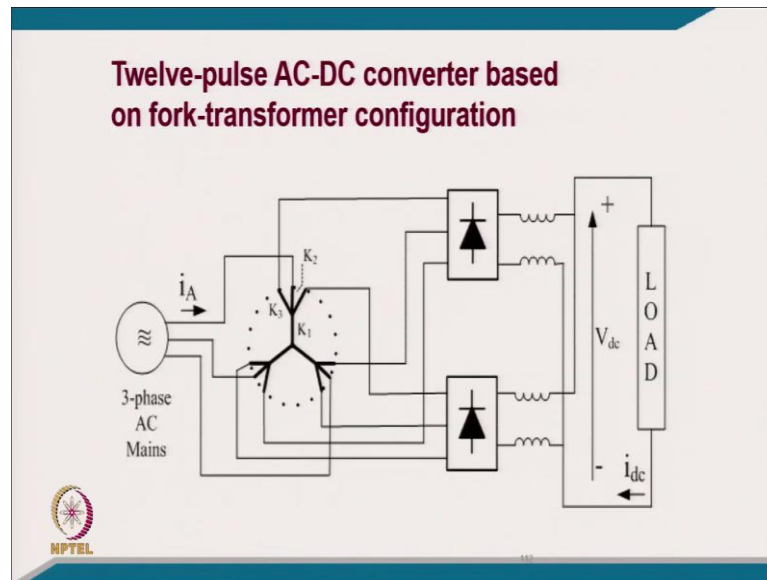
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(Refer Slide Time: 57:14)



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

$$V_a = V_s \angle 0^\circ, \quad V_b = V_s \angle -120^\circ, \quad V_c = V_s \angle 120^\circ$$
$$K_1 + K_2 = 1$$

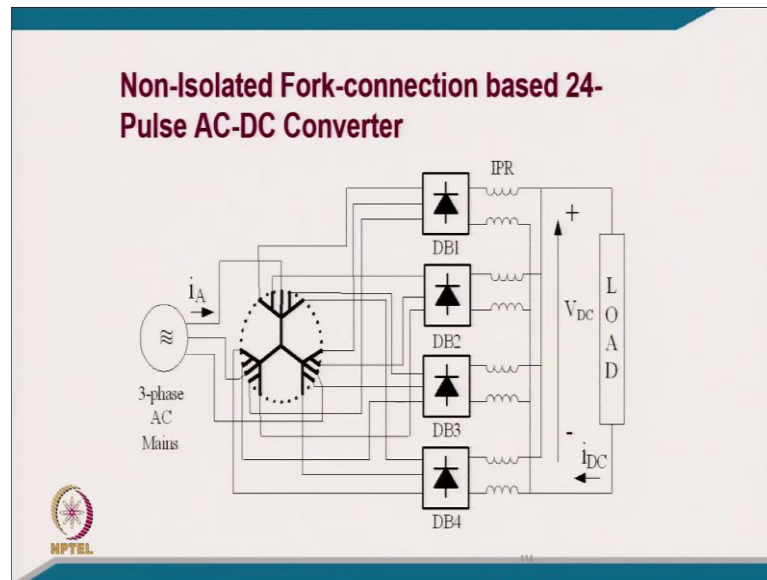
Output voltages of this configuration are expressed as

$$V_{a1} = K_1 V_a - K_3 V_b$$
$$V_{a2} = K_1 V_a - K_3 V_c$$
$$K_1 = 0.8165, \quad K_2 = 0.1835, \quad K_3 = 0.2988$$

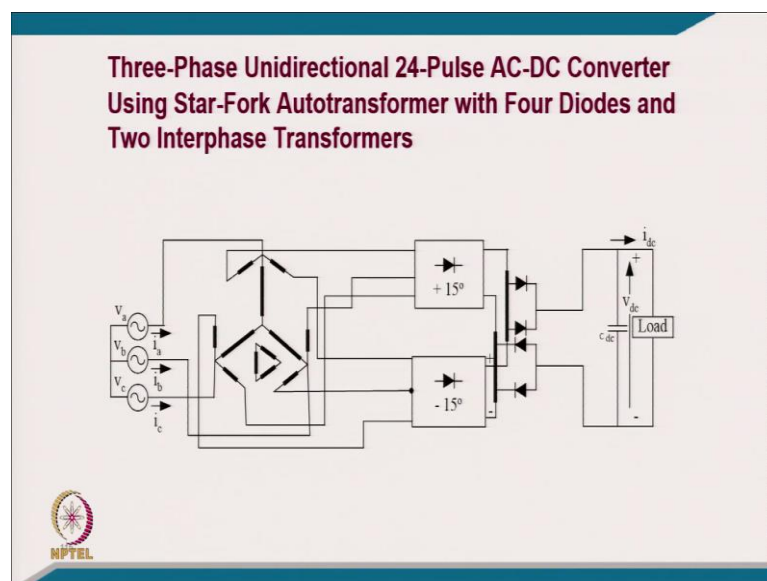
NPTEL



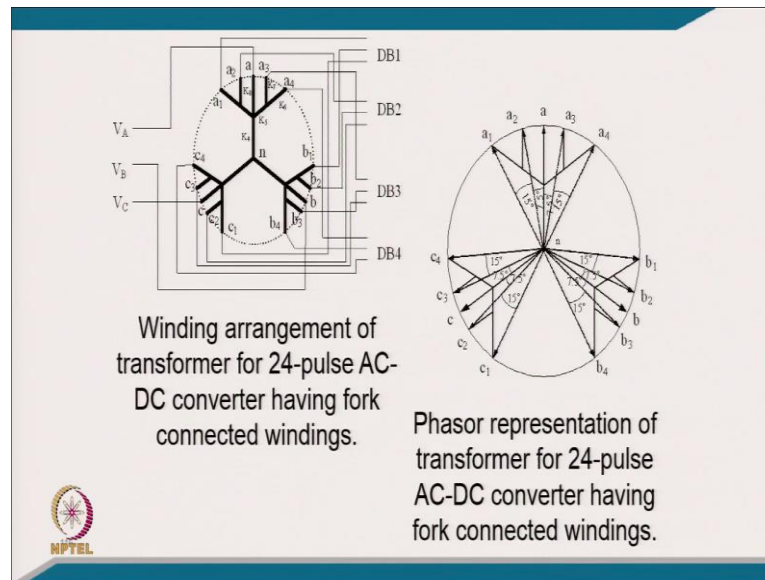
(Refer Slide Time: 58:00)



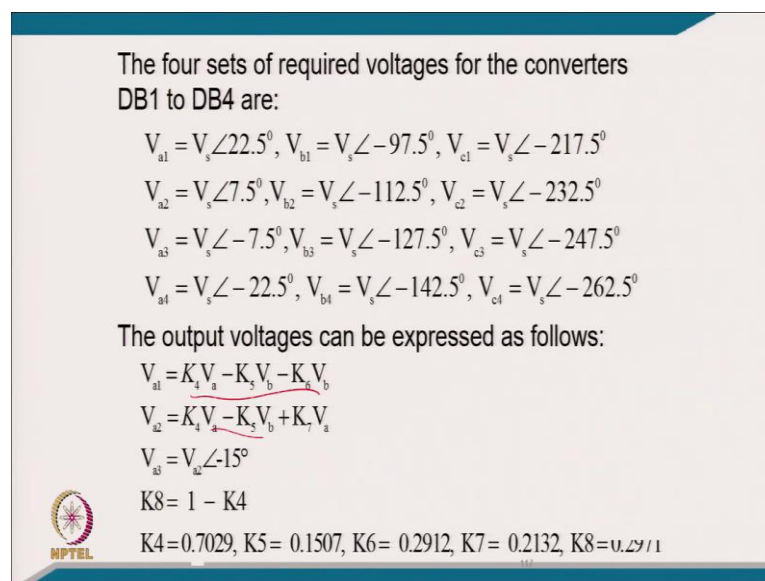
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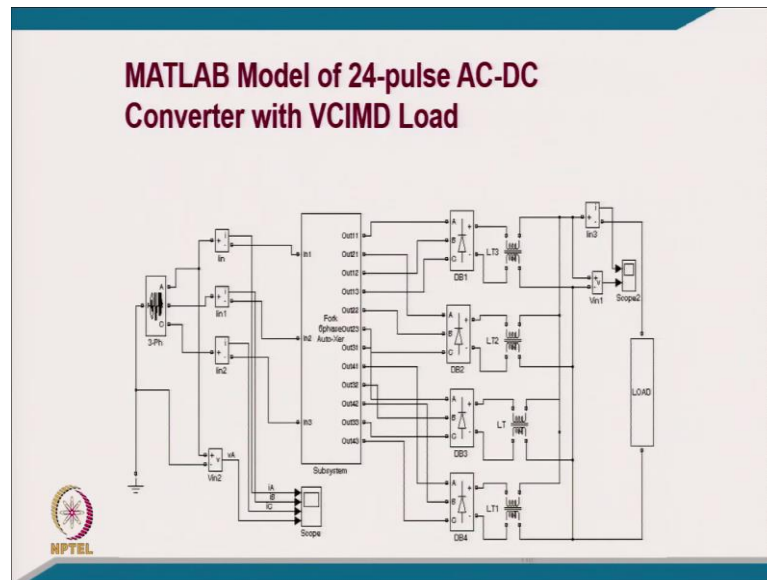
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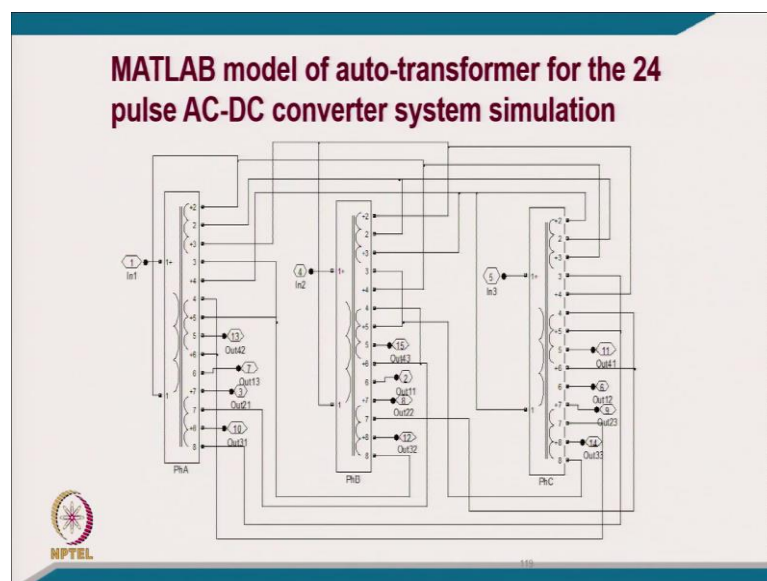
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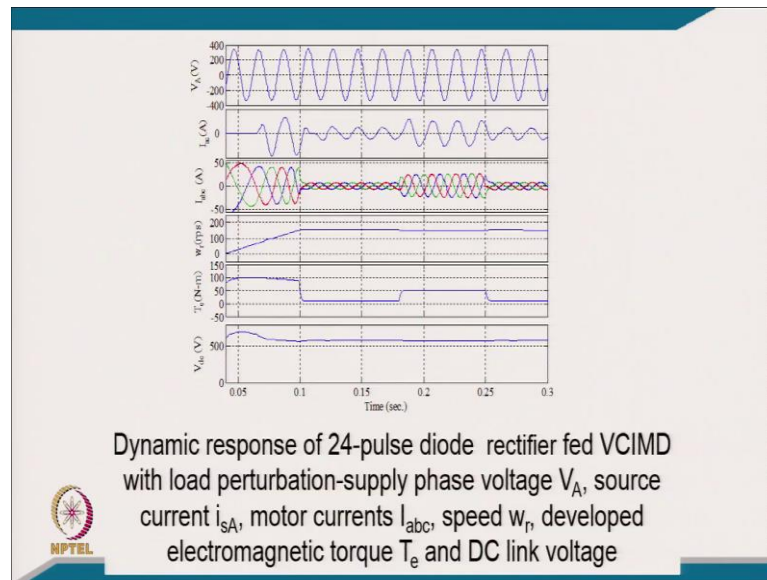
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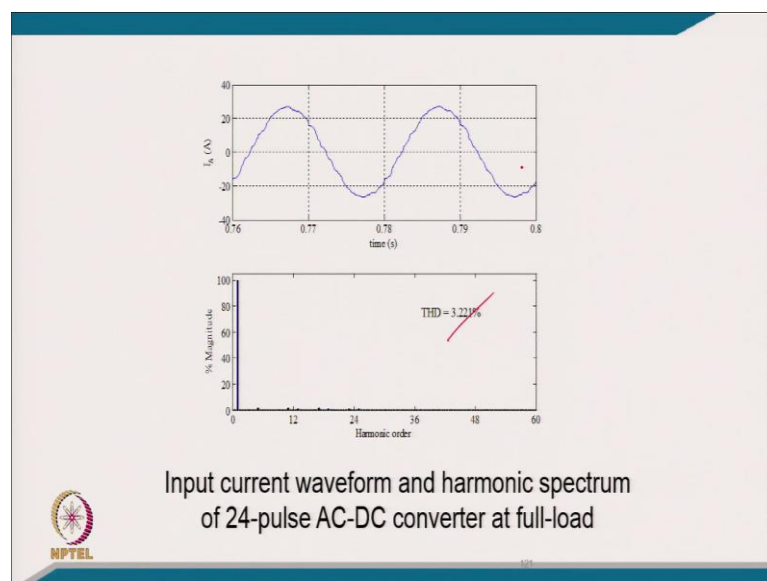
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### Comparison of Power Quality Parameters of Different AC-DC Converters


Topology	Load		AC Mains Current $I_{m}$ (A)		% THD of $I_{m}$ at		Distortion Factor DF		Displacement Power Factor DPF		Power Factor PF		DC Voltage (V)	
	Light	Full	Light	Full	Light	Full	Light	Full	Light	Full	Light	Full	Light	Full
	Load	Load	Load	Load	Load	Load	Load	Load	Load	Load	Load	Load	Load	Load
6-pulse	10.58	8.701	19.12	74.68	31.24	0.9110	0.9491	0.9798	0.9768	0.8926	0.9271	562.9	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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### 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 $I_{m}$ (A)	THD of $I_{m}$ (%)	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	0.9946	0.9897	0.9846	554.2	13.21	0.002
	60%	3.981	13.58	9.383	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	0.9982	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



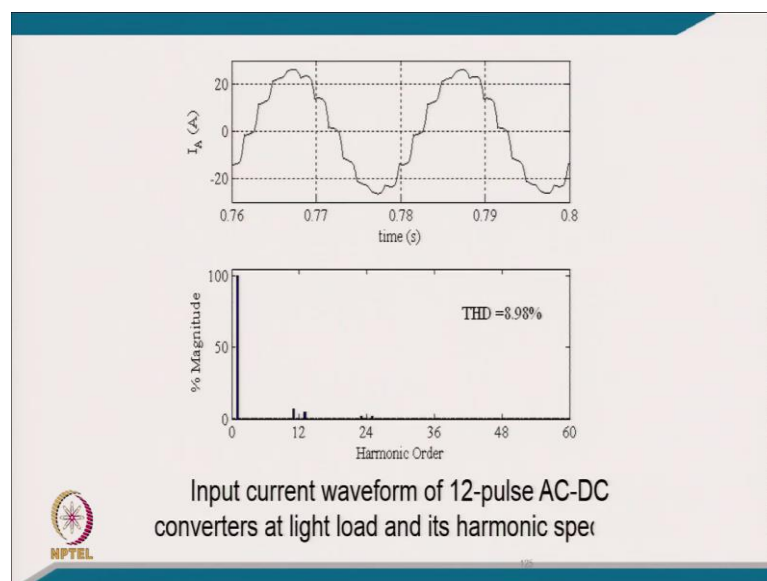
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### MATLAB model of the proposed autotransformer for 24-pulse AC-DC converter

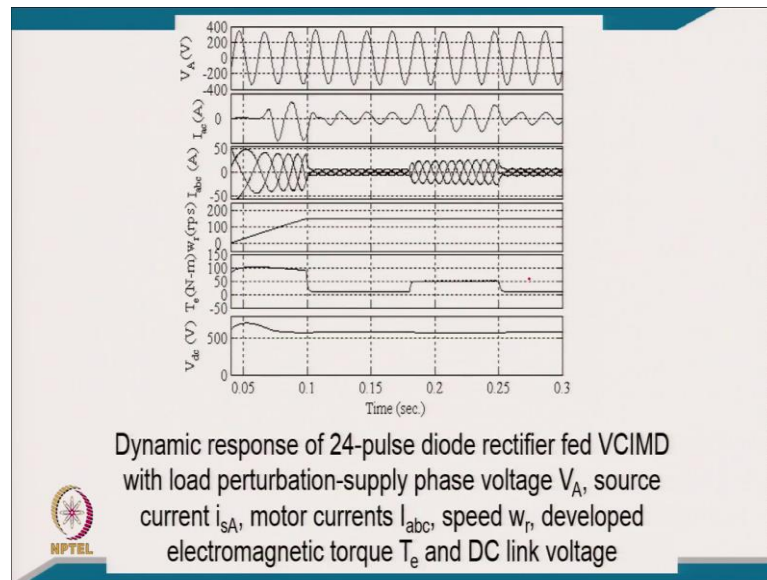
Topology	Load	AC Mains Current $I_{ac}$ (A)		% THD of $I_{ac}$ at		Distortion Factor DF		Displacement Power Factor DPF		Power Factor PF		DC Voltage (V)	
		Light	Full	Light	Full	Light	Full	Light	Full	Light	Full	Light	Full
	Load	Load	Load	Load	Load	Load	Load	Load	Load	Load	Load	Load	Load
<b>6-pulse</b>	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
<b>12-pulse</b>	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
<b>24-pulse</b>	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



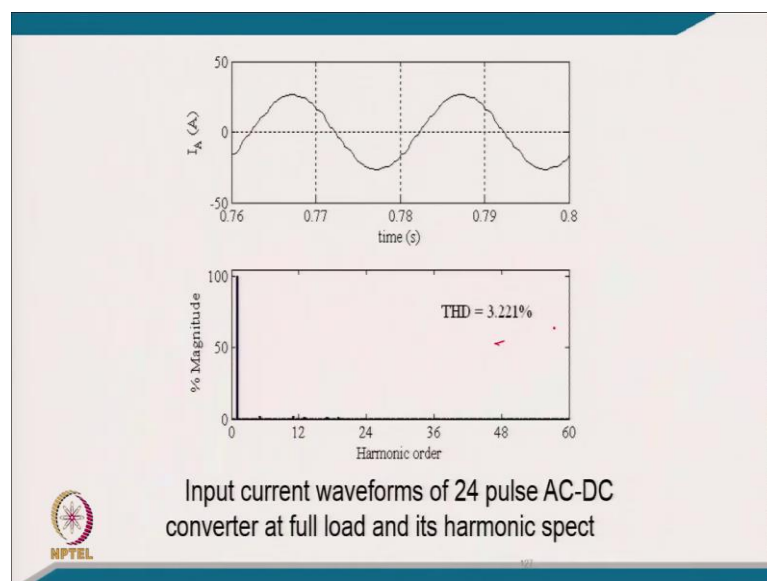
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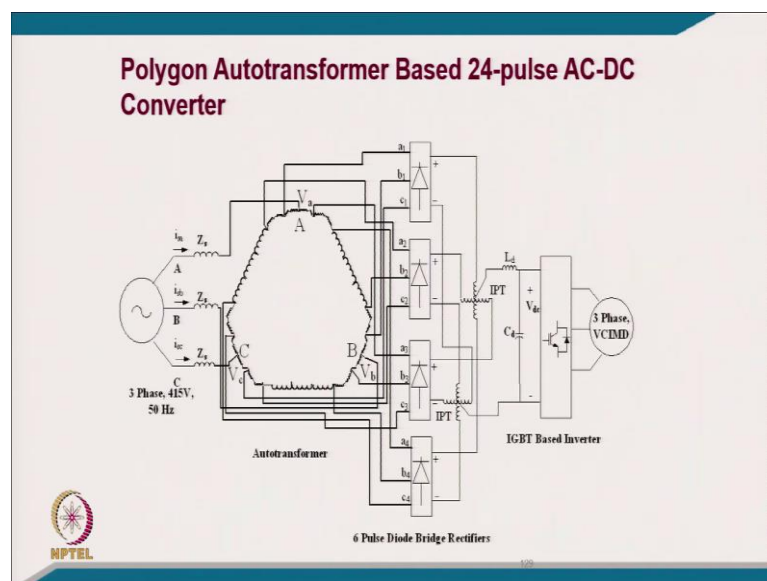
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### Comparison of magnetic ratings in different AC-DC converters

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

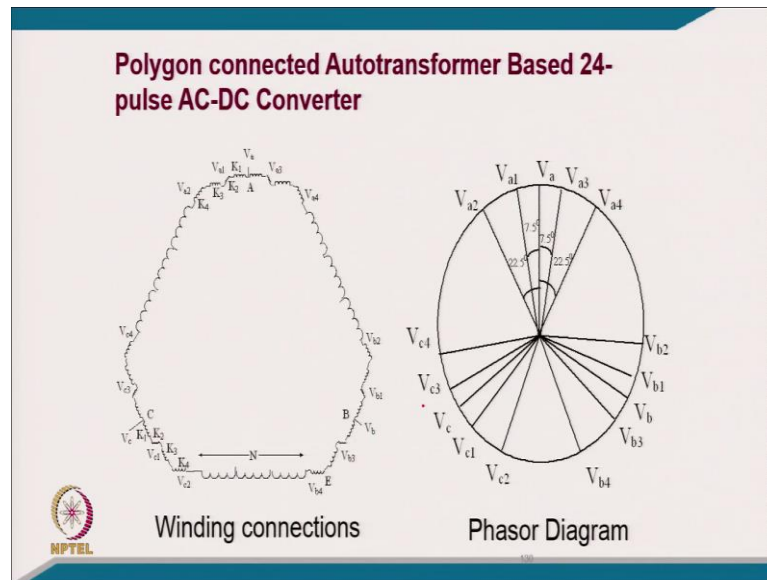


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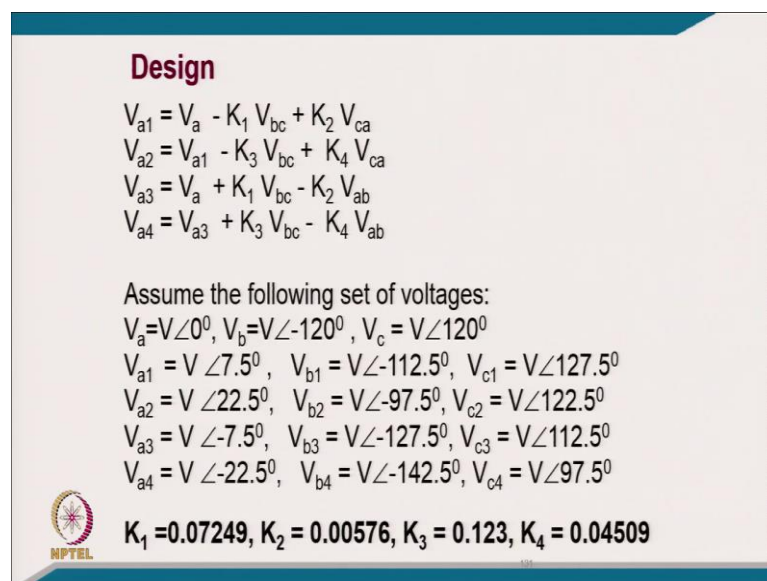




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Load (%)	THD (%)		CF of $I_s$	DF	DPF	PF	$V_{dc}$ (V)
	$I_s$	$V_t$					
20	5.22	1.76	1.43	.998	.989	.988	557
40	4.65	1.90	1.43	.999	.990	.989	553
60	4.41	2.31	1.43	.999	.989	.989	551
80	4.05	2.51	1.44	.999	.988	.988	547
100	3.20	2.73	1.44	.999	.988	.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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## Multipulse AC-DC Converters for Bidirectional Power Flow


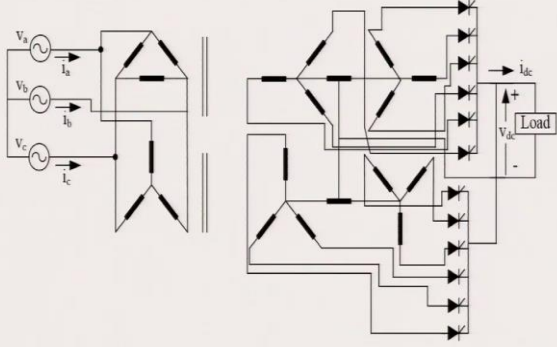
Bidirectional Multipulse Full-Wave AC-DC converters



The slide features a title in red text and a subtitle in blue and black text. The NPTEL logo is located in the bottom-left corner.

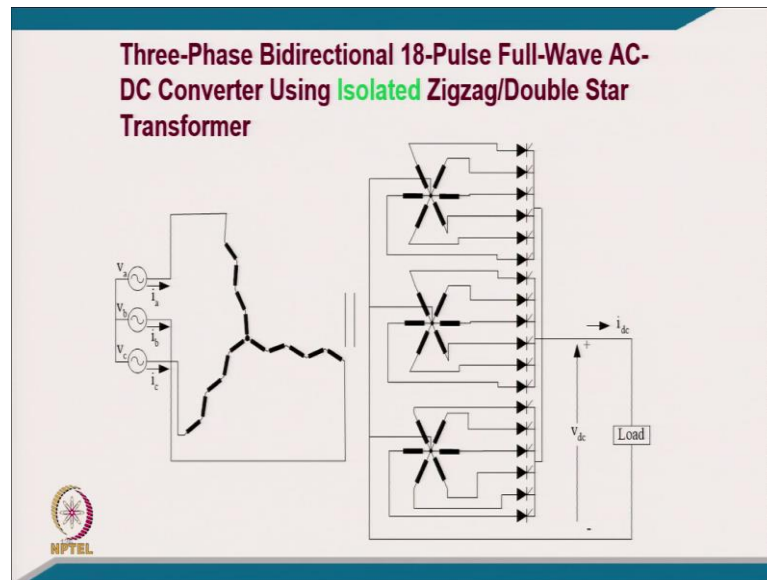
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### Three-Phase Bidirectional 12-Pulse Full-Wave AC-DC Converter Using Isolated Delta-Star/Double Star Three Windings Transformers

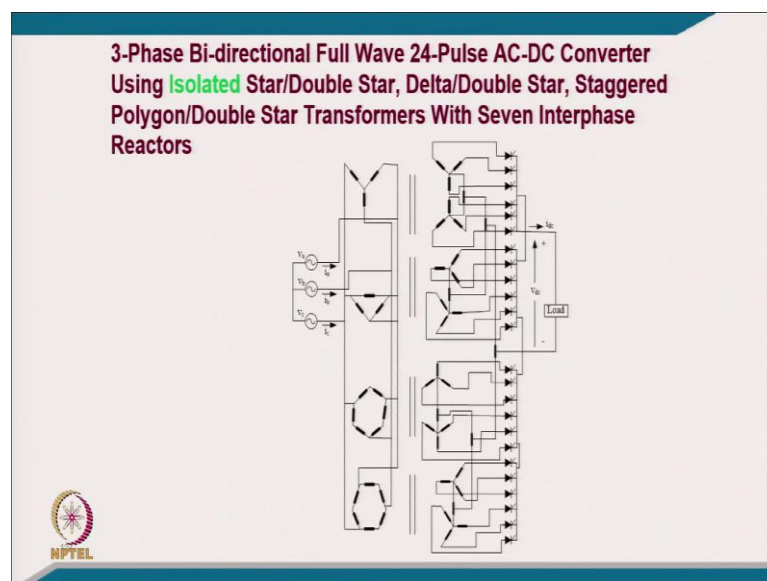


The diagram illustrates a three-phase bidirectional 12-pulse full-wave AC-DC converter. On the left, three AC voltage sources ( $V_a$ ,  $V_b$ ,  $V_c$ ) are connected to a transformer with a delta primary and a double star secondary. The secondary windings are connected to a full-bridge rectifier circuit consisting of six diodes. The DC output terminals are labeled with current  $i_{dc}$  and voltage  $V_{dL}$  across a load. The NPTEL logo is in the bottom-left corner.

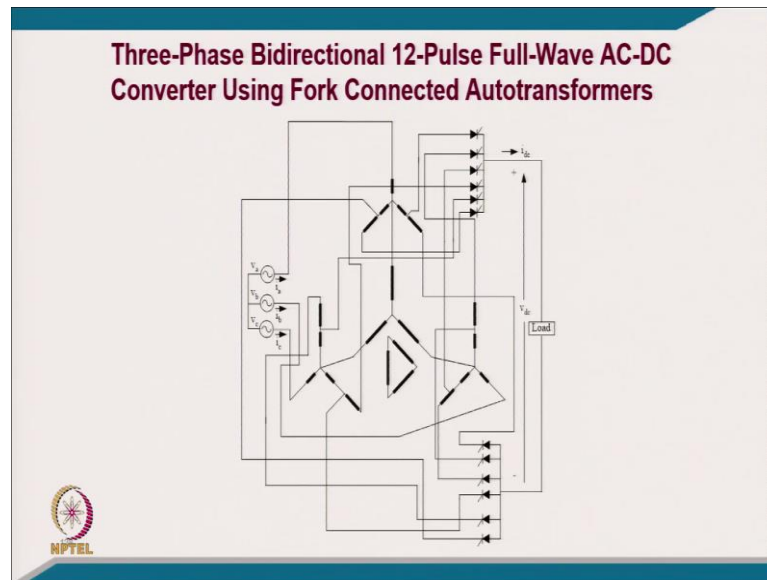
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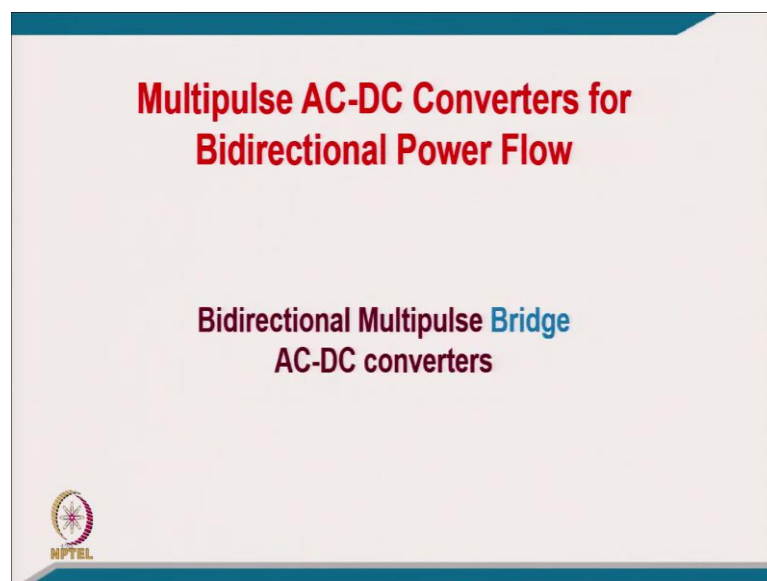
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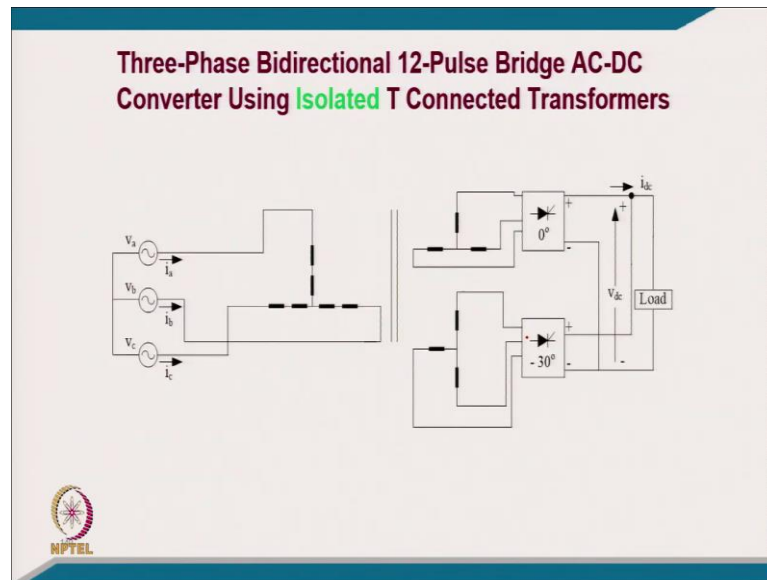
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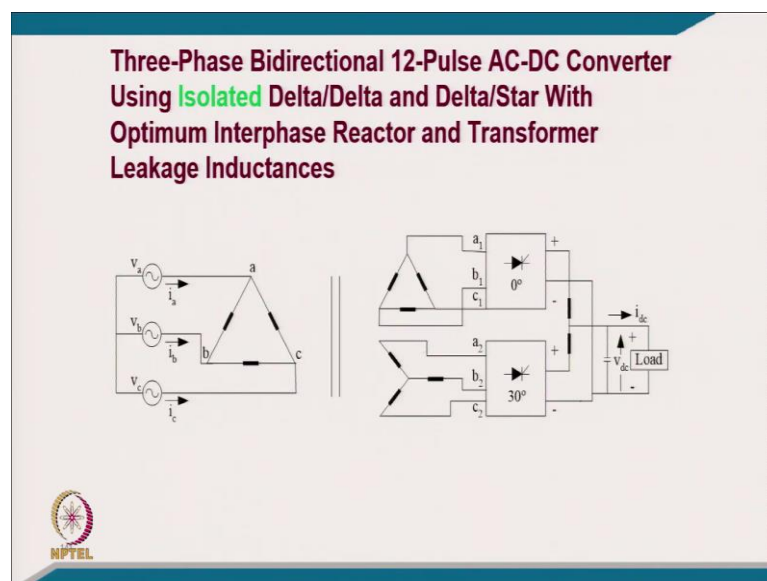
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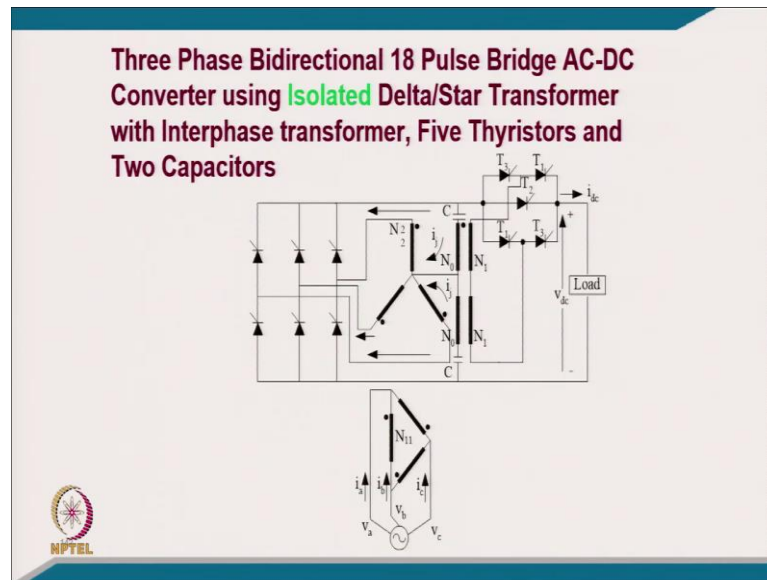
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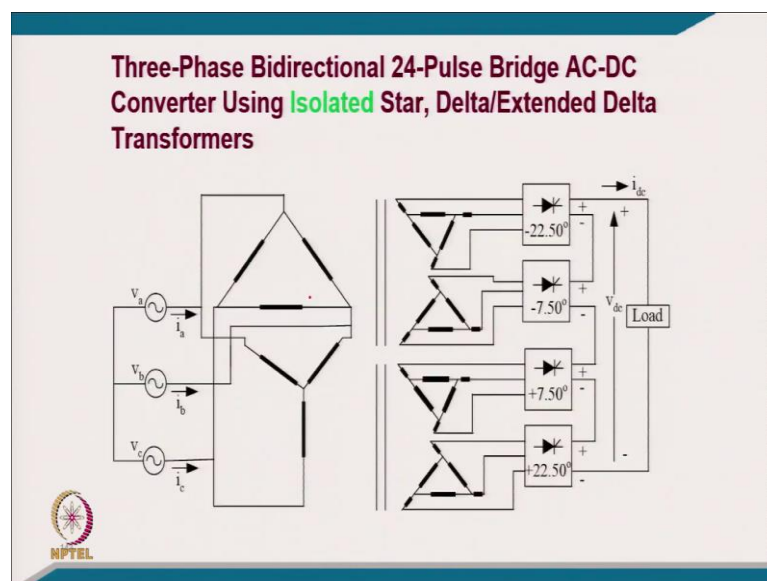
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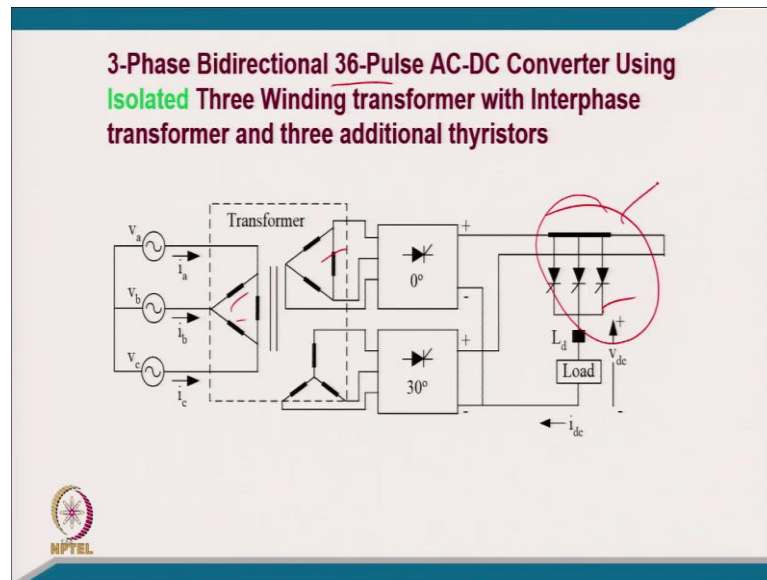
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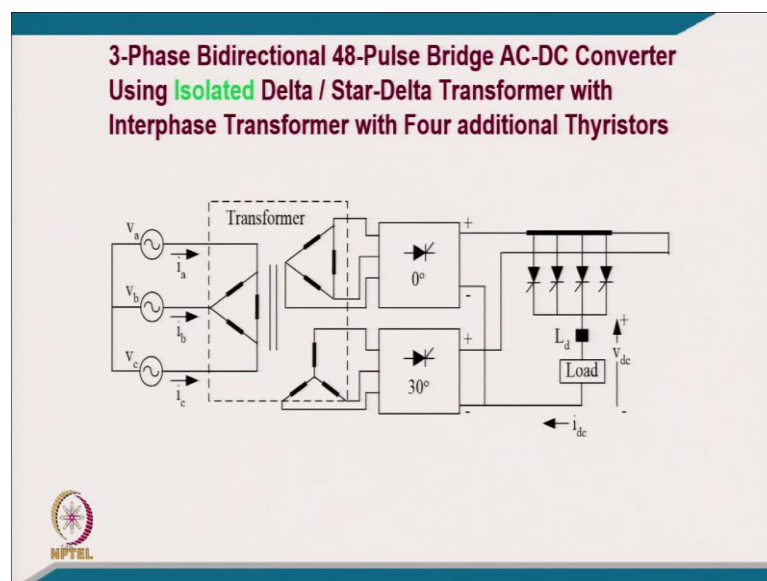
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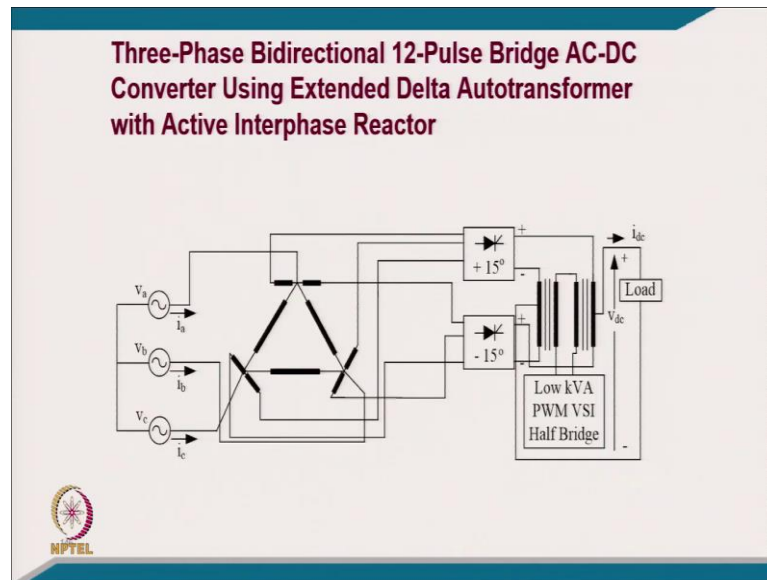


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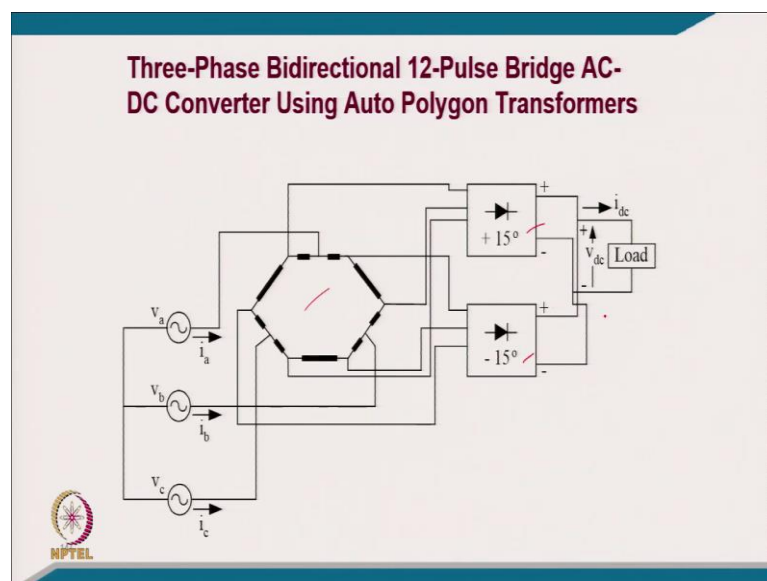




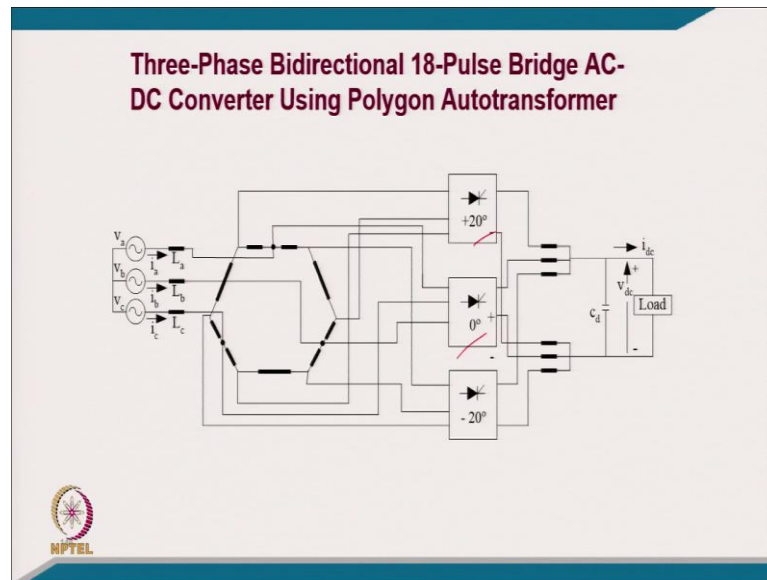
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Thank you.