Multipulse Converter

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Introduction

- The rectifiers can be configured as 12-, 18- and 24-pulse rectifiers, powered by a phase shifting transformer with a number of secondary windings.
- Each secondary winding feeds a six-pulse diode rectifier.
- The dc output of the six-pulse rectifiers is connected to a voltage source inverter.

Advantages

- Ability to reduce the line current harmonic distortion
- low-order harmonic currents generated by the six-pulse rectifiers are canceled through Phase-shifting transformer
- does not require any LC filters or power factor compensators
- Phase-shifting transformer provides an effective means to block common-mode voltages

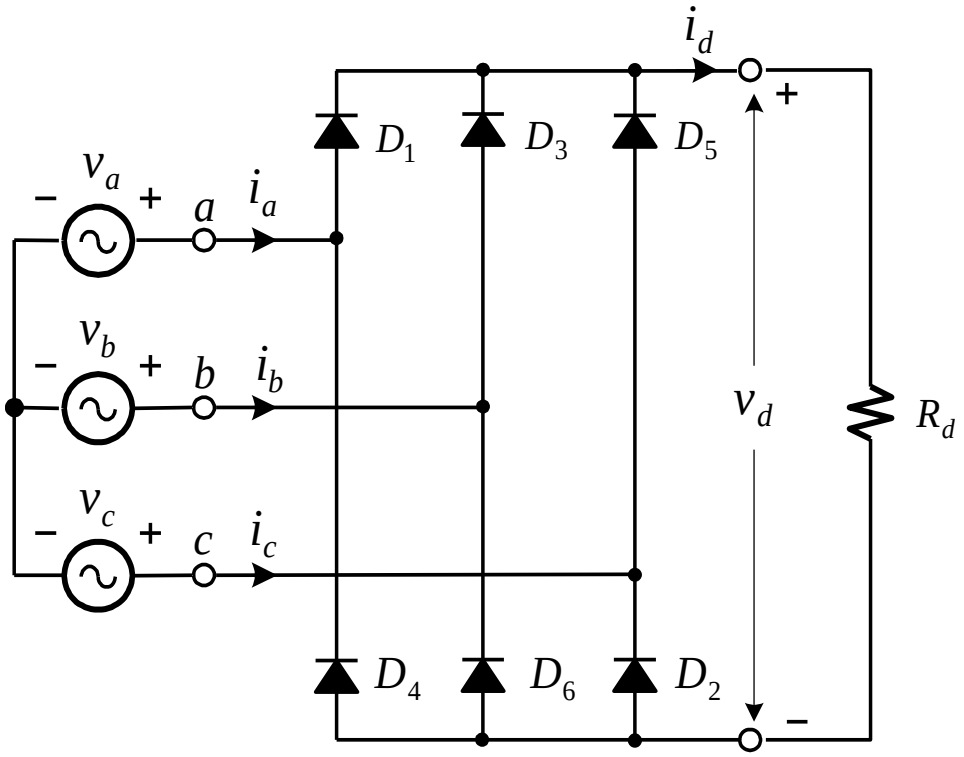
Disadvantages

- Requires phase shifting transformer
- Higher the No. of pulses, increased transformer cost
- More No. of semiconductor devices are used

Classification

- **Series type multipulse rectifier**
  - All six pulse rectifier are connected in series at DC side
  - Medium power ASD as front end converter
  - NPC inverter
- **Separate type multipulse rectifier**
  - Each six pulse rectifier feeds a separate DC load
  - H-Bridge inverter

Six-pulse Diode Rectifier



Supply Voltages:

$$v_a = \sqrt{2}V_{PH}\sin(\omega t)$$

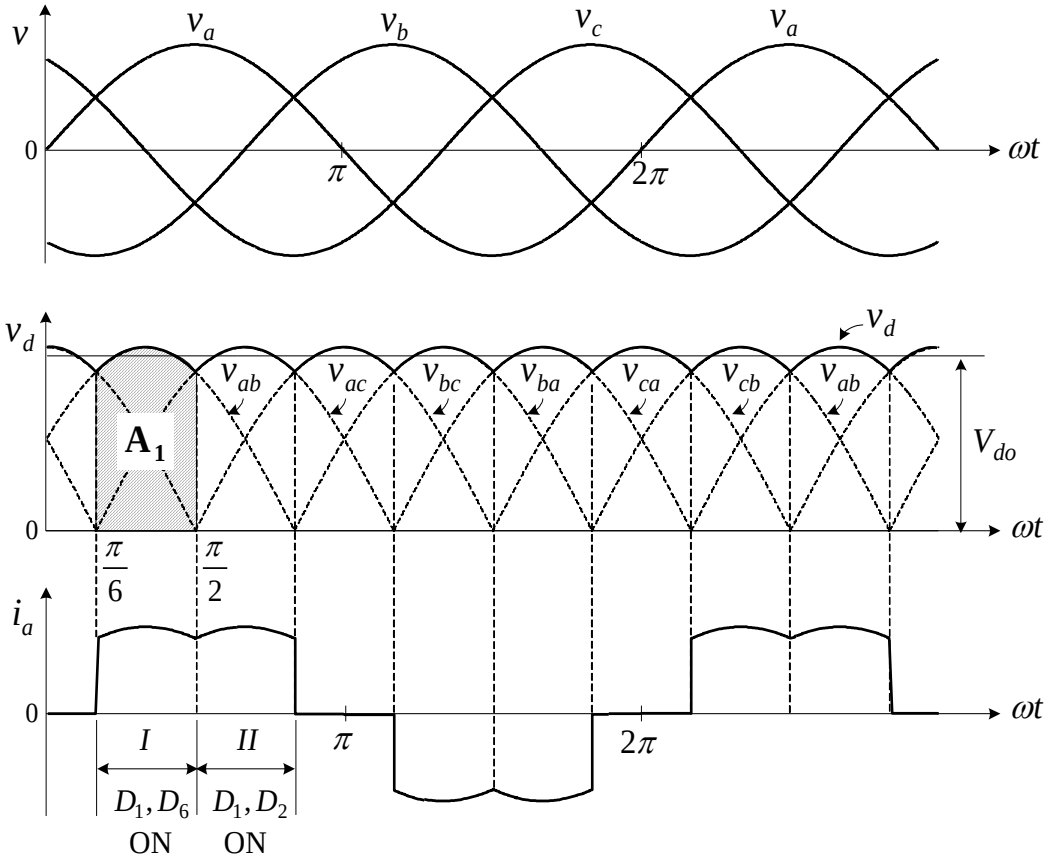
$$v_b = \sqrt{2}V_{PH}\sin(\omega t - 2\pi/3)$$

$$v_c = \sqrt{2}V_{PH}\sin(\omega t - 4\pi/3)$$

$$v_{ab} = v_a - v_b = \sqrt{2}V_{LL}\sin(\omega t + \pi/6)$$

Six-pulse Diode Rectifier

Waveforms



$$V_{do} = \frac{\text{area } \mathbf{A_1}}{\pi/3} = \frac{1}{\pi/3}\int_{\pi/6}^{\pi/2}\sqrt{2}V_{LL}\sin(\omega t + \pi/6)d(\omega t) = \frac{3\sqrt{2}}{\pi}V_{LL} \approx 1.35V_{LL}$$

Six-pulse Diode Rectifier

- **Definition of Power Factor (PF)**

Per-phase average (real) power: $$P = \frac{1}{2\pi}\int_0^{2\pi} v_a \times i_a \, d(\omega t) = V_a \, I_{a1} \cos\phi_1$$

Per-phase apparent power: $$S = V_a \, I_a$$

Total power factor (PF): $$PF = \frac{P}{S} = \frac{V_a \, I_{a1} \cos\phi_1}{V_a \, I_a} = \frac{I_{a1}}{I_a}\cos\phi_1 = DF \times DPF$$

Distortion factor (DF) : $$DF = I_{a1} / I_a$$

Displacement power factor (DPF) : $$DPF = \cos\phi_1$$

PF = f(THD) : $$PF = \frac{DPF}{\sqrt{1 + THD^2}}$$

Six-pulse Diode Rectifier

- **Per Unit System**

Rated power, rated lint-to-line voltage: S_R, V_R

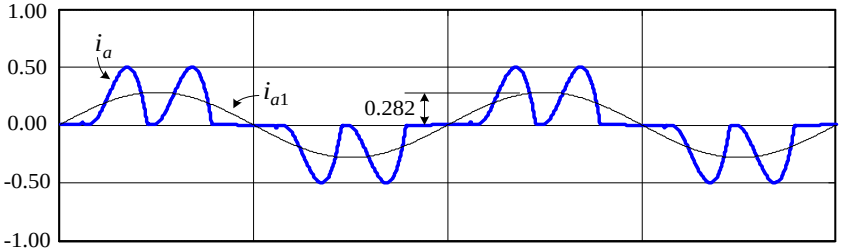
Base voltage and frequency: $V_B = \frac{V_R}{\sqrt{3}}$ and $\omega_B = 2\pi f_1$

Base current and impedance: $I_B = \frac{S_R}{3V_B}$ and $Z_B = \frac{V_B}{I_B}$.

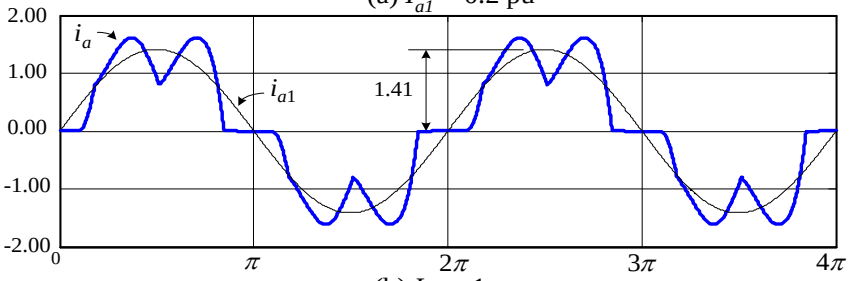
Base inductance and capacitance: $L_B = \frac{Z_B}{\omega_B}$ and $C_B = \frac{1}{\omega_B Z_B}$

Six-pulse Diode Rectifier

- Typical Waveforms / Harmonic Content



(a) I_{a1} = 0.2 pu

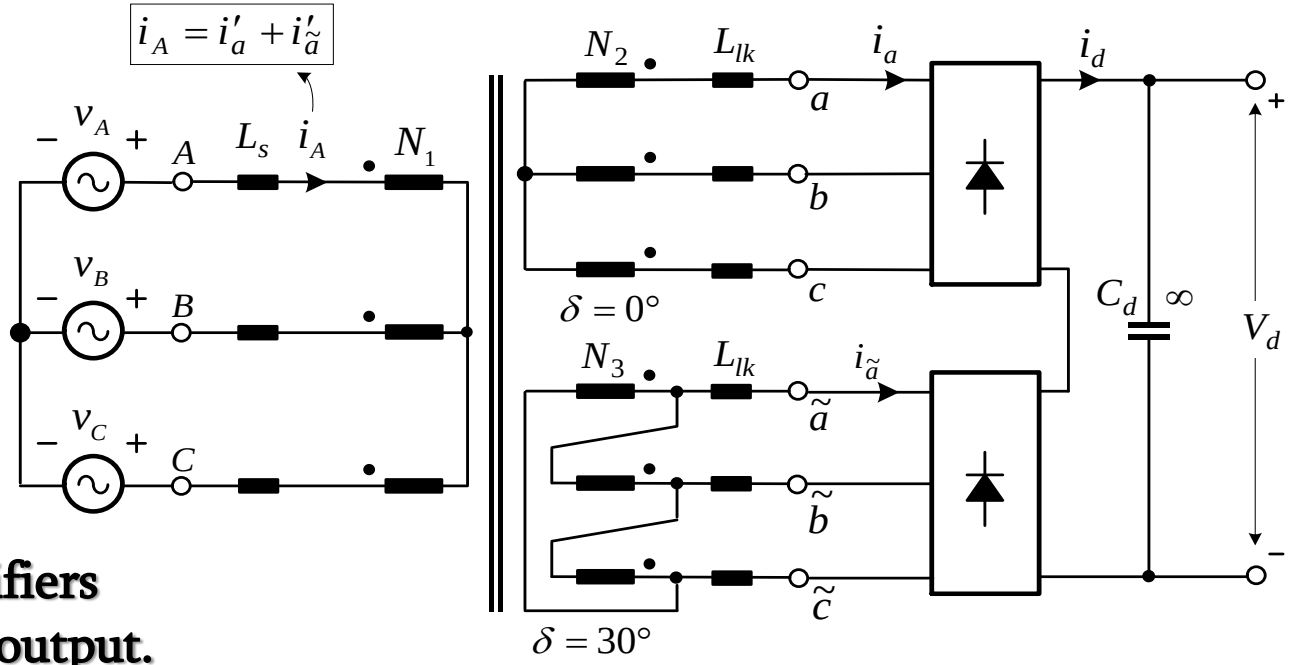


(b) I_{a1} = 1 pu

Harmonics ***n***	**5**	**7**	**11**	**13**	**17**	**19**	**23**	**25**	**THD (%)**
I_{an}/I_{a1} (%) $I_{a1}=0.2\text{pu}$	63.4	38.7	8.99	8.64	4.22	3.61	2.48	2.02	75.7
I_{an}/I_{a1} (%) $I_{a1}=1\text{pu}$	30.4	8.79	6.31	3.40	2.30	1.89	1.04	1.03	32.7

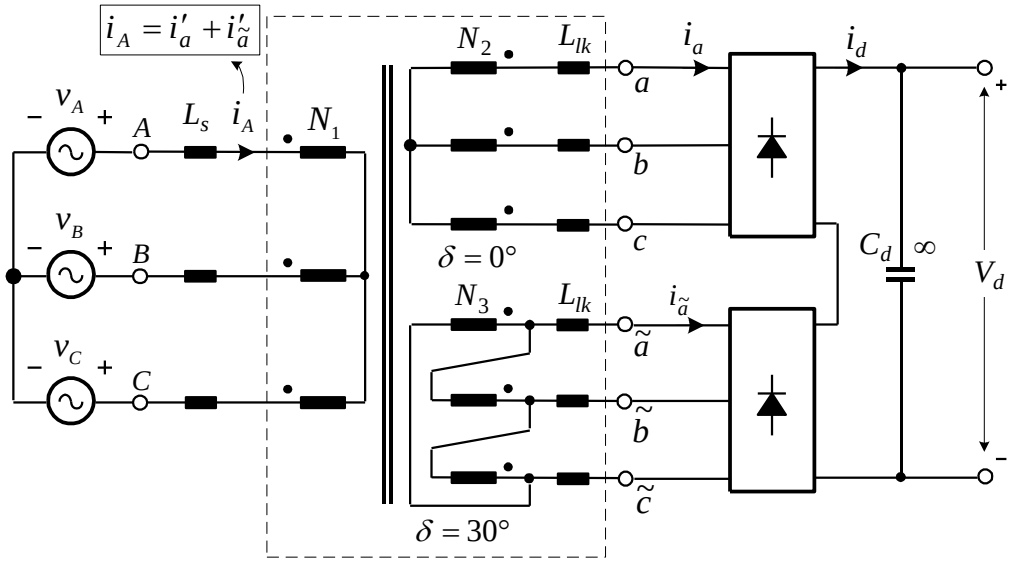
12-pulse Diode Rectifier

- Rectifier Topology

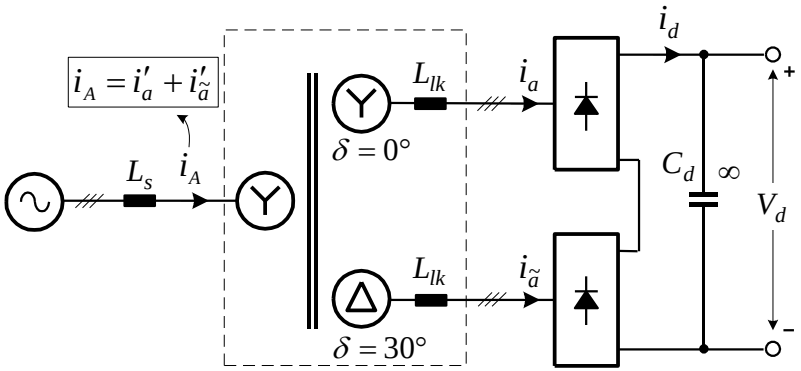


- Series type:
  Two six-pulse rectifiers are in series at the output.
- Phase shifting transformer: $\delta = \angle V_{\tilde{a}\tilde{b}} - \angle V_{AB} = 30°$
- Secondary line-to-line voltage: $V_{ab} = V_{\tilde{a}\tilde{b}} = V_{AB}/2$
- Turns ratio: $\frac{N_1}{N_2} = 2$ and $\frac{N_1}{N_3} = \frac{2}{\sqrt{3}}$.

12-pulse Diode Rectifier



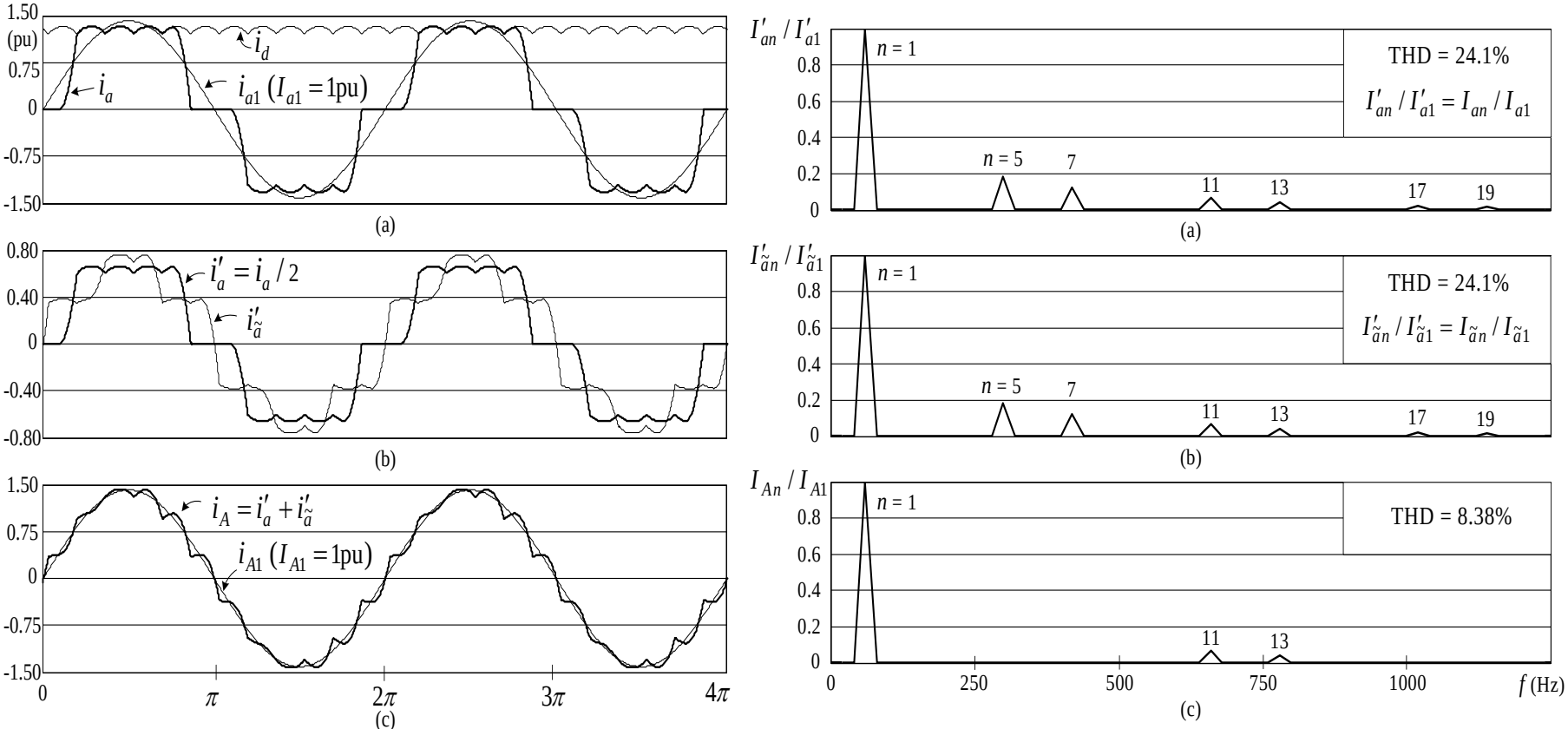
(a) 12-pulse diode rectifier



(b) Simplified diagram

12-pulse Diode Rectifier

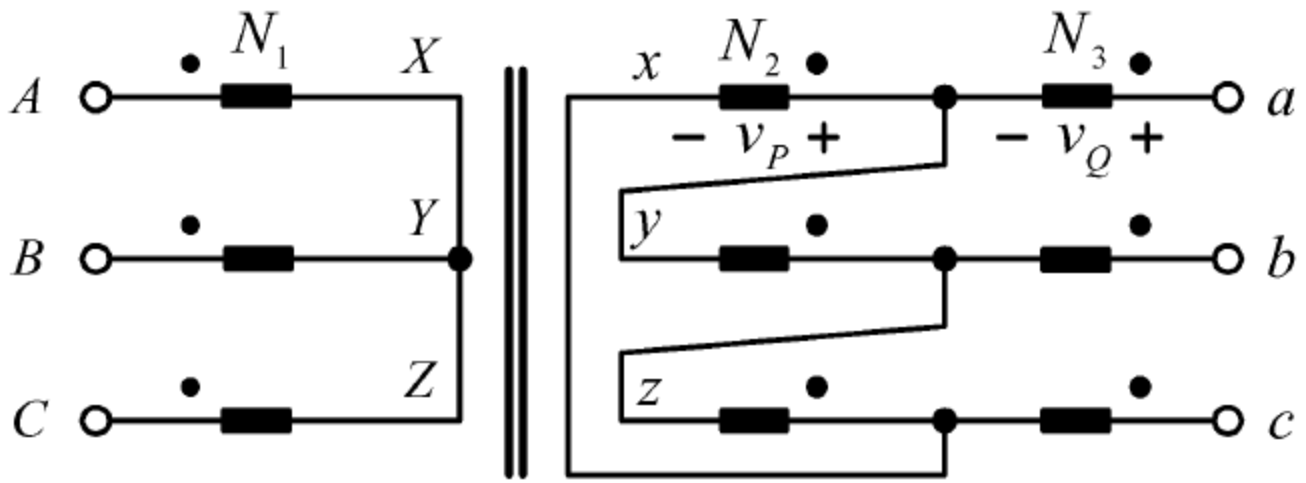
- Waveforms and FFT



- No 5th or 7th harmonics in the line current.
- Primary line current THD: 8.38%

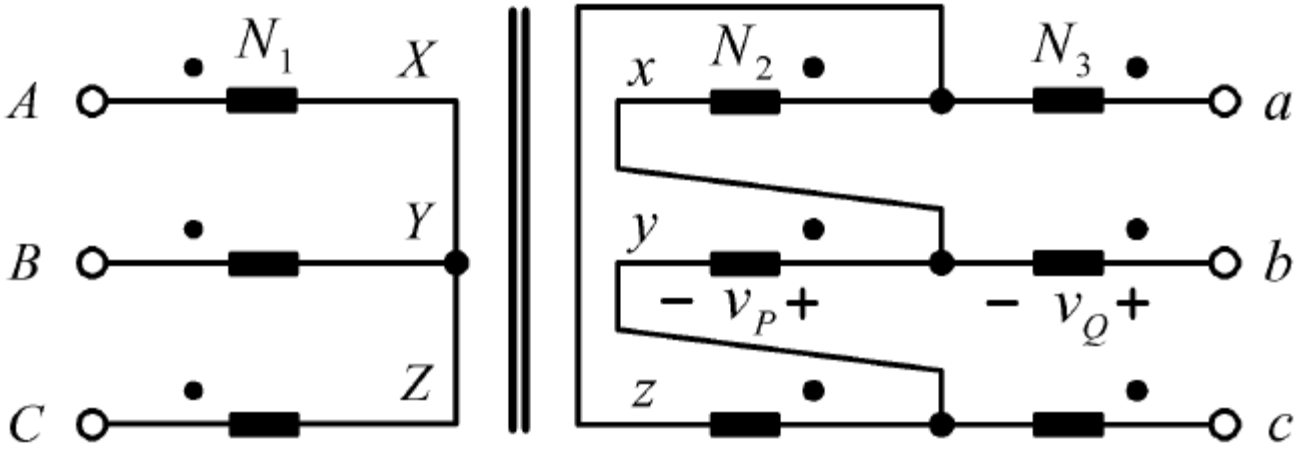
Phase Shifting Transformer

- Transformer Connection Y/Z1



Phase Shifting Transformer

- Transformer Connection Y/Z2



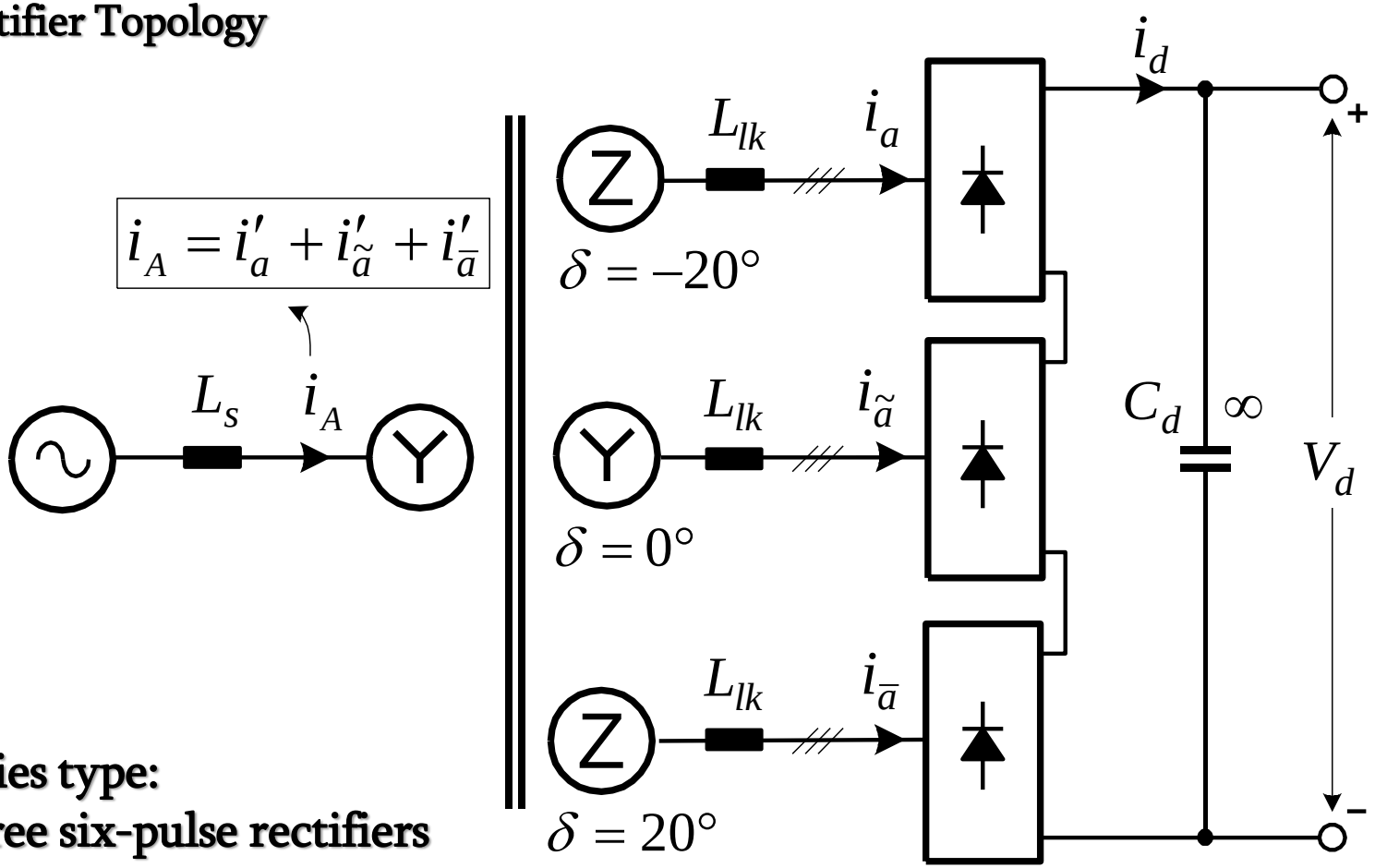
Phase Shifting Transformer

δ $(\angle\overline{V}_{ab} - \angle\overline{V}_{AB})$		$\frac{N_3}{N_2 + N_3}$	$\frac{N_1}{N_2 + N_3}$	Applications
Y/Z-1	Y/Z-2			
0°	0°	1.0	$1.0\frac{V_{AB}}{V_{ab}}$	12-, 18-, and 24-pulse rectifiers
15°	–15°	0.366	$0.707\frac{V_{AB}}{V_{ab}}$	24-pulse rectifiers
20°	–20°	0.227	$0.653\frac{V_{AB}}{V_{ab}}$	18-pulse rectifiers
30°	–30°	0	$0.577\frac{V_{AB}}{V_{ab}}$	12- and 24-pulse rectifiers

$\frac{V_{AB}}{V_{ab}}$ = 2, 3, and 4 for 12-, 18-, and 24-pulse rectifiers, respectively.

18-pulse Diode Rectifier

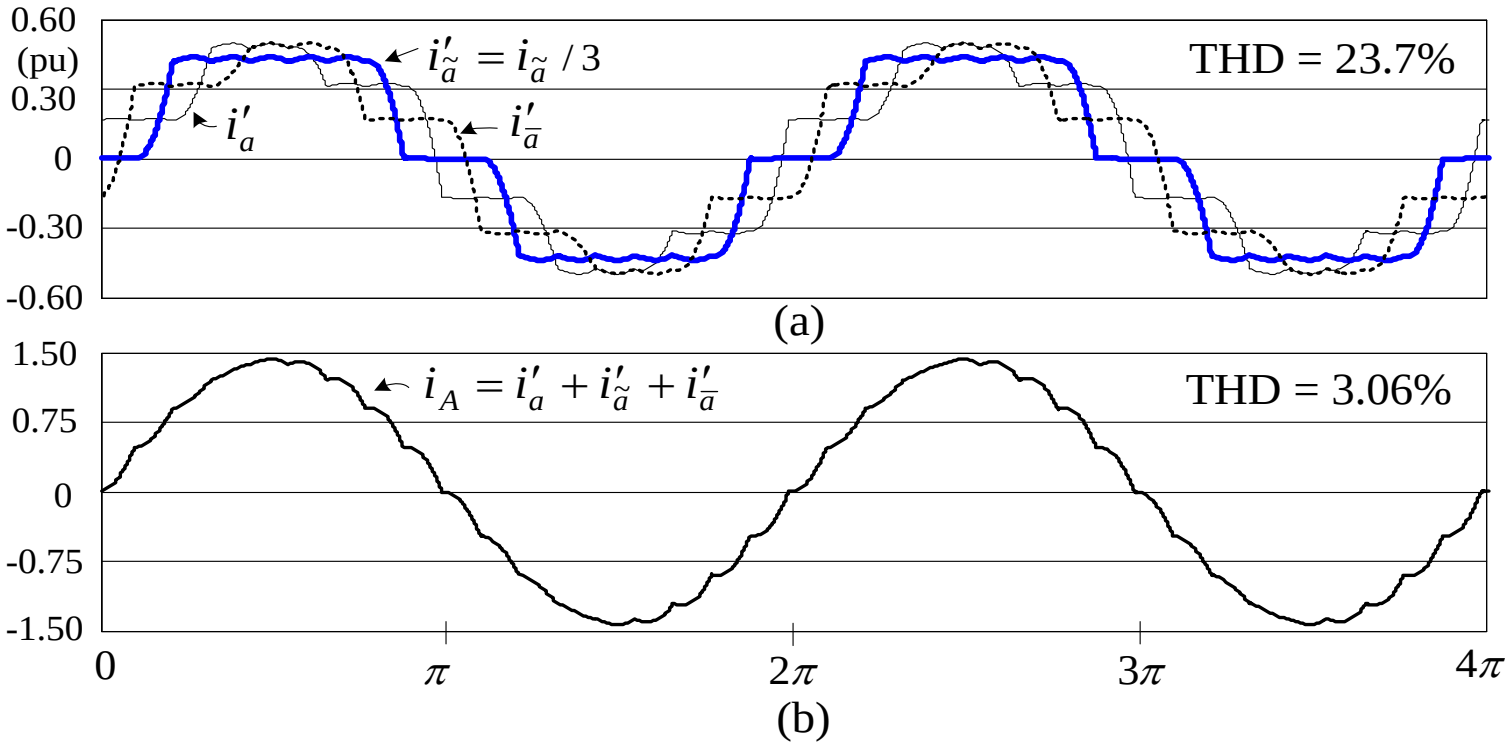
- Rectifier Topology



- Series type:
  Three six-pulse rectifiers are in series at the output.

18-pulse Diode Rectifier

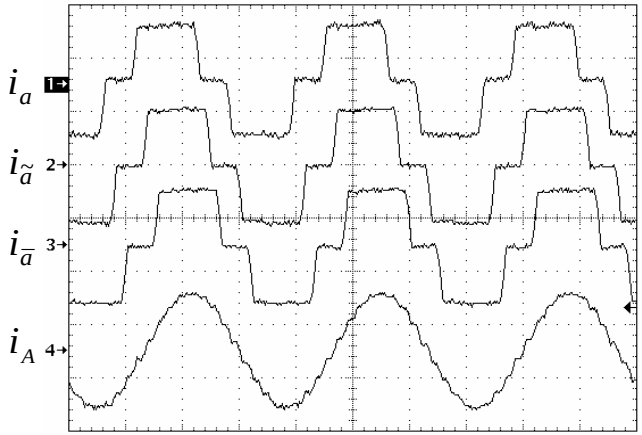
- Simulated Waveforms



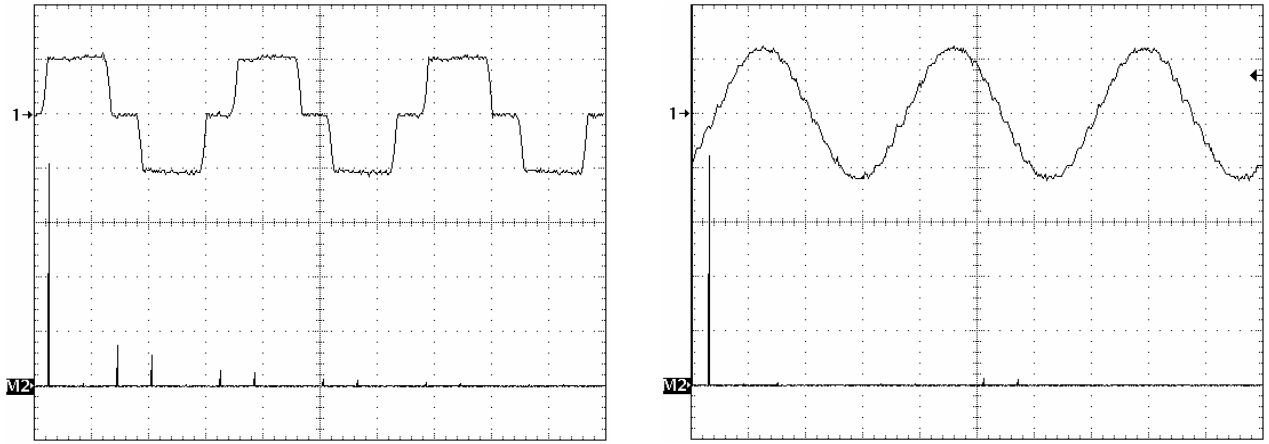
- No 5th, 7th, 11th, or 13th harmonics in the line current.
- Lowest harmonic: 17th
- Line current THD: 3.06%

18-pulse Diode Rectifier

- **Measured Waveforms**



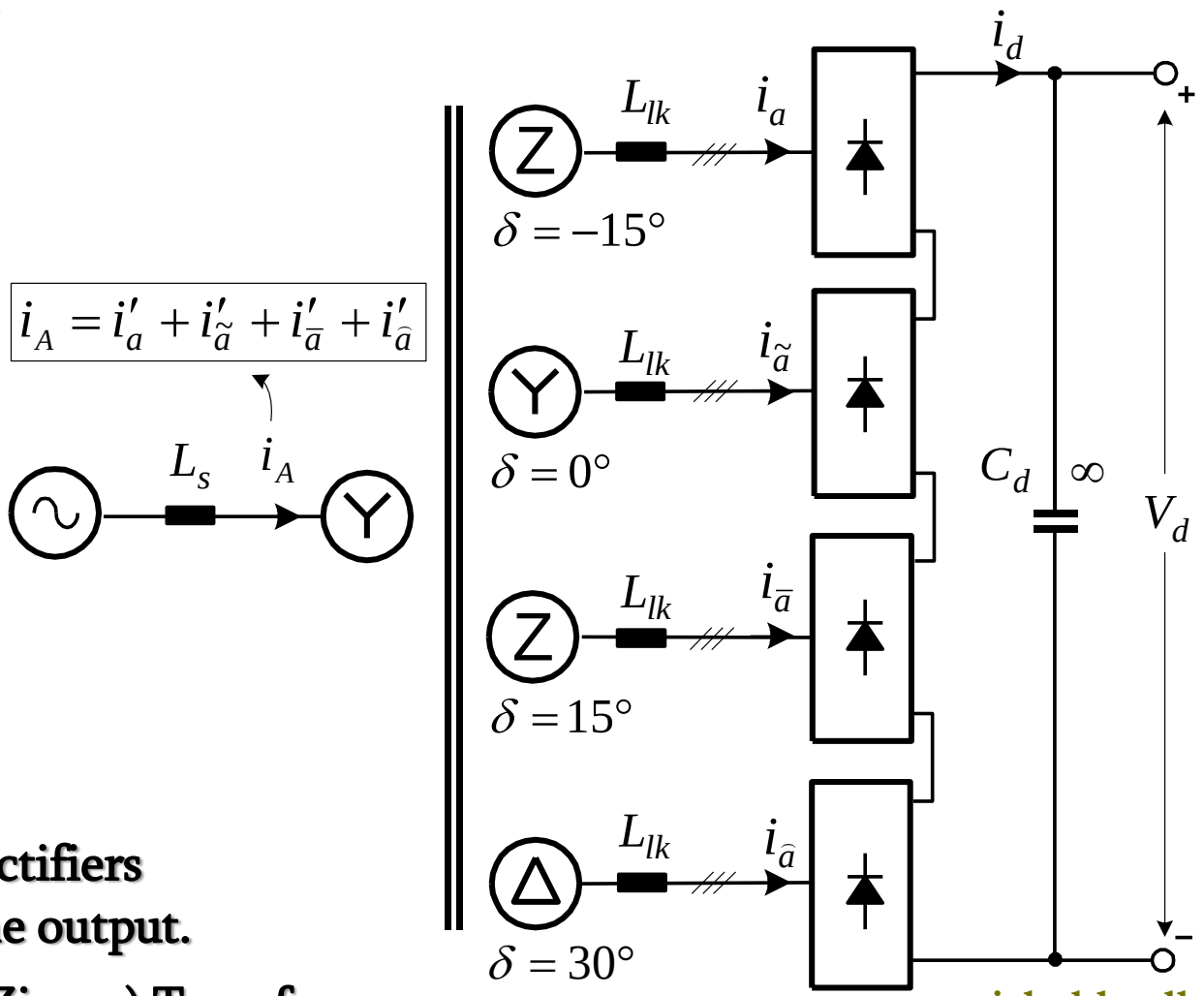
(a) Currents: $\sqrt{2}$ pu/div, 5ms/div



(b) Spectrum: $\sqrt{2}/5$ pu/div, 200Hz/div

24-pulse Diode Rectifier

- Rectifier Topology

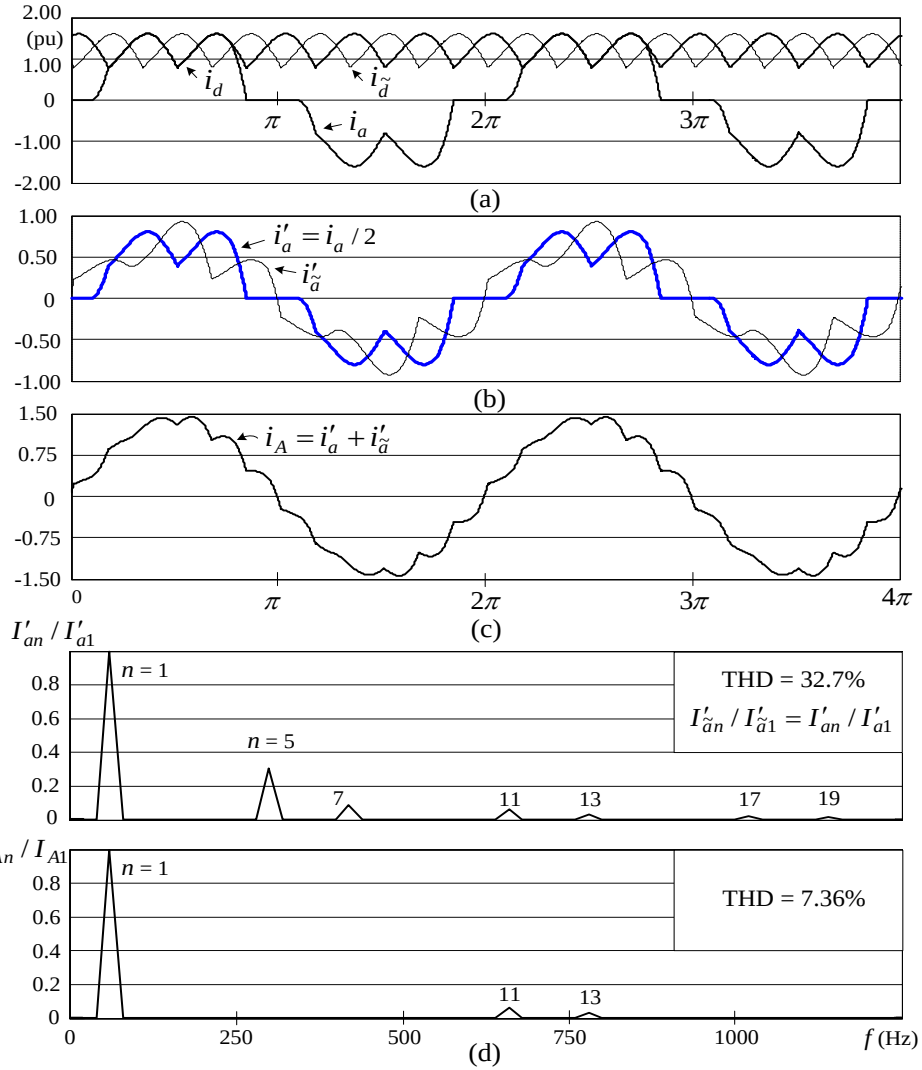


- Series type:
  Four six-pulse rectifiers
  are in series at the output.

Phase-Shifting :(Zigzag) Transformer

24-pulse Diode Rectifier

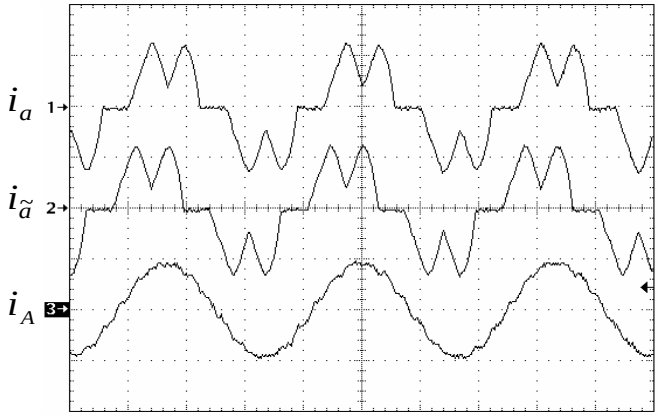
- Typical Waveforms



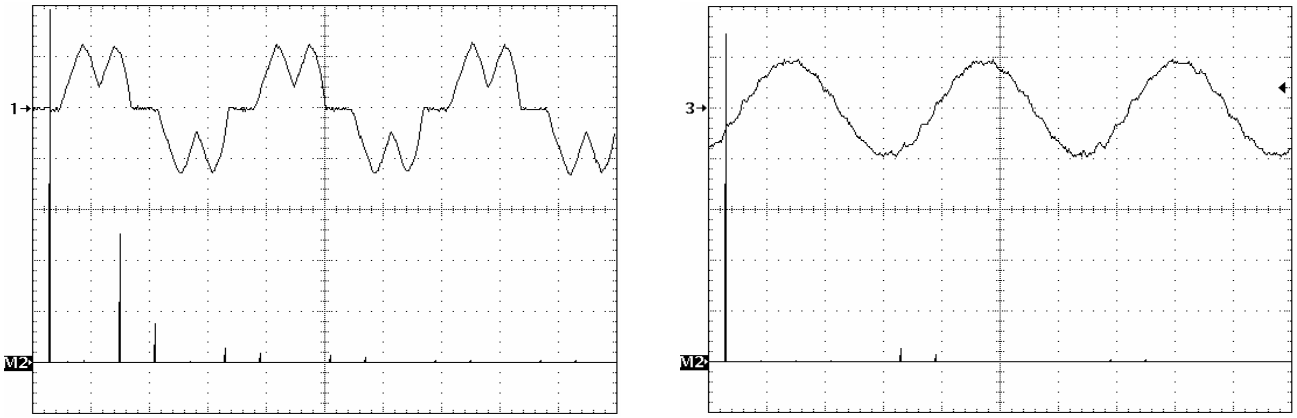
- Comparison with series-type:
  - DC current ripple: higher
  - Line current THD: close

24-pulse Diode Rectifier

- **Measured Waveforms**



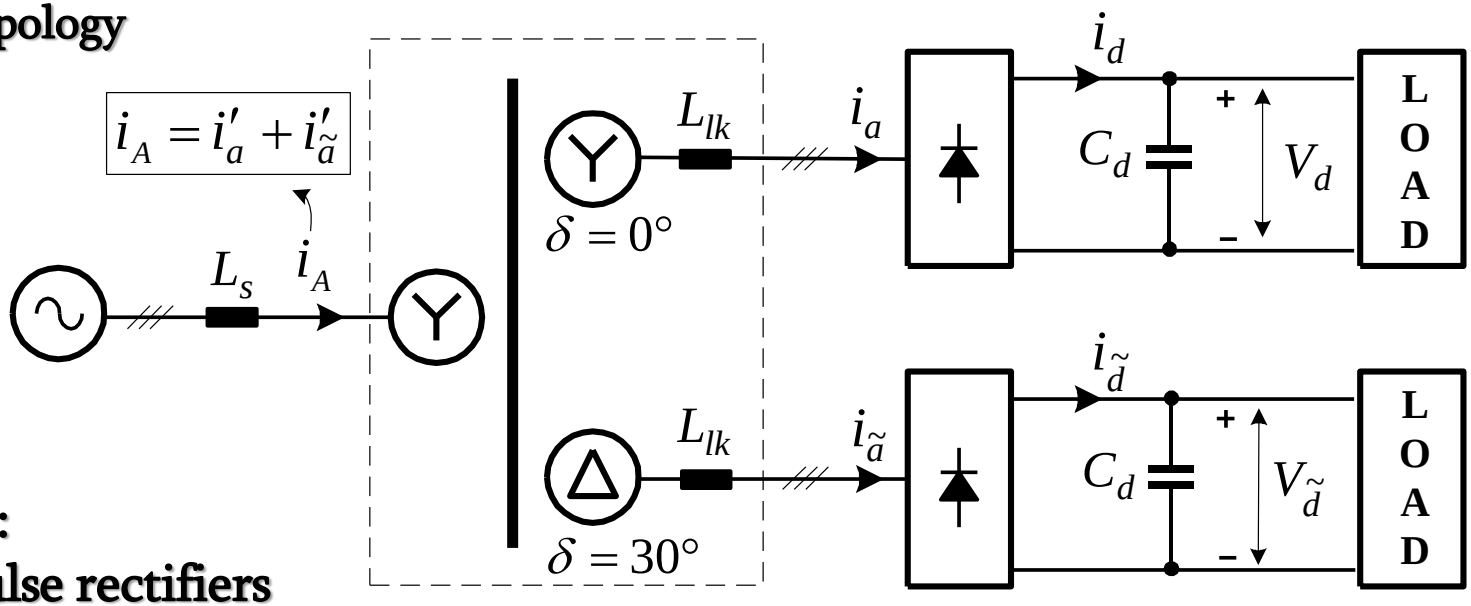
(a) Currents: $\sqrt{2}$ pu/div, 5ms/div



(b) Spectrum: $\sqrt{2}$ /10 pu/div, 200Hz/div

12-pulse Diode Rectifier (separate Type)

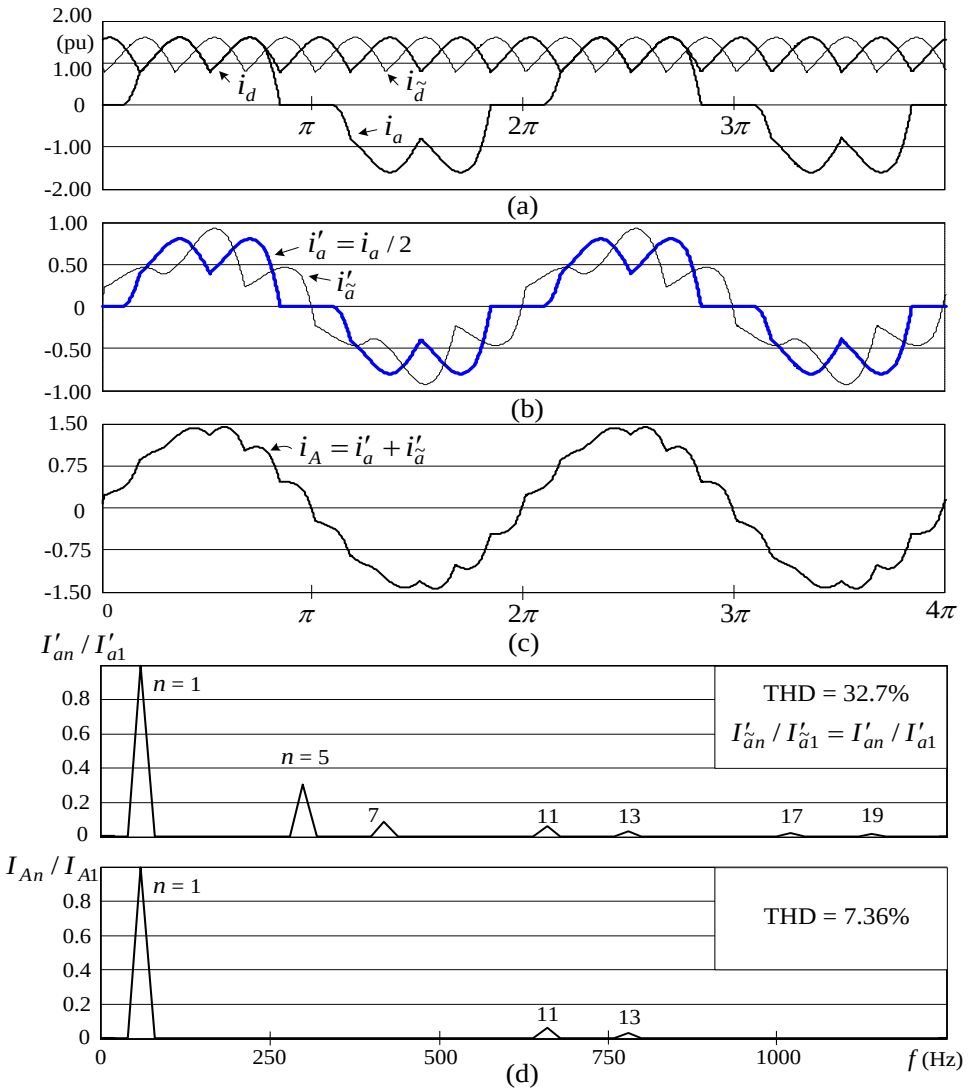
- Rectifier Topology



- Series type:
  Two six-pulse rectifiers
  are in Parallel at the output.
- Phase shifting transformer: $\delta = \angle V_{\tilde{a}\tilde{b}} - \angle V_{AB} = 30°$
- Secondary line-to-line voltage: $V_{ab} = V_{\tilde{a}\tilde{b}} = V_{AB}/2$
- Turns ratio: $\frac{N_1}{N_2} = 2$ and $\frac{N_1}{N_3} = \frac{2}{\sqrt{3}}$.

12-pulse Diode Rectifier (separate Type)

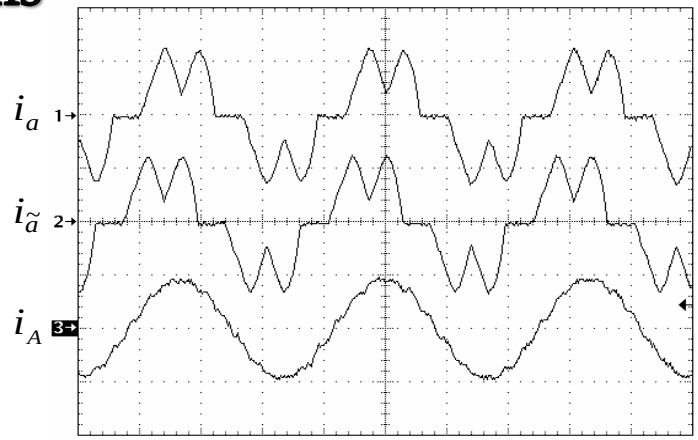
- Typical Waveforms



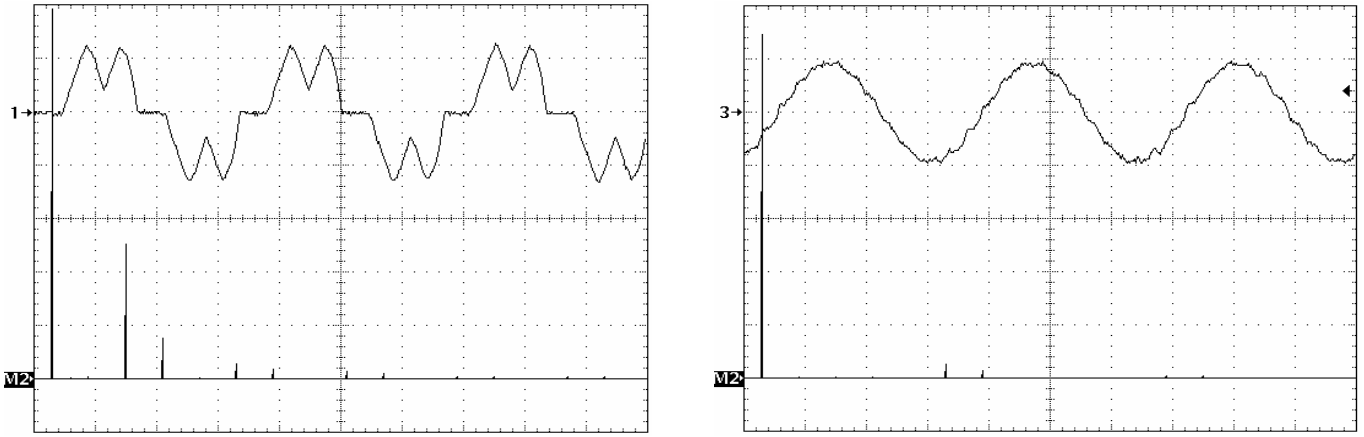
- Comparison with series-type:
  - DC current ripple: higher
  - Line current THD: close

12-pulse Diode Rectifier (separate Type)

- **Measured Waveforms**



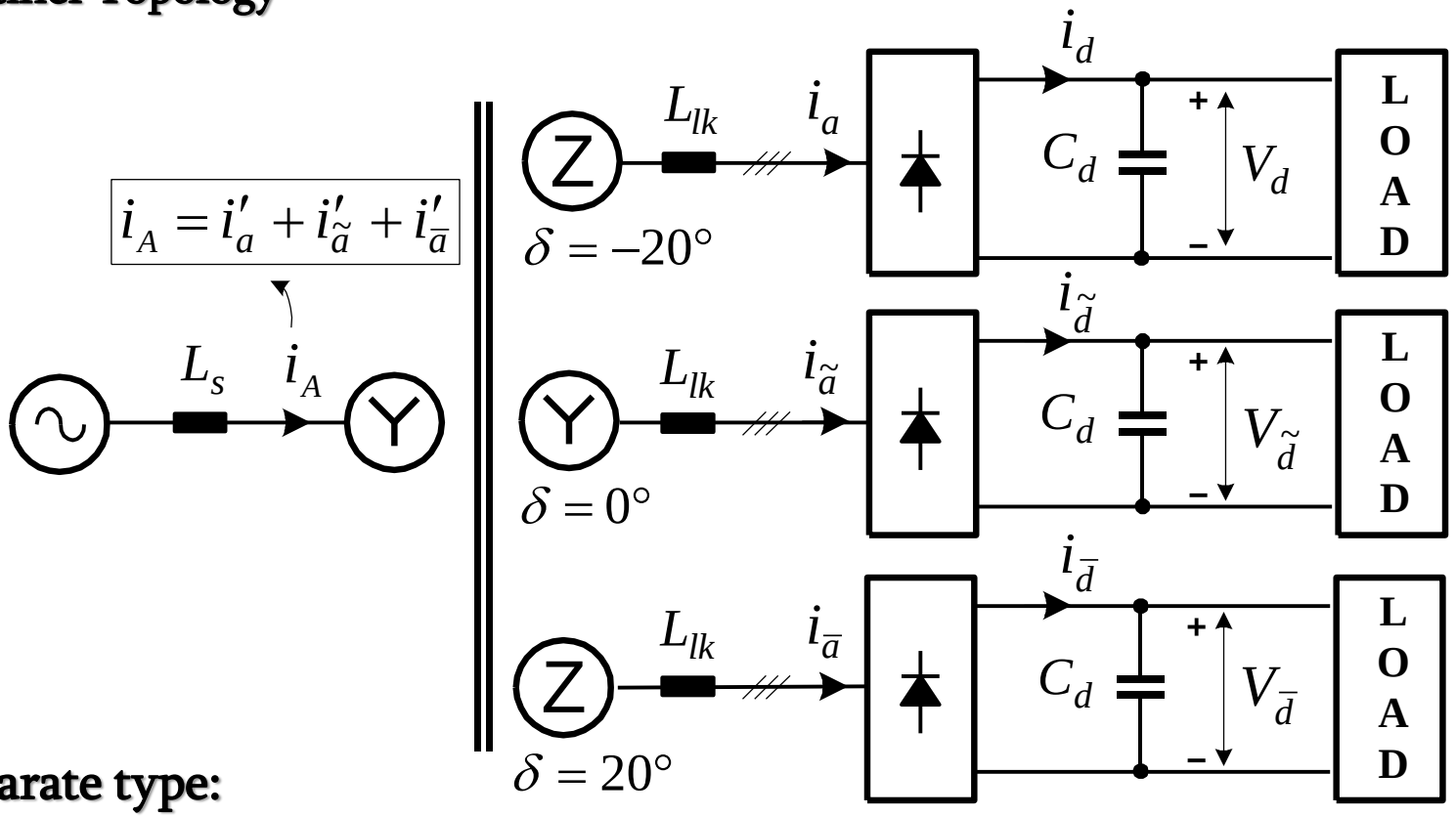
(a) Currents: $\sqrt{2}$ pu/div, 5ms/div



(b) Spectrum: $\sqrt{2}$ /10 pu/div, 200Hz/div

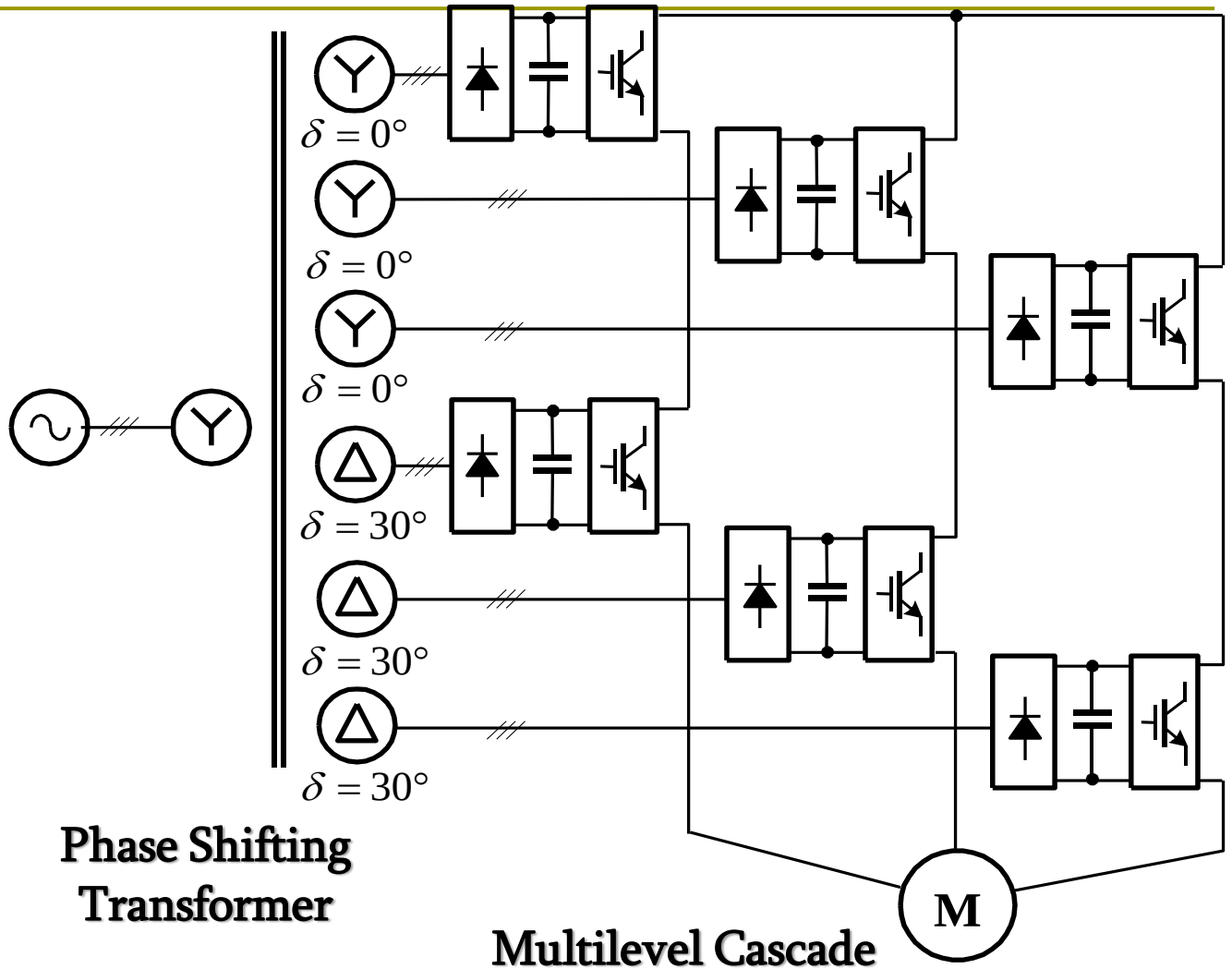
18-pulse Diode Rectifier

- Rectifier Topology



- Separate type:
  Three six-pulse rectifiers
  are in parallel at the output.

Application Example



Phase Shifting Transformer

Multilevel Cascade H-bridge Inverter Fed Drive

Reference

- Book:

High power converters and AC drives, Bin Wu

Thank You

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