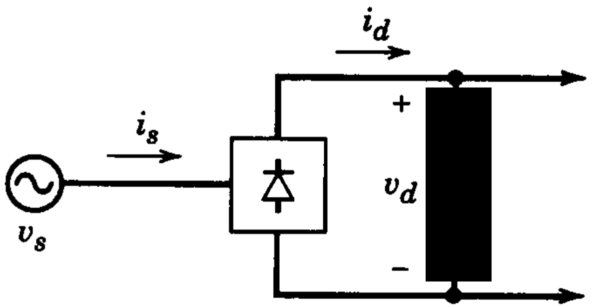
Chapter 2

Diode Rectifiers

a line-frequency diode rectifier:

a line-frequency AC voltage $\rightarrow$ an uncontrolled DC voltage



Uncontrolled utility interface (AC to DC)

DC voltages: a mean (DC) level + *an alternating ripple*

AC currents: non-sinusoidal

$\gamma_f = f_{R(rms)} / f_{mean}$ — ripple factor (DC voltage)

$\xi_f = f_{1(rms)} / f_{rms}$ — distortion factor (AC current)

Study focus:

analyzing waveforms of various rectifiers

DC output: voltage, current waveforms

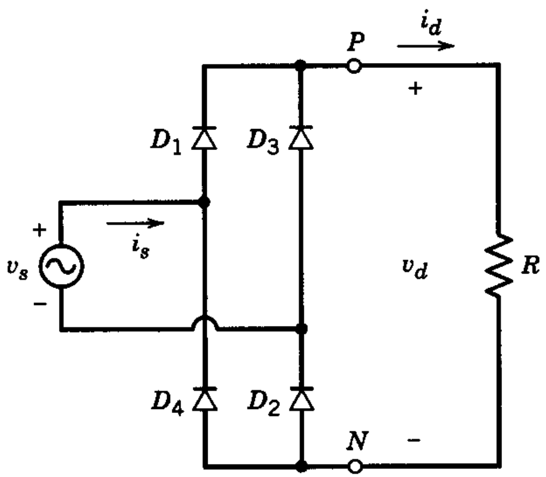
AC input: voltage, current waveforms

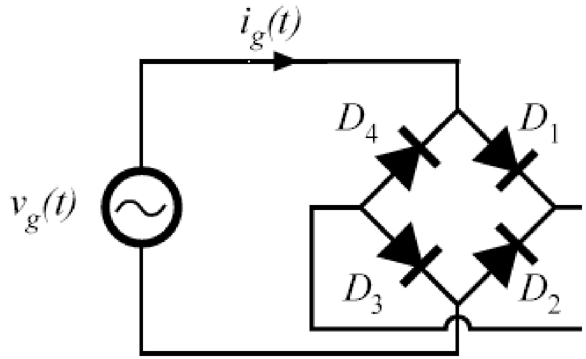
Devices: voltage, current waveforms

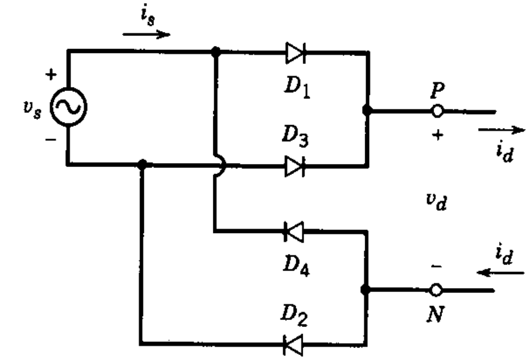
Assumption: 1) volt-drop negligible when conducting;
2) turn-on and turn-off times instantaneous.

a key point: commutation

Single-phase bridge







Load: pure resistance

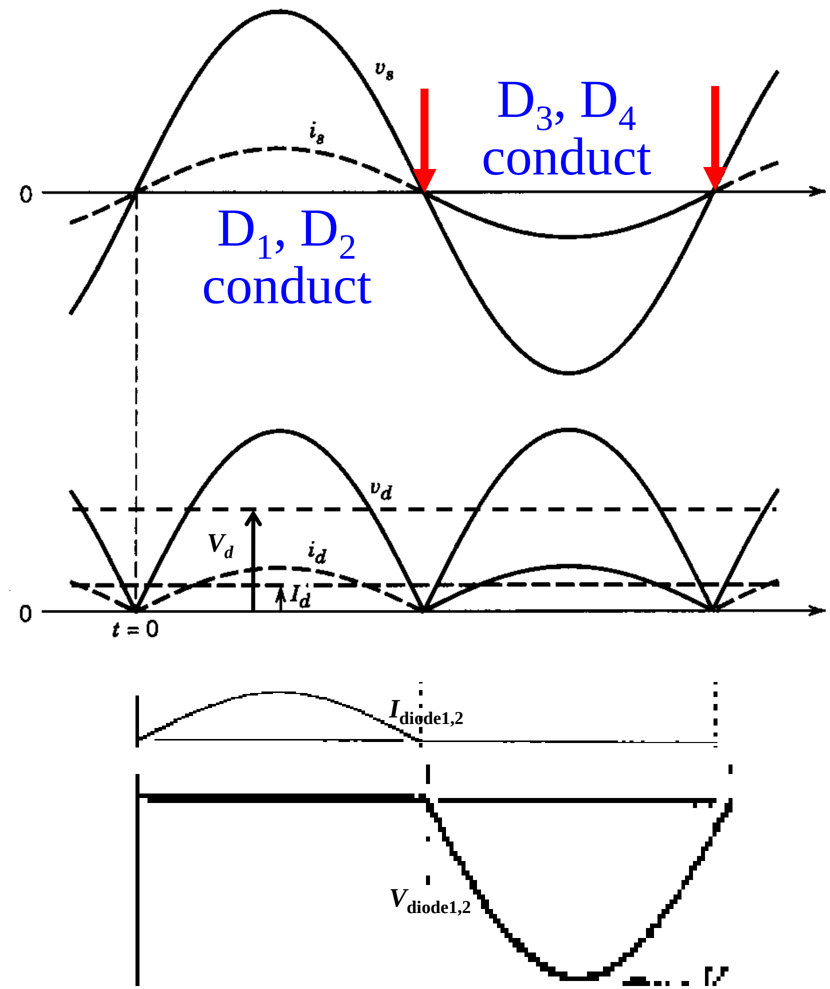
DC output: v_d, i_d

AC input: v_s, i_s

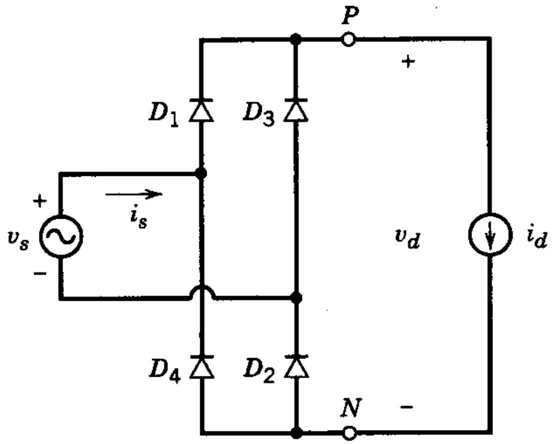
Devices: v_{diode}, i_{diode}

Commutation

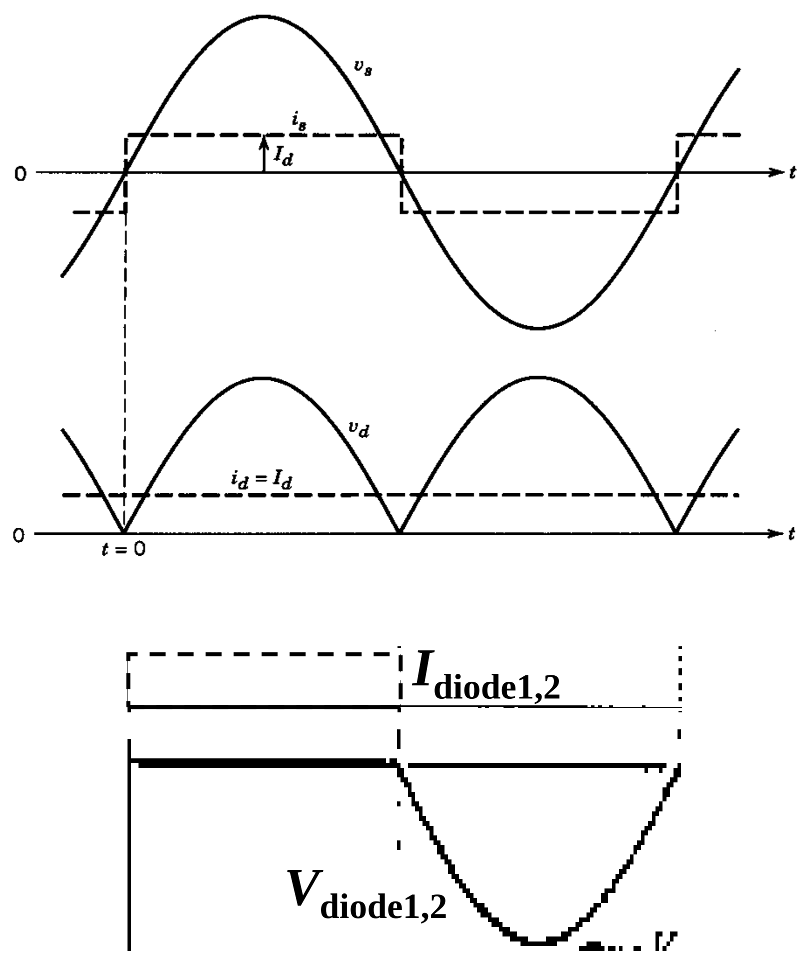
$$V_d = 2V_{smax}/\pi \qquad I_d = V_d/R$$



Single-phase bridge



Inductive Load (R-L)



Load: idealized inductive

DC output: v_d, i_d

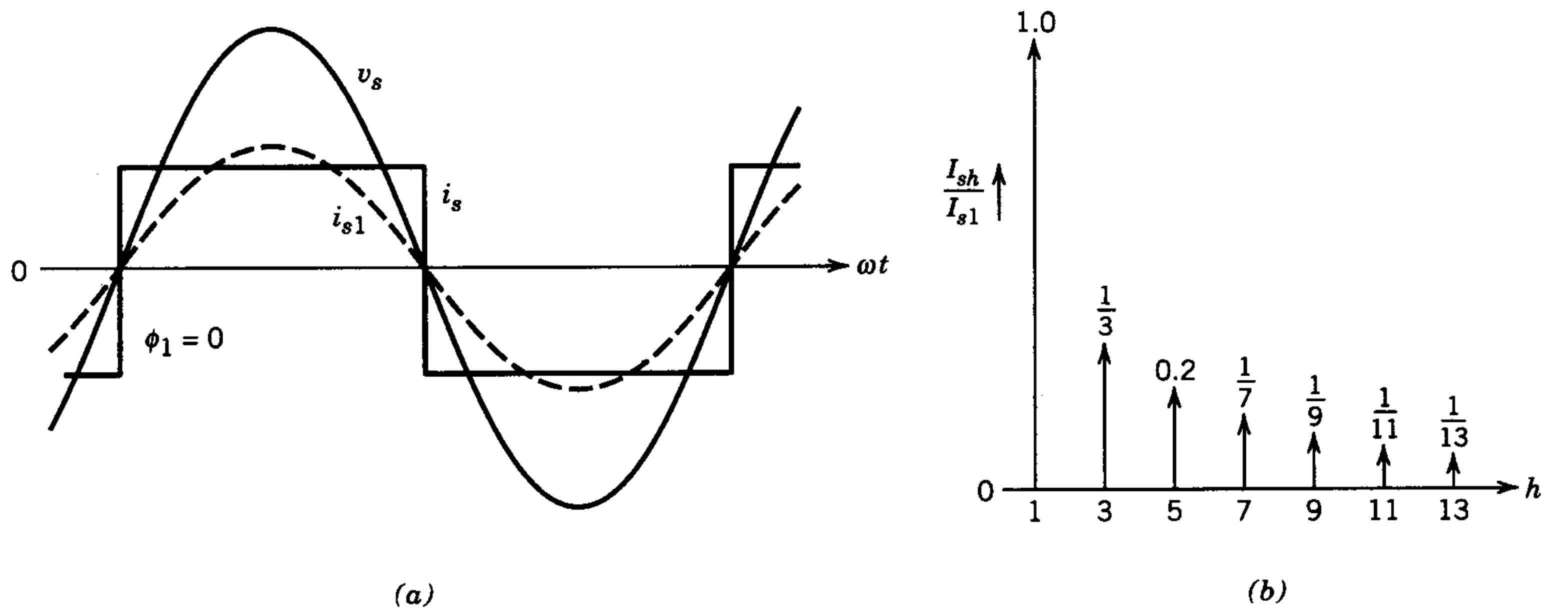
AC input: v_s, i_s

Devices: v_{diode}, i_{diode}

$$V_d = 2V_{smax}/\pi \qquad I_d = V_d/R$$

Single-phase bridge

Input current and its harmonic components



$$I_{s1} = 0.9I_d$$

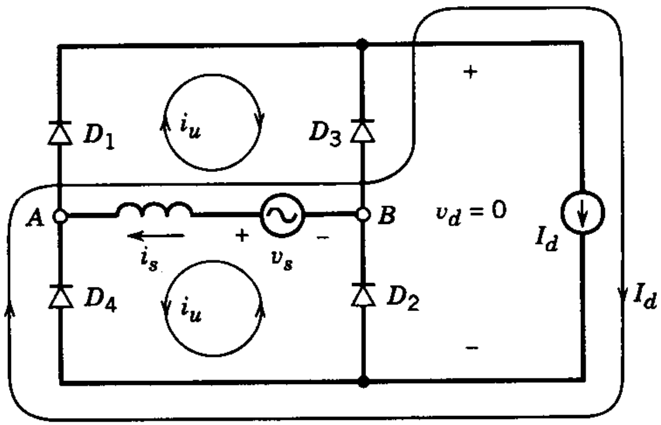
$$\xi \text{ (distortion factor)} = I_{s1}/\, I_s = 0.9$$

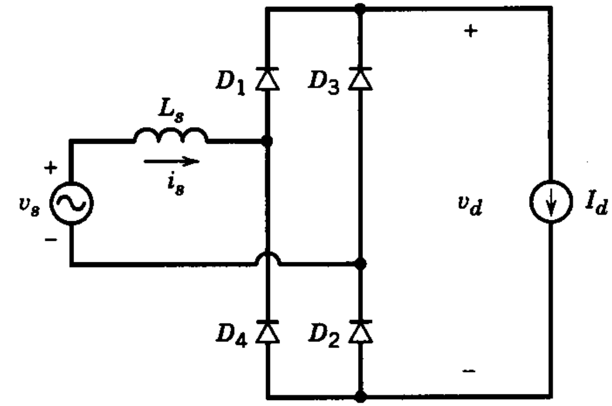
$$\text{PF (power factor)} = \xi \cos\phi_1 = 0.9$$

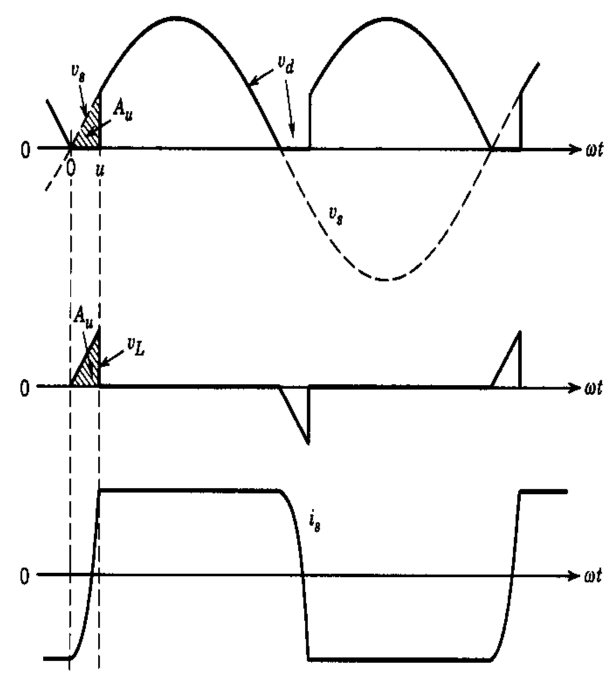
Single-phase bridge

Circuit analysis with ac-side inductance

Understanding current commutation







$$v_s = V_{smax}\sin\omega t = L_s di_s/dt$$

$$[t = 0,\quad i_s = -I_d] \quad \mathbf{i_s = V_{smax}/(\omega L_s) \bullet (1 - \cos\omega t) - I_d}$$

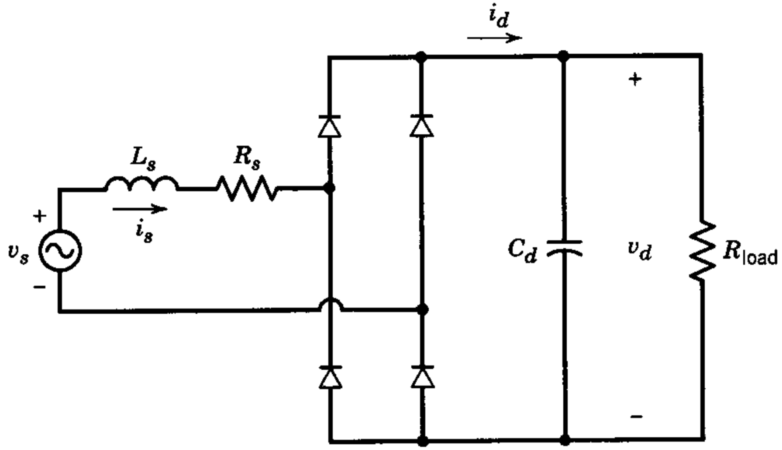
$$\omega t = \boldsymbol{u}\ \textbf{\textit{(overlap angle)}},\quad i_s = I_d$$

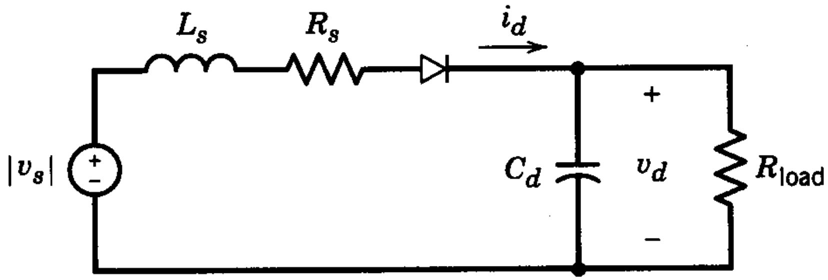
$$I_d = V_{smax}/(\omega L_s) \bullet (1 - \cos u) - I_d$$

$$\mathbf{\cos u = 1 - 2\omega L_s I_d / V_{smax}}$$

$$\mathbf{V_d = V_{smax} / \pi\ (1 + \cos u)}$$

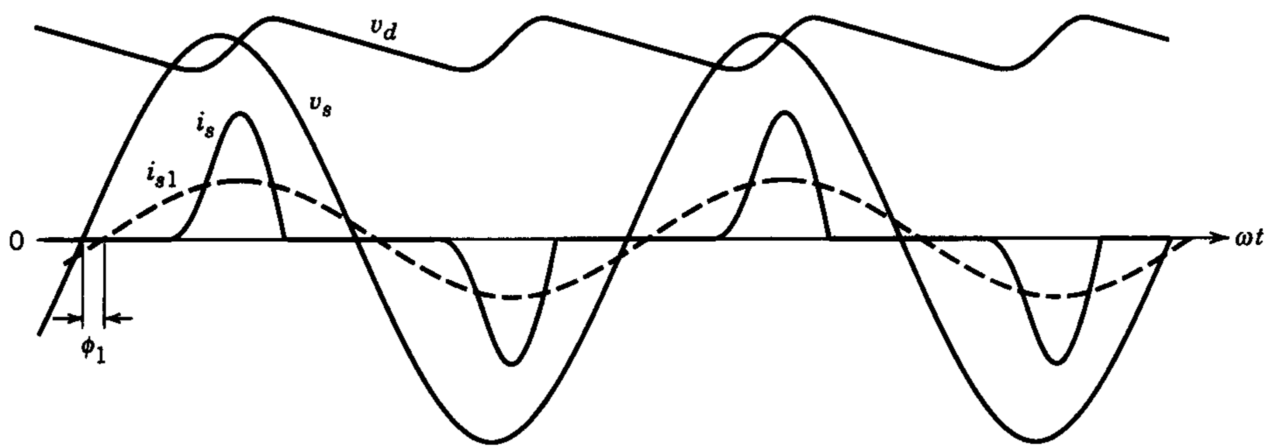
Single-phase bridge





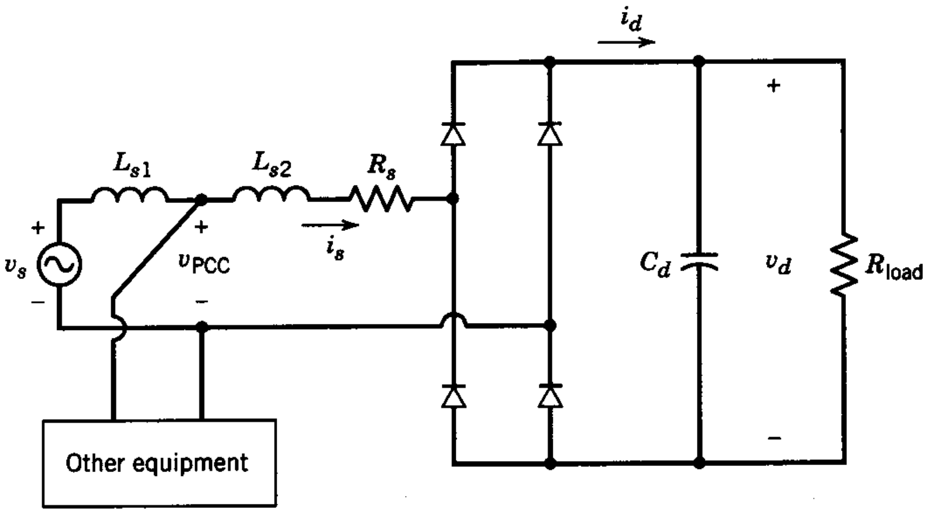
Equivalent circuit on one-half cycle basis

Practical diode-bridge rectifier with a filter capacitor.

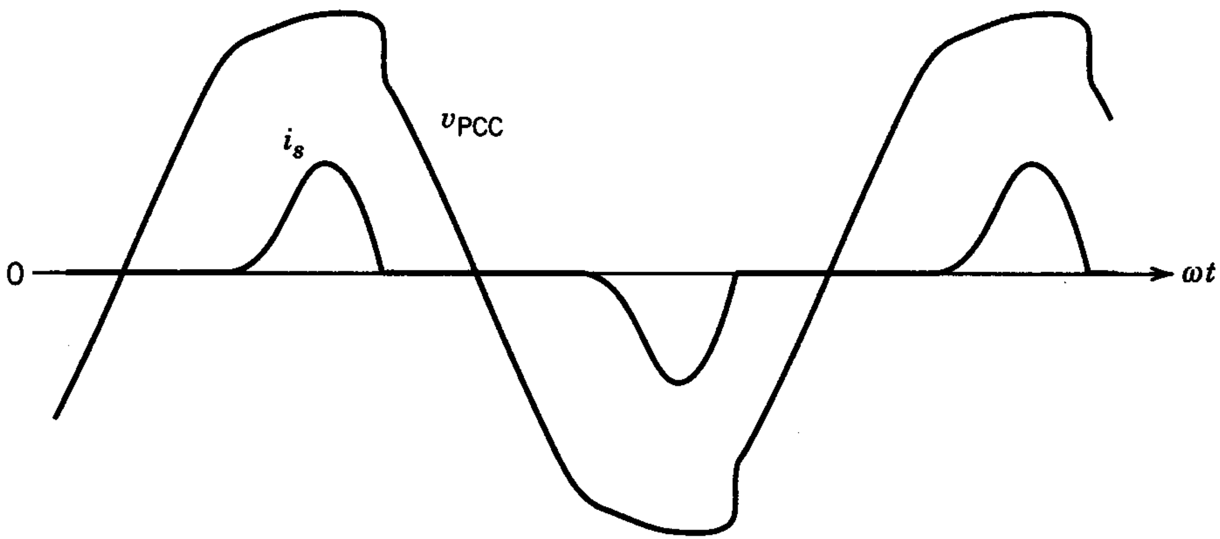


V_s=120V at 60Hz, L_s=1mH, R_s=1mΩ, C_d=100µF, R_{load}=20Ω.

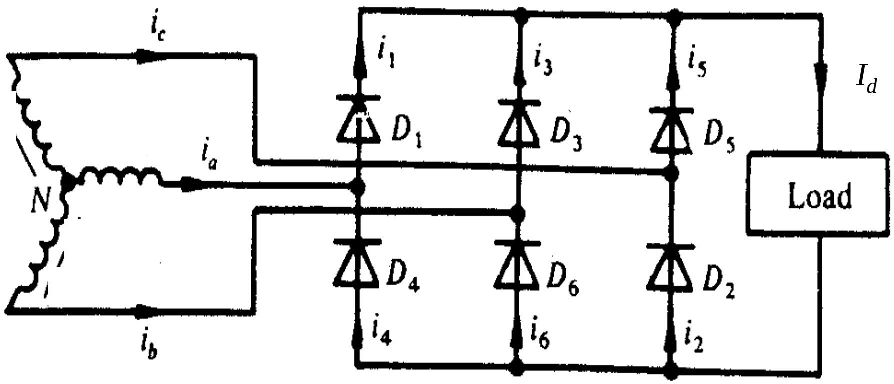
Single-phase bridge

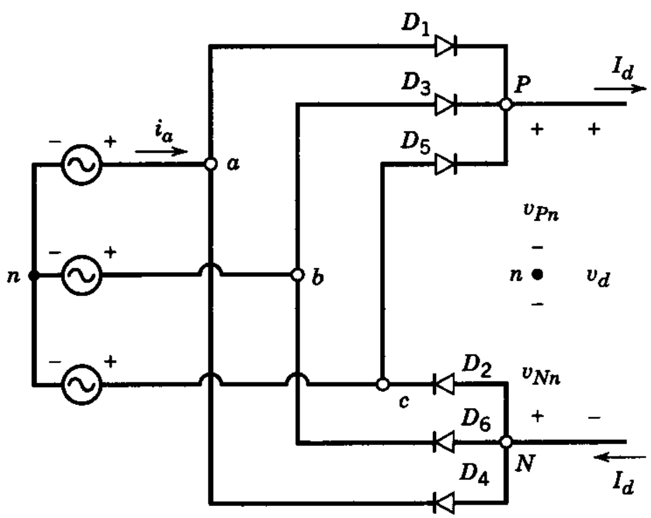


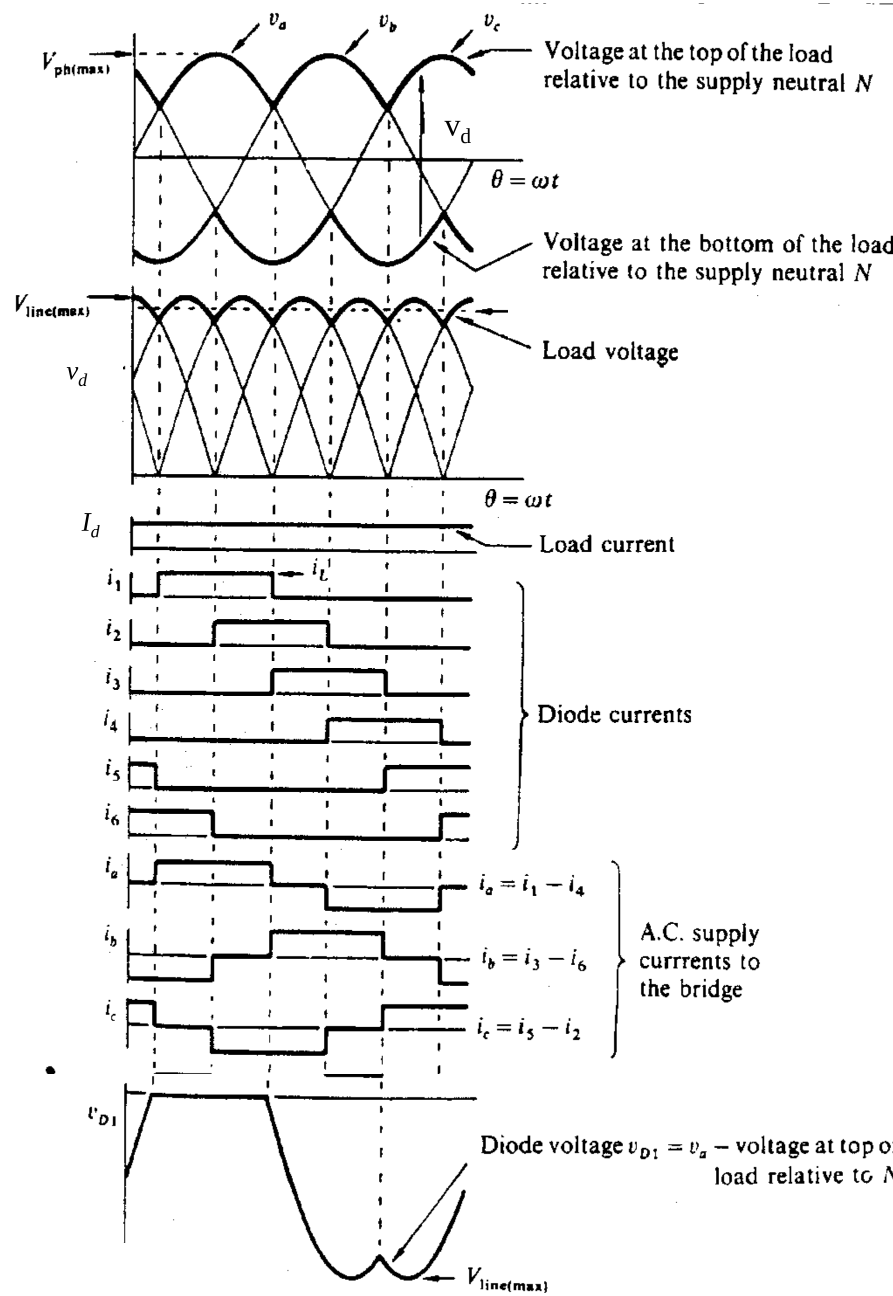
Line-Voltage Distortion



Three-phase bridge





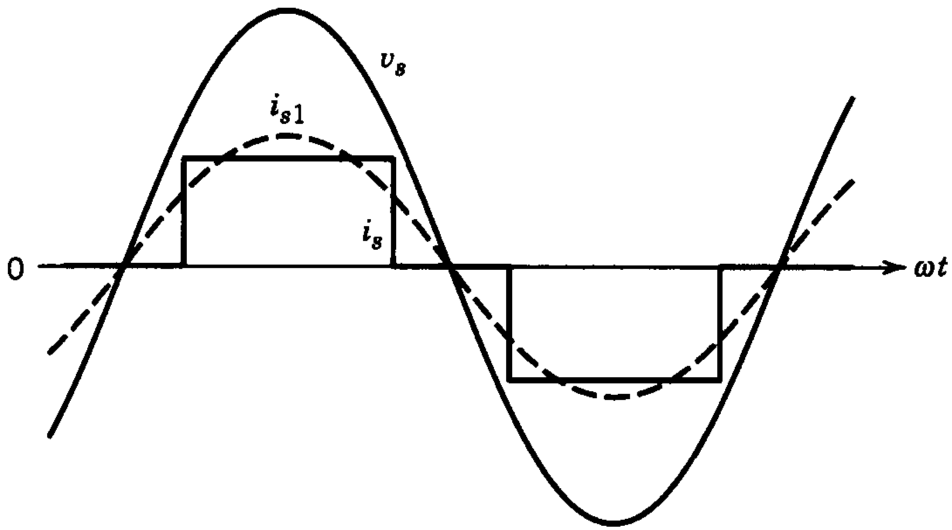


$$V_d = 2 \times 3\sqrt{3}/2\pi \, V_{ph(max)}$$

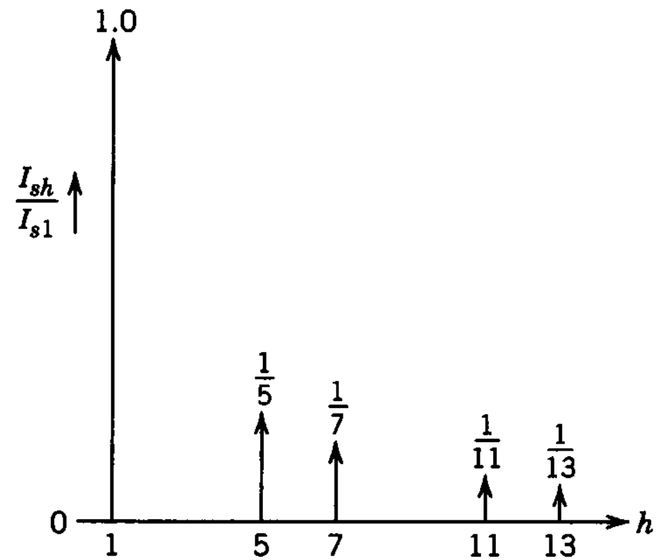
$$= 3/\pi \, V_{line(max)}$$

Three-phase bridge

Input current and its harmonic components



(a)



(b)

$$I_{s1} = 0.78 I_d$$

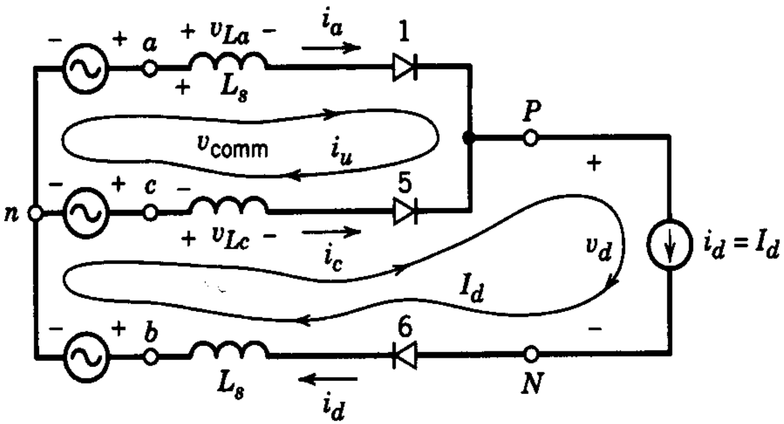
ξ (distortion factor) = I_{s1} / I_s = 0.955

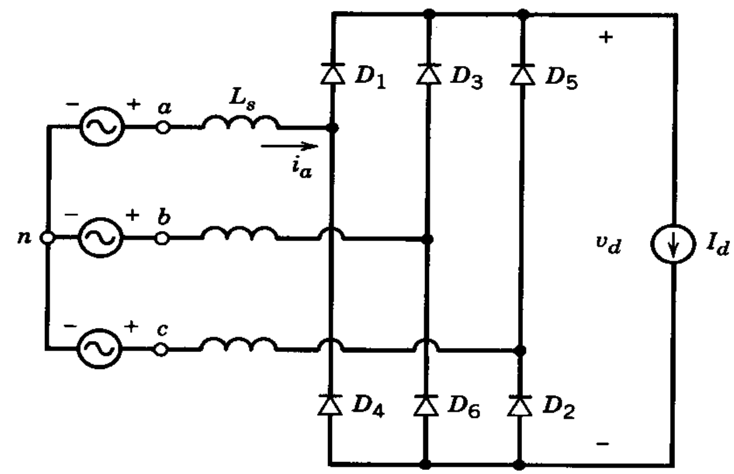
PF (power factor) = $\xi \cos\phi_1$ = 0.955

Three-phase bridge

Circuit analysis with ac-side inductance

Understanding current commutation





$$v_a - v_c = \sqrt{3}V_{line(max)}\sin\omega t = 2L_s di_u/dt$$

$$i_a = i_u, \qquad i_c = I_d - i_u$$

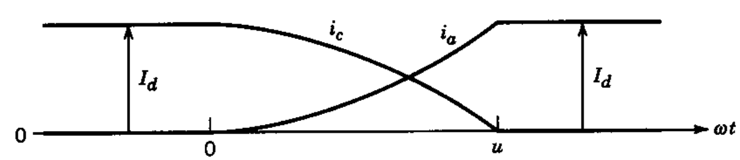
$$t = 0, \quad i_u = 0$$

$$\boldsymbol{i_a = i_u = V_{line(max)}/(2\omega L_s) \bullet (1 - \cos\omega t)}$$

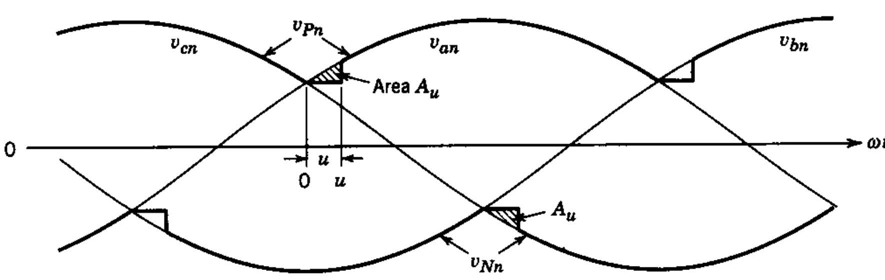
$$\omega t = \boldsymbol{u}, \quad i_a = I_d \qquad (\omega L_s = X)$$

$$\boldsymbol{\cos u = 1 - 2XI_d/V_{line(max)}}$$

$$\boldsymbol{V_d = 3V_{line(max)} / 2\pi\, (1 + \cos u)}$$



(b)



(c)

Diode Rectifiers

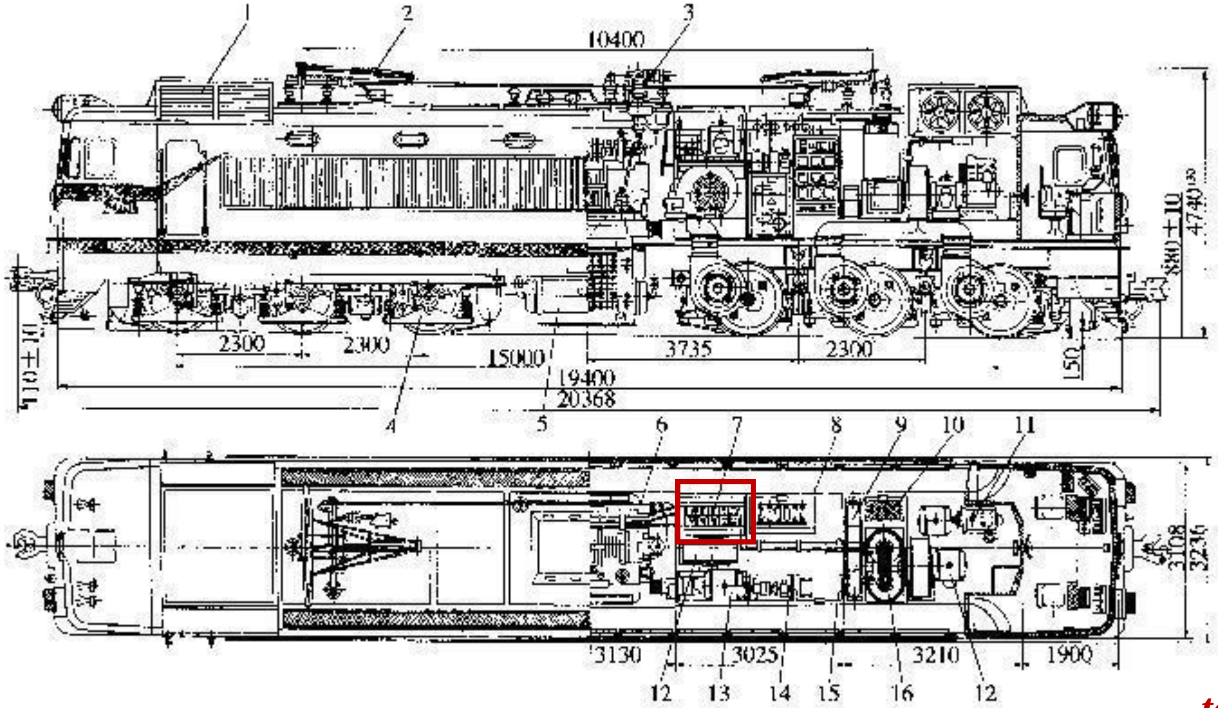
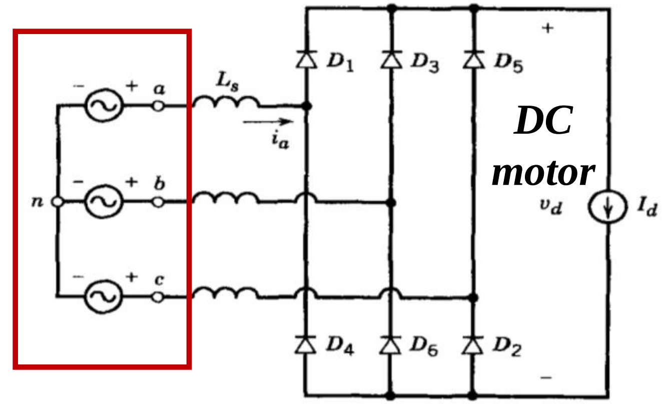


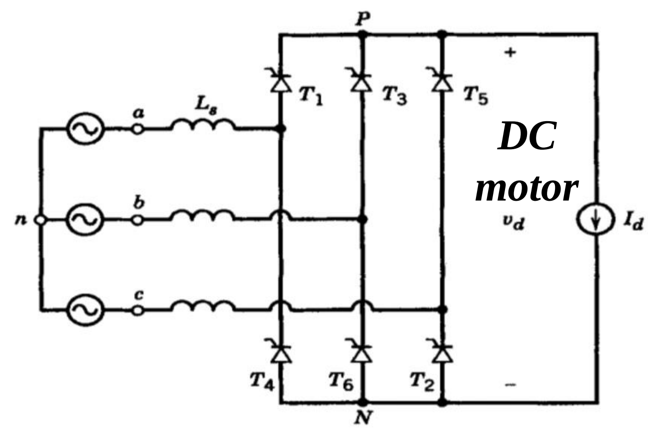
图 3·2·1-1 SS_1 型电力机车总体布置

1—车体；2—受电弓；3—主断路器；4—转向架；5—主风缸；6—主变压器；7—整流柜；8—高压柜；9—蓄电池箱；10—电源柜（Ⅰ）/励磁柜（Ⅱ）；11—压缩机；12—牵引通风机；13—劈相机；14—控制柜（Ⅰ）/升弓压缩机（Ⅱ）；15—低压柜；16—平波电抗器。

SS1, 1968



AC source w/ tapped transformer



Thyristor-based AC/DC

Summary:

- Diode rectifier: uncontrolled AC-DC
- Function analysis according to key waveforms

Key waveforms

DC output:	v_d, i_d
AC input:	v_s, i_s
Devices:	v_{diode}, i_{diode}

Commutation

⇨

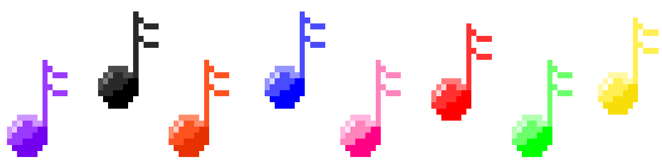
Calculations according to waveforms

DC output:	V_d, I_d
AC input:	I_{s1}, ξ, PF

Considering impact of load and ac-side inductance

Required both for single-phase and three-phase diode rectifiers

The End



Supplement 2-1 Harmonics and Power Factor

Harmonic analysis

Any periodic waveform can be expressed mathematically as a Fourier series.

$$\mathbf{f = f_{mean} + \Sigma a_n \sin n\omega t + \Sigma b_n \cos n\omega t}$$

$$f_{mean} = (1/2\pi)\int_0^{2\pi} f\, d(\omega t)$$

$$a_n = (1/\pi)\int_0^{2\pi} f \sin n\omega t\, d(\omega t), \qquad b_n = (1/\pi)\int_0^{2\pi} f \cos n\omega t\, d(\omega t)$$

$$f_{n(rms)} = 1/1.414 \bullet (a_n^2 + b_n^2)^{1/2}$$

$$f_{rms} = (f_{mean}^2 + \Sigma f_{n(rms)}^2)^{1/2} \qquad f_{R(rms)} = (\Sigma f_{n(rms)}^2)^{1/2}$$

$\mathbf{\gamma_f = f_{R(rms)} / f_{mean}}$ — ripple factor (DC voltage)

$\mathbf{\xi_f = f_{1(rms)} / f_{rms}}$ — distortion factor (AC current)

Power factor

$$\boldsymbol{\lambda = P/S}$$

P − *active mean power*: $P = U_0 I_0 + \Sigma\, U_{n(rms)} I_{n(rms)} \cos\phi_n$

S − *apparent power:* $S = U_{rms} I_{rms}$

supply phase voltage — sinusoidal

$$P = U_{1(rms)} I_{1(rms)} \cos\phi_1, \quad S = U_{1(rms)} I_{rms}$$

$$\boldsymbol{\lambda = \xi_i \cos\phi_1}$$

ξ_i — *input current distortion factor*

$\cos\phi_1$ — *input displacement factor*