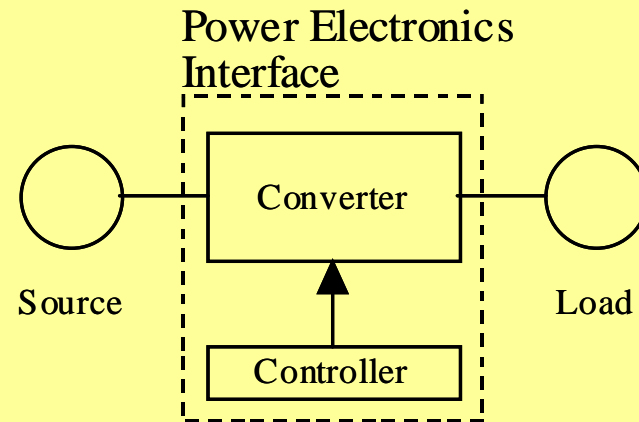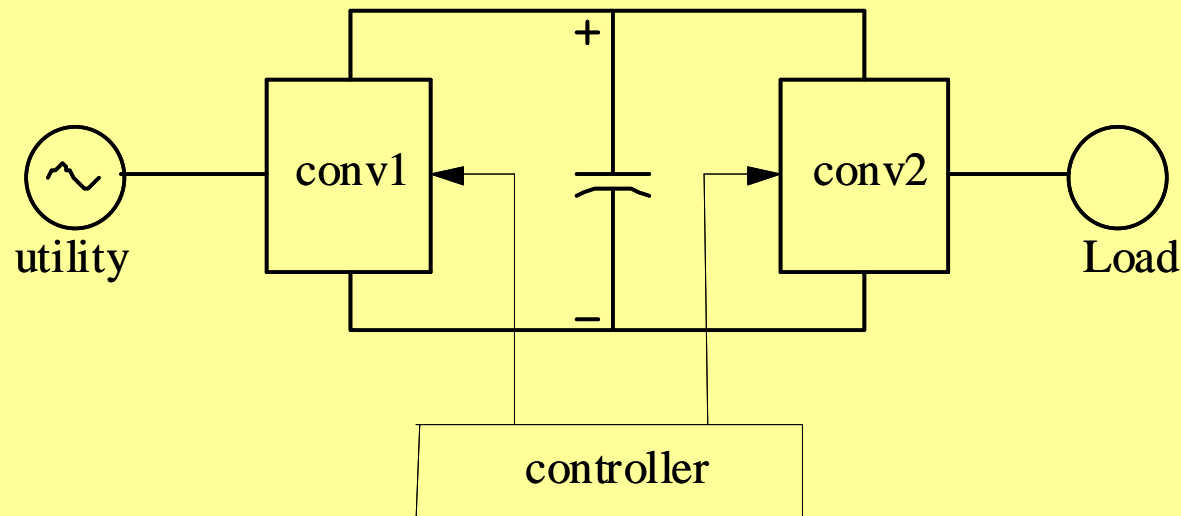# Characterizing the Nonlinear Loads

- Diode Rectifiers: Nonlinear Loads
  - Power Factor (PF)
  - Displacement Power Factor (DPF)
  - Total Harmonic Distortion (THD)
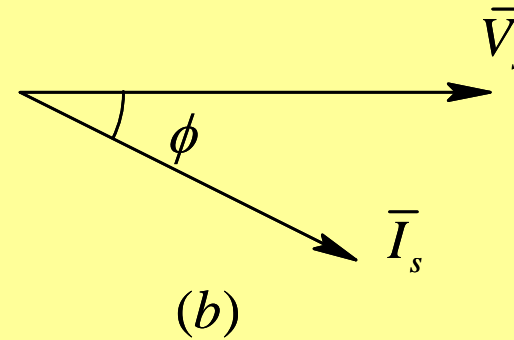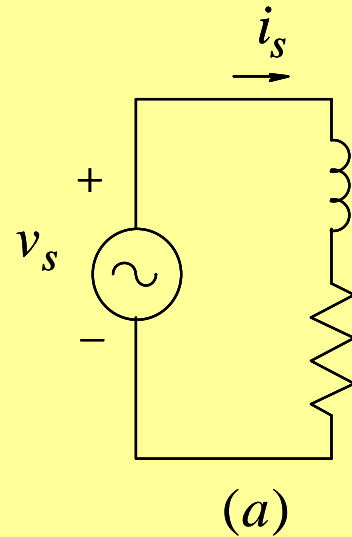- Harmonic Guideline IEEE-519

Power Electronics Interface

Converter

Source

Load

Controller

Voltage-link structure

+

conv1

utility

conv2

Load

−

controller

Linear and Nonlinear Loads

Linear Loads

(a)

(b)
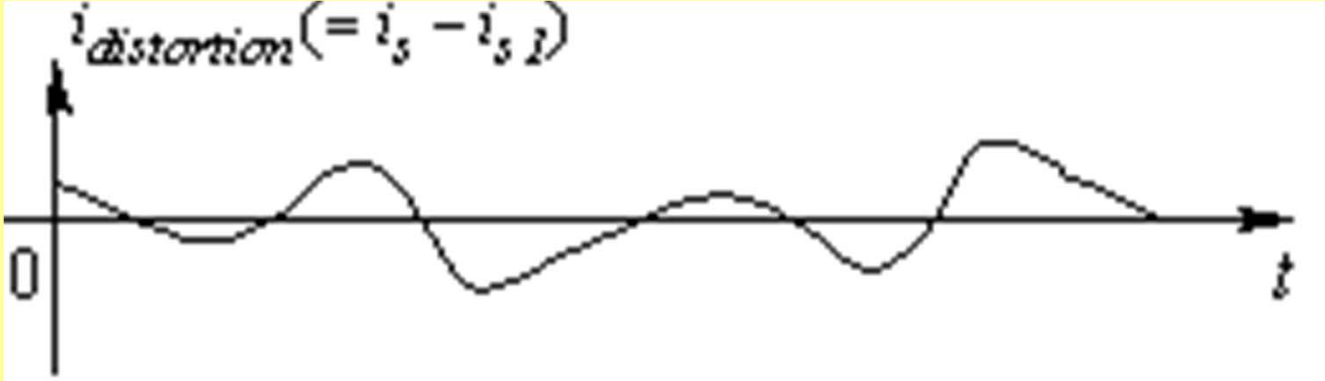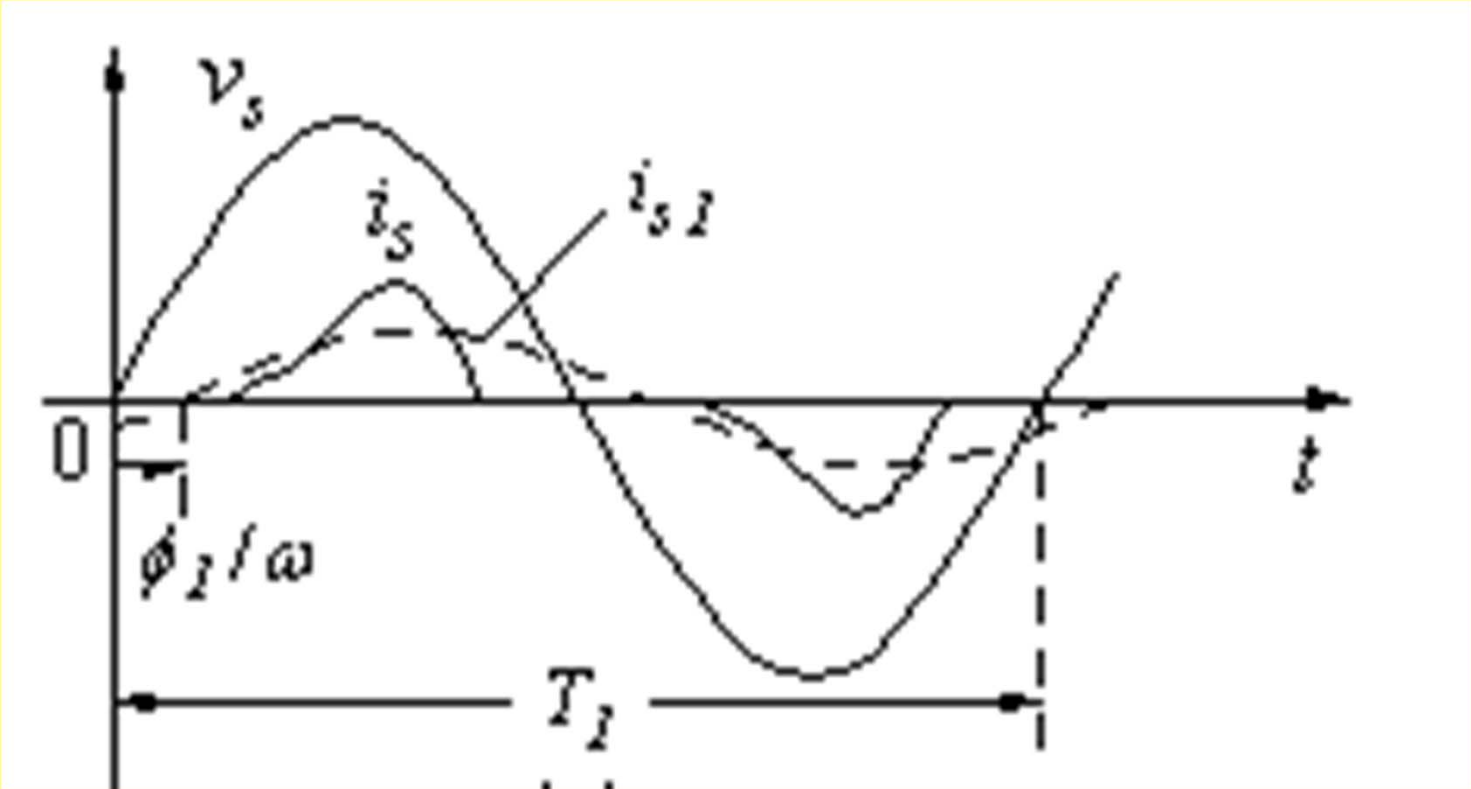
$$P = V_s \, I_s \cos\phi \qquad\qquad PF = \frac{P}{V_s I_s} = \cos\phi$$

$$I_s = \frac{P}{V_s \cdot PF}$$

Nonlinear Loads

Obtaining Harmonic Components by Fourier Analysis

$$g(t) = G_0 + \sum_{h=1}^{\infty} g_h(t) = G_0 + \sum_{h=1}^{\infty} \{a_h \cos(h\omega t) + b_h \sin(h\omega t)\}$$

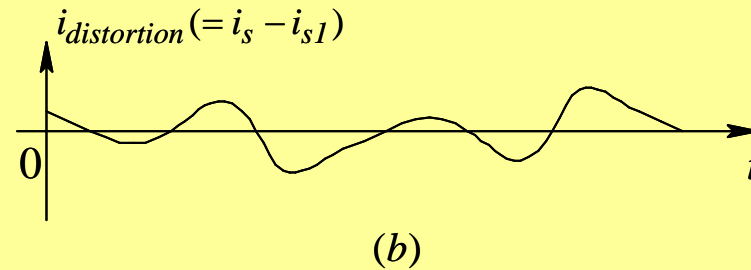$$G_0 = \frac{1}{2\pi} \int_0^{2\pi} g(t) \cdot d(\omega t)$$
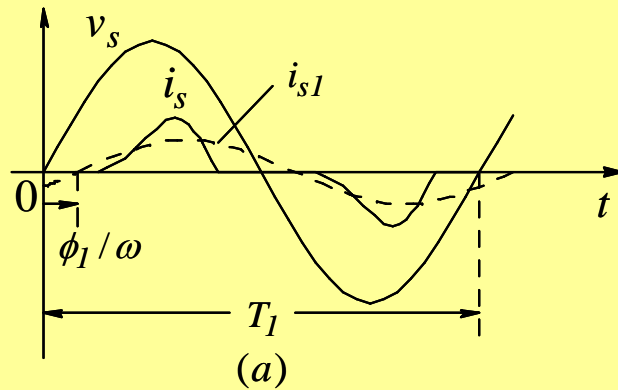
$$a_h = \frac{1}{\pi} \int_0^{2\pi} g(t) \cos(h\omega t) d(\omega t) \quad h = 1, 2, \ldots, \infty$$

$$b_h = \frac{1}{\pi} \int_0^{2\pi} g(t) \sin(h\omega t) d(\omega t) \quad h = 1, 2, \ldots, \infty$$

$$\overline{G}_h = G_h \angle \phi_h \qquad G_h = \frac{\sqrt{a_h^2 + b_h^2}}{\sqrt{2}} \qquad \tan \phi_h = \frac{-b_h}{a_h}$$

$$G = \sqrt{G_0^2 + \sum_{h=1}^{\infty} G_h^2}$$

Nonlinear Loads

(a)

(b)

Total Harmonic Distortion: $\%THD = 100 \times \dfrac{I_{distortion}}{I_{s1}}$
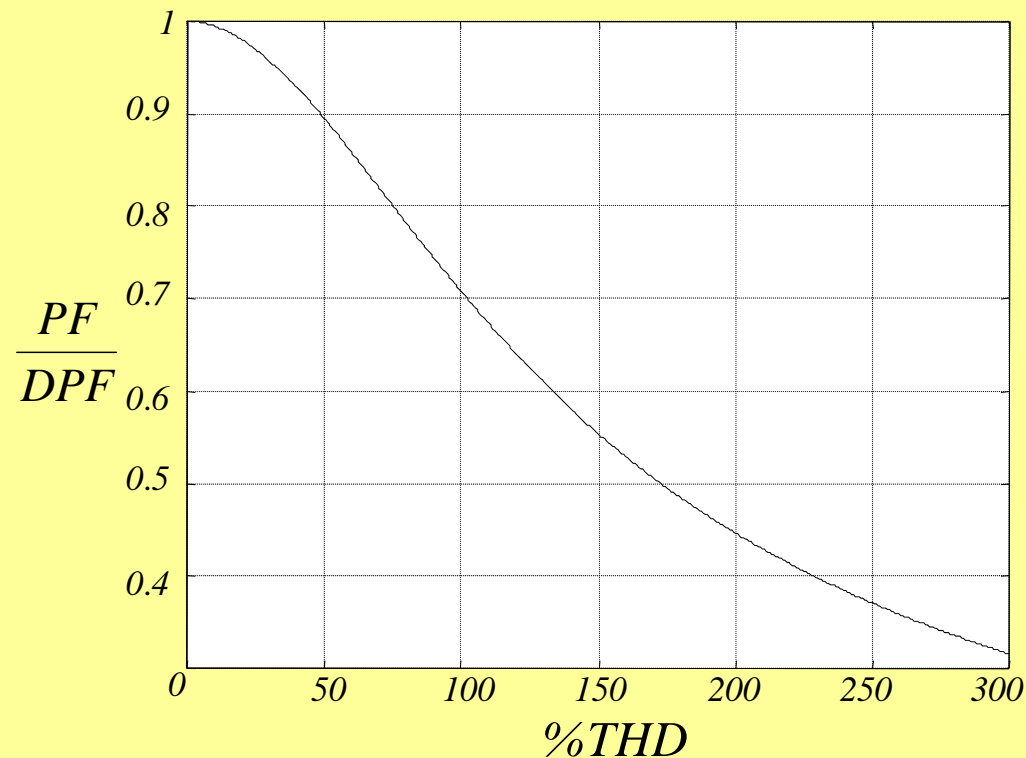
Displacement Power Factor: $DPF = \cos \phi_1$

$$I_s = \sqrt{I_{s1}^2 + I_{distortion}^2}$$

$$P = V_s I_{s1} \underbrace{\cos\phi_1}_{DPF}$$

$$PF = \frac{I_{s1}}{I_s}(DPF) = \frac{DPF}{\sqrt{1+THD^2}}$$

Harmonic Currents Decrease the Power Factor -
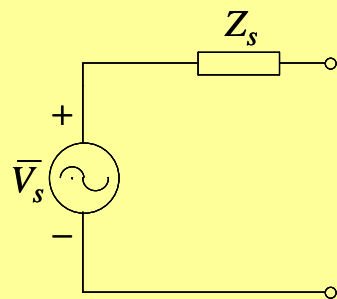
$$\frac{PF}{DPF} = \frac{1}{\sqrt{1+THD^2}}$$

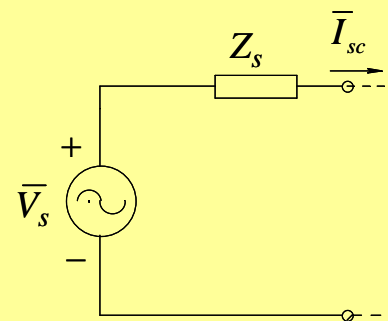❑ Ratio of actual power factor to displacement power factor decreases with increasing THD

Harmonic Guidelines: IEEE – 519

I_{SC}/I_1	Odd Harmonic Order h					Total Harmonic Distortion(%)
	$h < 11$	$11 \le h \le 17$	$17 \le h \le 23$	$23 \le h \le 35$	$35 \le h$	
< 20	4.0	2.0	1.5	0.6	0.3	5.0
20 – 50	7.0	3.5	2.5	1.0	0.5	8.0
50 – 100	10.0	4.5	4.0	1.5	0.7	12.0
100 – 1000	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

Short-Circuit Current: I_{sc}

(a)   (b)

Harmonic Guidelines: IEEE - 519

I_{SC} / I_1	Odd Harmonic Order h					Total Harmonic Distortion(%)
	$h < 11$	$11 \leq h \leq 17$	$17 \leq h \leq 23$	$23 \leq h \leq 35$	$35 \leq h$	
< 20	4.0	2.0	1.5	0.6	0.3	5.0
$20 - 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 - 100$	10.0	4.5	4.0	1.5	0.7	12.0
$100 - 1000$	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

❑ Limits on allowable harmonic currents drawn by loads of various relative magnitudes
❑ Relative magnitude of load currents is based on Short Circuit Ratio (SCR)

Summary

Characterizing the Nonlinear Loads

- Diode Rectifiers as Nonlinear Loads
  - Power Factor (PF)
  - Displacement Power Factor (DPF)
  - Total Harmonic Distortion (THD)
- Harmonic Guideline IEEE-519