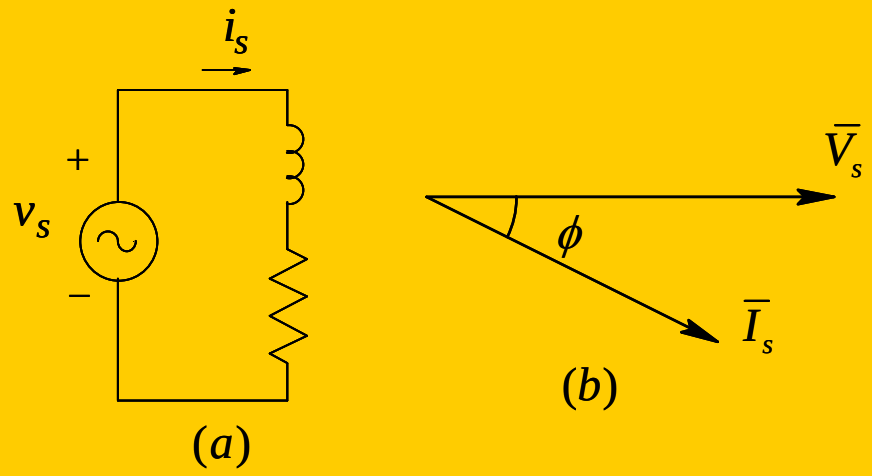
Linear and Nonlinear Loads

Linear Load

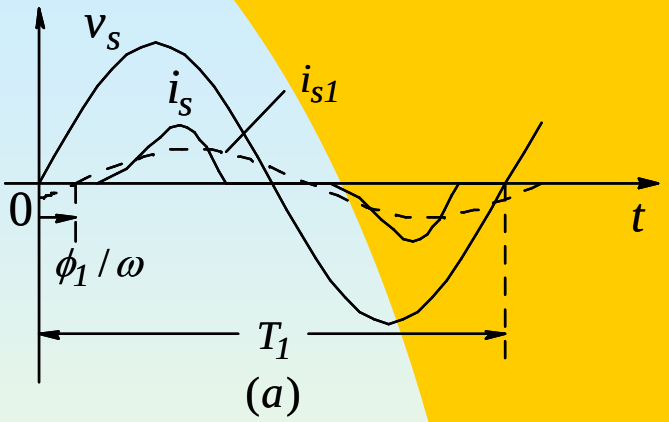


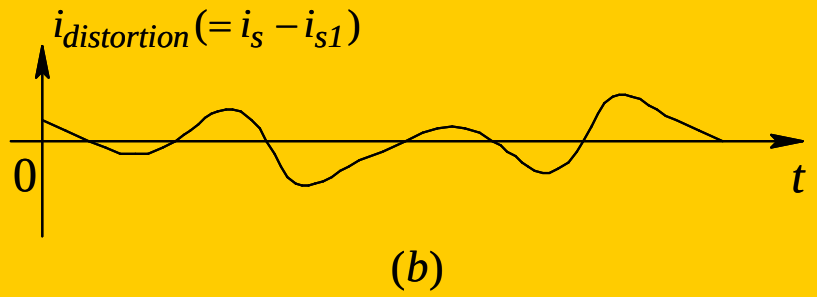
$$P = V_s\, I_s \cos\phi$$

$$PF = \frac{P}{V_s I_s} = \cos\phi$$

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

Nonlinear Loads





Obtaining Harmonic Components by Fourier Analysis

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

$$G_0 = \frac{1}{2\pi}\int_0^{2\pi} g(t) \cdot d(\omega t)$$

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

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

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

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

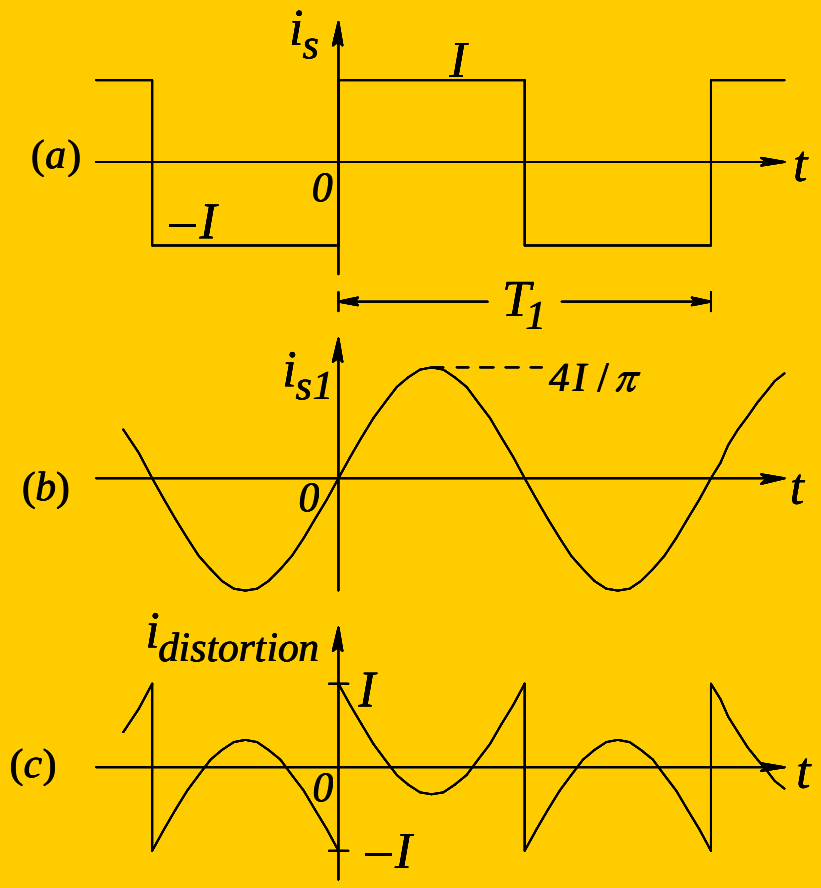
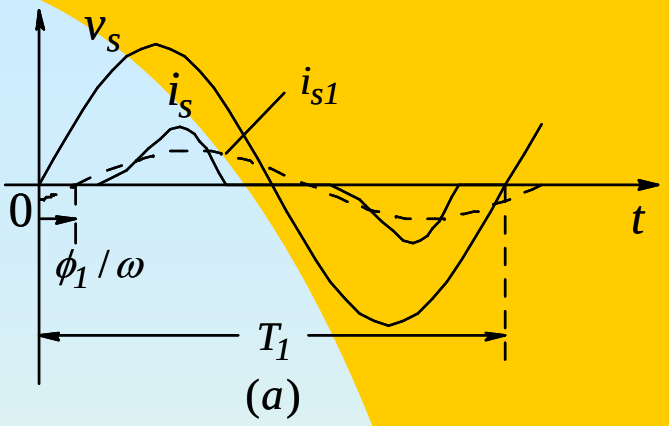
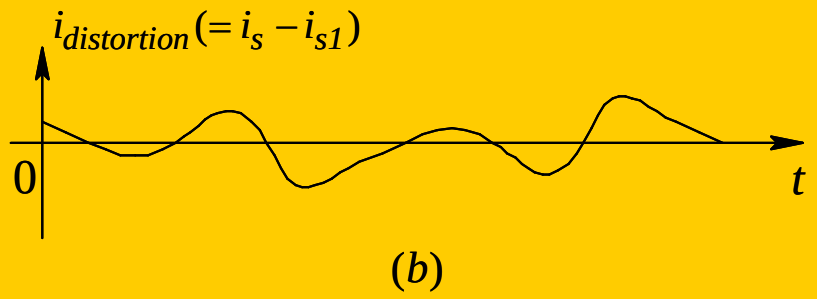


Figure 8-16 Example 8-1.

Nonlinear Loads





Total Harmonic Distortion: $\%THD = 100\ x\ \dfrac{I_{distortion}}{I_{s1}}$

Displacement Power Factor: $DPF = \cos\ \phi_1$

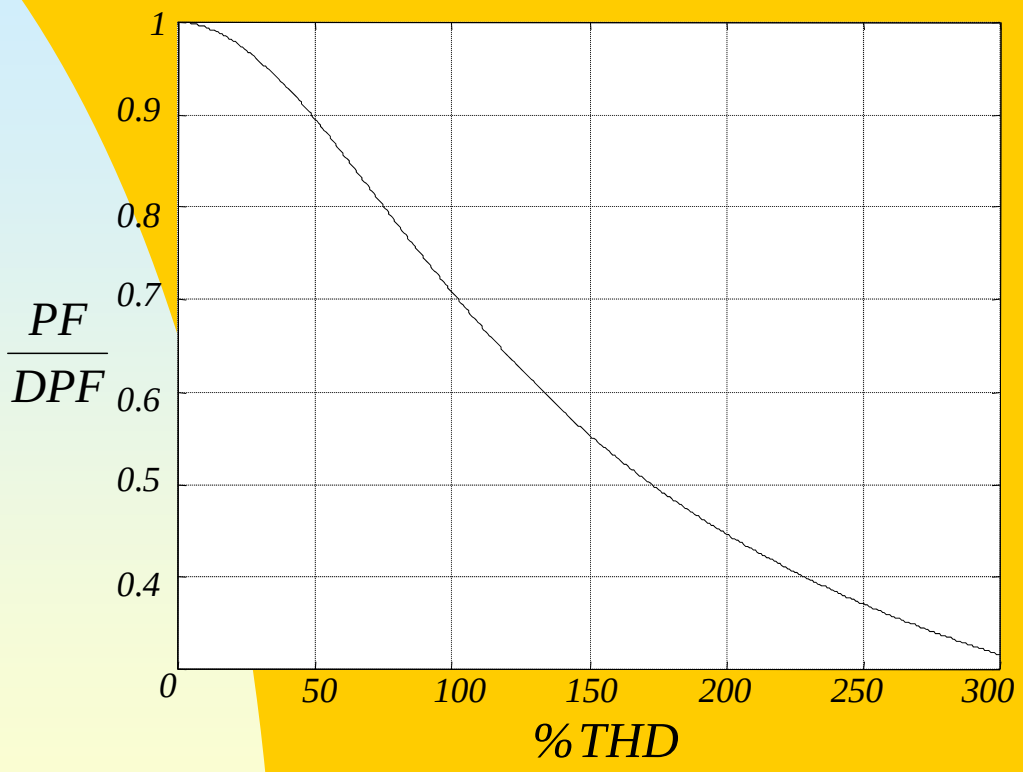
$$I_s = \sqrt{I_{s1}^2 + I_{distortion}^2}$$

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

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

Harmonic Currents Lower 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

	Odd Harmonic Order *h*					Total Harmonic Distortion(%)
I_{SC} / I_1	$h < 11$	$11 \le h \le 17$	$17 \le h \le 23$	$23 \le h \le 35$	$35 \le h$	
< 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*

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

Short-Circuit Current: I_{sc}

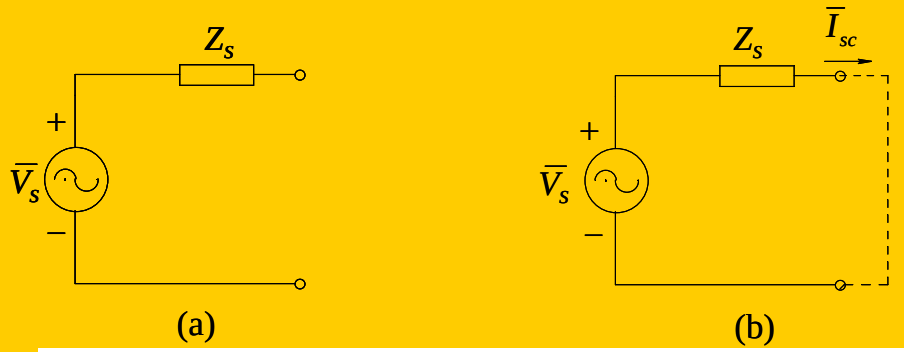


Figure 8-18 (a) Utility Supply, (b) Short-Circuit Current.

Load Management

- Time-of-Day Rate
- Demand-Side Management
- Negotiate with large Customers

Retail Price of Electricity in the U.S.

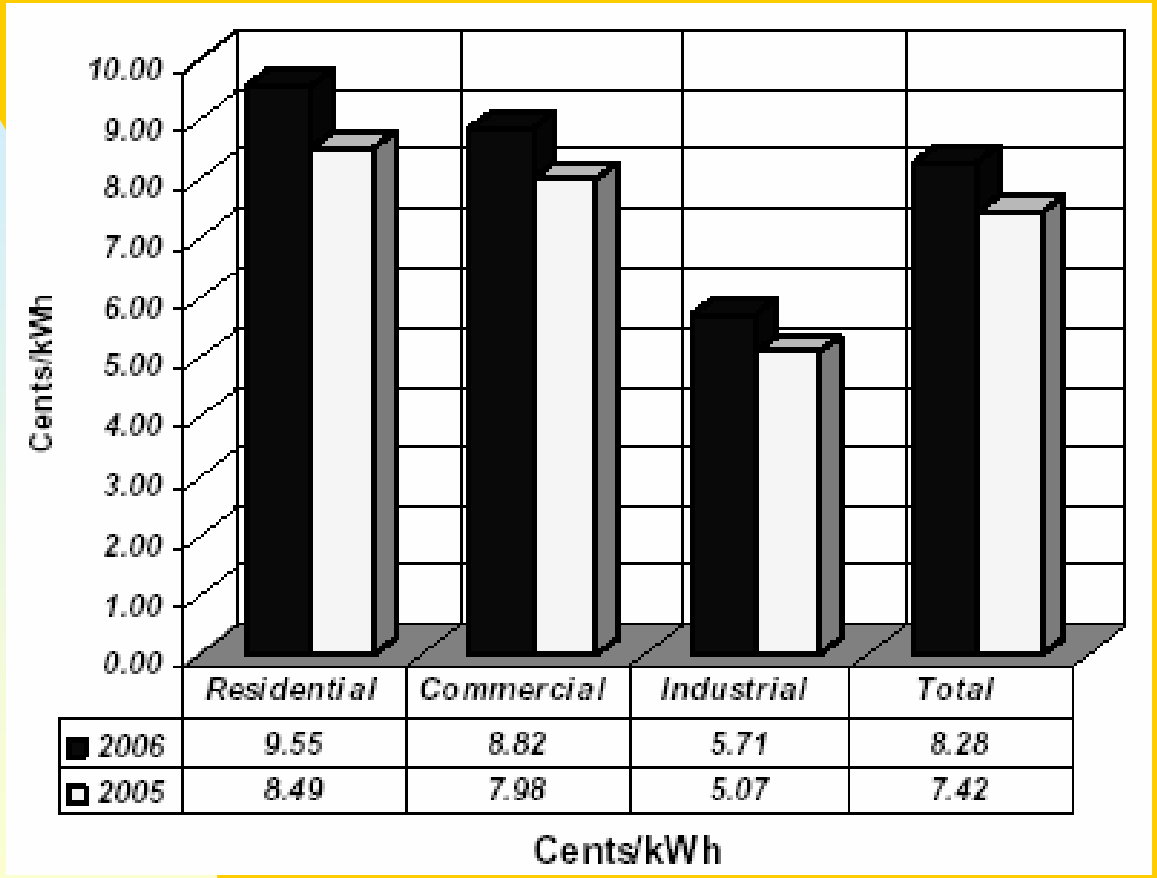


Fig. 8-19 Average retail price of electricity to ultimate customers [4].

Summary

- Distribution Systems
- Power System Loads
- Power-Electronics Based Loads
- Power Quality Considerations
- Load Management
- Price of Electricity