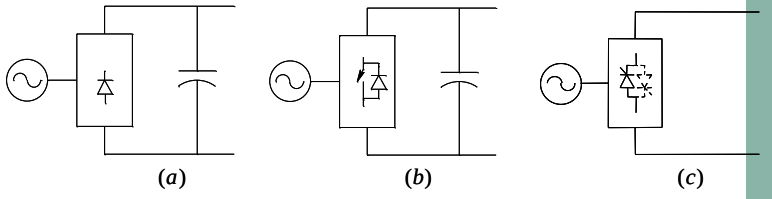
Characterizing the Nonlinear Loads

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

1

1

Types of Rectifier Front-Ends

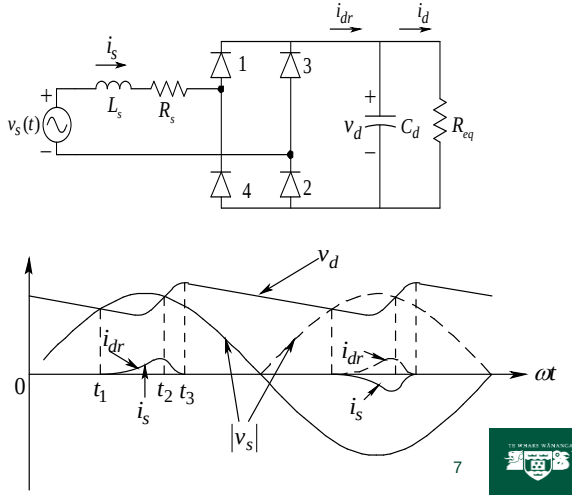


- Diode-bridge rectifiers
- Switch-mode converters
- Thyristor converter

3

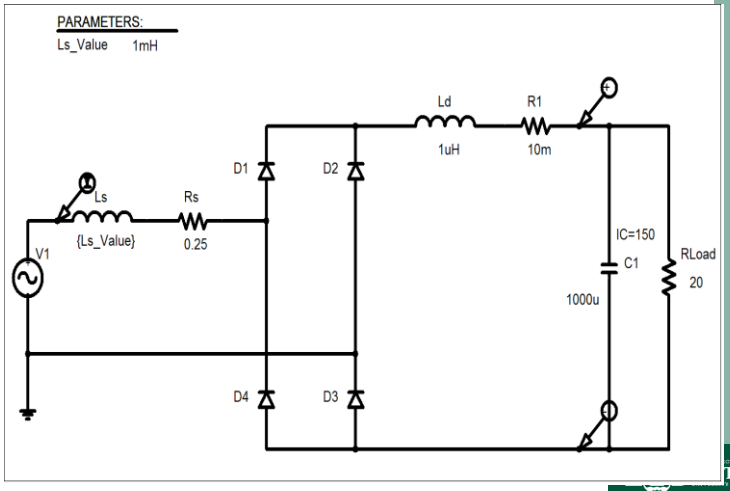
3

Peak-Charging Circuit



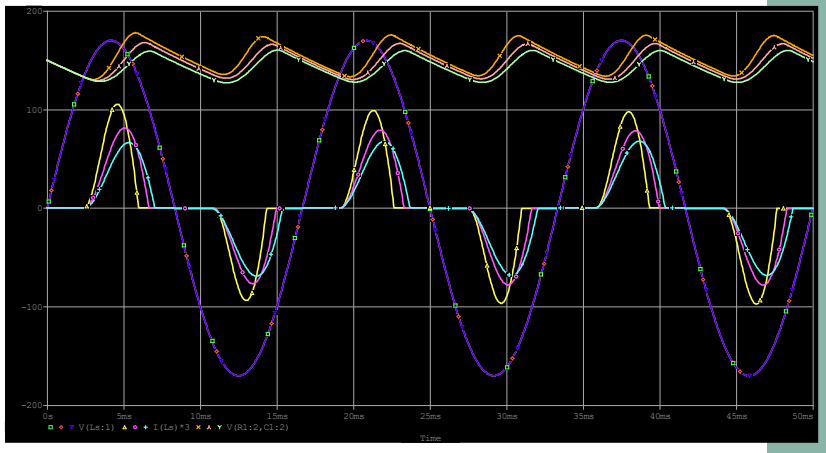
7

PSpice Modeling:



10

Simulation Results

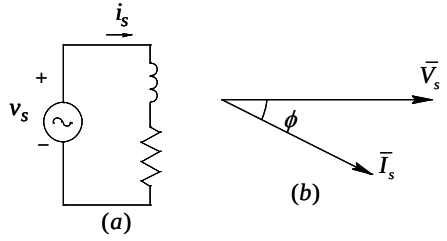


11

11

Linear and Nonlinear Loads

Linear Loads



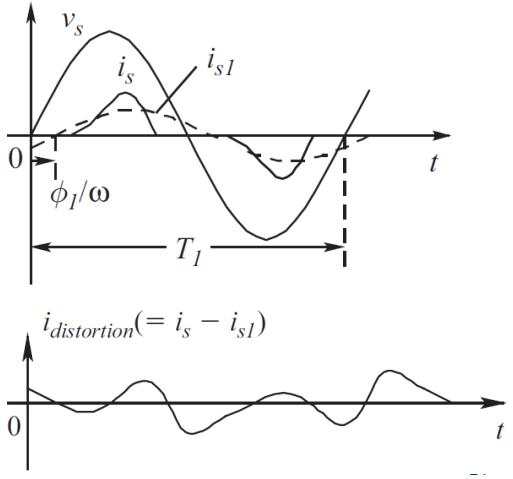
$$P = V_s I_s \cos\phi \qquad PF = \frac{P}{V_s I_s} = \cos\phi$$

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

13

13

Nonlinear Loads



14

Why do harmonics occur?

- When a sine wave is applied to magnetic components (Transformers, Motors, Inductors, Capacitors), The current draw from the them is nonlinear to maintain the EM.
- The magnitude of harmonic current is different for order of Harmonic.
- The lower the harmonic, the higher the current (relative)

15

15

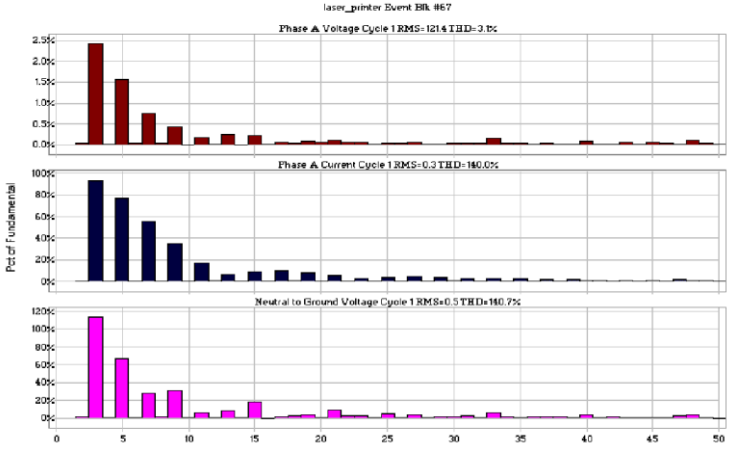
Why Harmonics

- If we have a drive that has the fundamental current of 100A at 50 Hz,
- Then current at second harmonic is 50A
- Fifth is 20A (100/5)
- 7th is 14.28
- Combining these values – 84.28
- This is the extra apparent power that the supply has to provide.
- But who uses it?

16

16

Example Harmonics



17

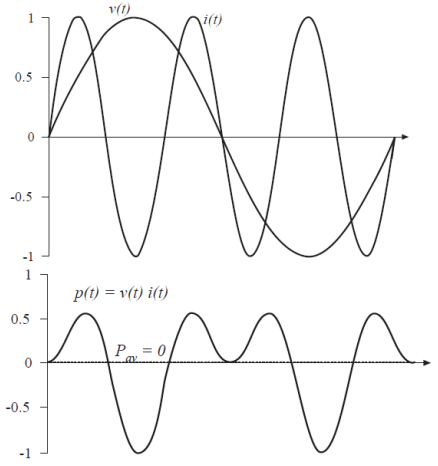
17

Example

Voltage: fundamental only

Current: third harmonic only

Power: zero average



18

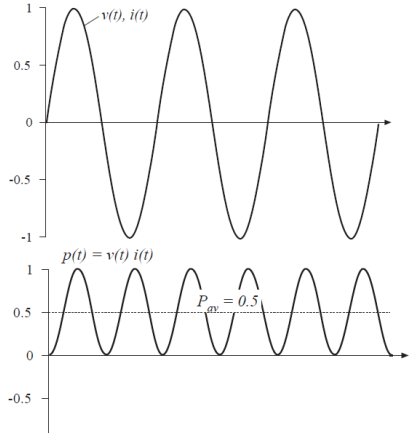
18

Example 2

Voltage: third harmonic only

Current: third harmonic only, in phase with voltage

Power: nonzero average



19

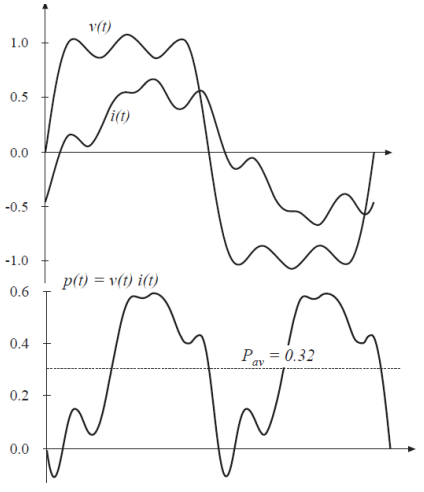
19

Example 3

Voltage: 1st, 3rd, 5th

Current: 1st, 5th, 7th

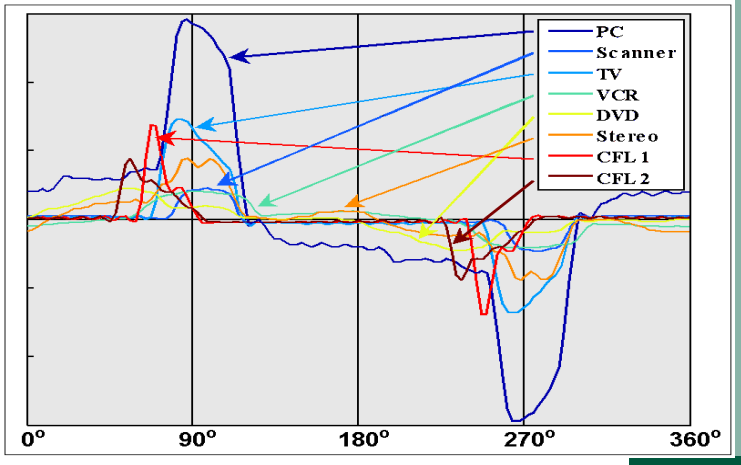
Power: net energy is transmitted at fundamental and fifth harmonic frequencies



20

20

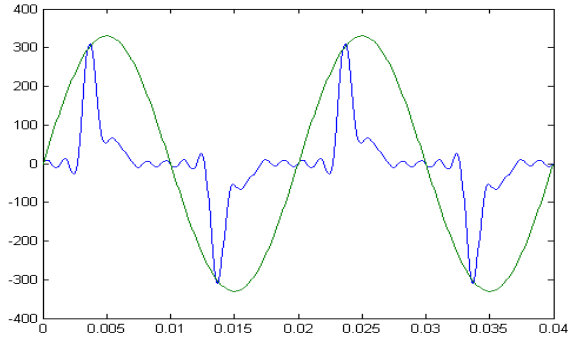
Current Load profiles



21

21

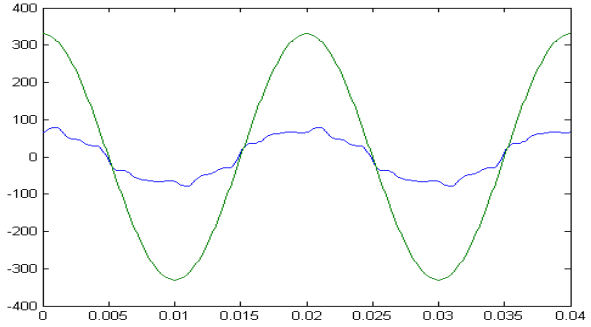
Low PF



22

22

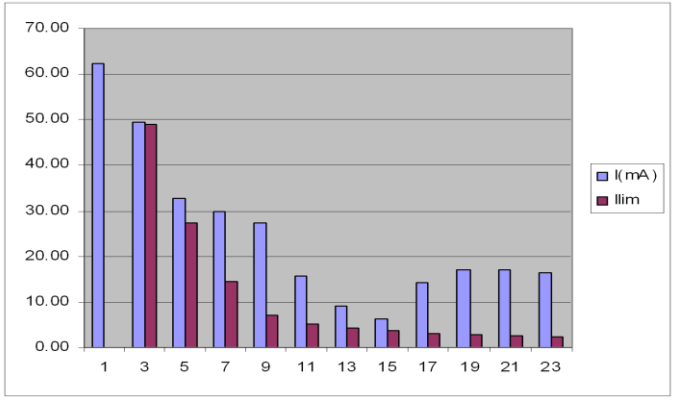
High PF



23

23

LPF Harmonics

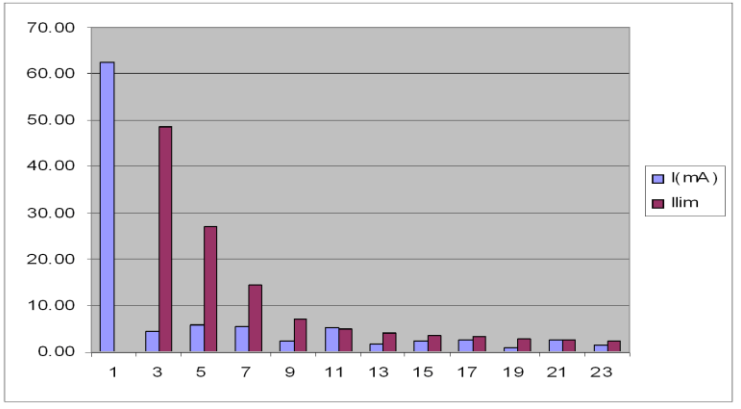


24

VICTORIA UNIVERSITY OF WELLINGTON

24

HPF Harmonics



25

VICTORIA UNIVERSITY OF WELLINGTON

25

Harmonic Interaction

	LPF Lamp1	LPF Lamp2	Combined Load
Power	13.5W	13.8W	27.3W
Irms	108mA	99.5mA	199mA
PF	0.51	0.56	0.57
THDi	145.25%	118.79%	128.15%
K-Factor	52.98	44.65	46.91

26

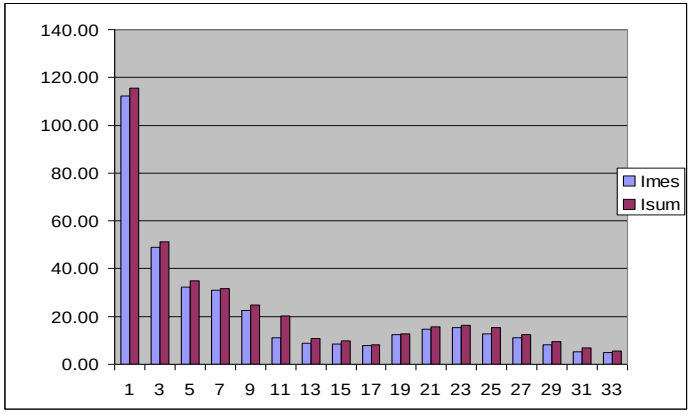
26

	HPF Lamp	LPF Lamp	Combined Load
Power	12.8W	13.2W	26.0W
Irms	56.4mA	99.6mA	143mA
PF	0.94	0.56	0.76
THDi	18.12%	126.85%	70.51%
K-Factor	4.83	85.60	38.66

27

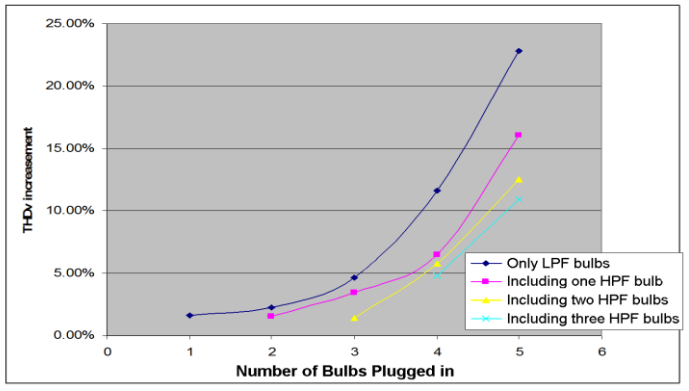
27

FFT of combined LPF and HPF



28

28



29

29

Obtaining Harmonic Components by Fourier Analysis

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

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

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

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

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

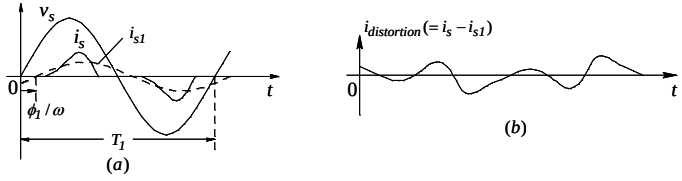
$$G = \sqrt{G_0^2 + \sum_{h=1}^{\infty} G_h^2}$$

Link

30

30

Nonlinear Loads



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

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

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

$$P = V_s I_{s1}\cos\phi_1$$

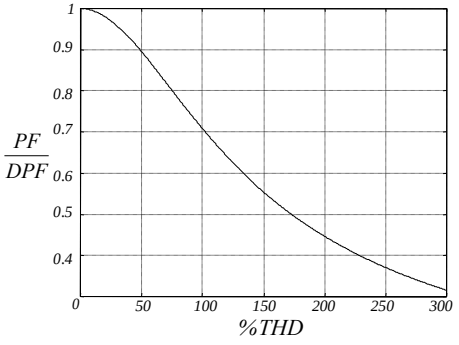
$$PF = \frac{I_{s1}}{I_s}(DPF) = \frac{DPF}{\sqrt{1+THD^2}}$$

31

31

Harmonic Currents Decrease the Power Factor -

$$\frac{PF}{DPF} = \frac{1}{\sqrt{1+THD^2}}$$

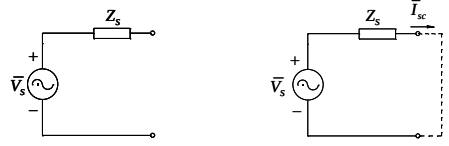


- Ratio of actual power factor to displacement power factor decreases with increasing THD

Harmonic Guidelines: IEEE – 519

	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

Short-Circuit Current: I_{sc}



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)

34

34

AS/NZS 61000.3.2 (2009)

Table 3 – Limits mainly for Class D equipment

NOTE - Refer to Clause 7.3b) for limits for Class C equipment

Harmonic order n	Maximum permissible harmonic current per watt mA/W	Maximum permissible harmonic current A
3	3,4	2,30
5	1,9	1,14
7	1,0	0,77
9	0,5	0,40
11	0,35	0,33
$13 \le n \le 39$ (odd harmonics only)	$\frac{3,85}{n}$	See Table 1

35

35

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

Concept Quiz

For a given Power P drawn by a load at a given voltage level, the current drawn by that load is larger in magnitude if the power factor is smaller.

A. True (correct)

B. False

Clicker Quiz

A power-electronic load is supplied by a sinusoidal utility-source with the rms voltage of 120 V. The rms value of the current drawn is 10 A. The fundamental-frequency component of the current drawn has the rms value of 8 A, and it lags the utility voltage waveform by 15 degrees.

Calculate the power factor of operation for this load.

A. 0.966
B. 0.773
C. 0.8
D. None of the above

38

VICTORIA UNIVERSITY OF WELLINGTON

38