Power Quality
Notes 1-2 (AK)

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Class #1 - Hour #2 (4/5/05) Introduction to Voltage Distortion

- Definitions
- CBEMA Curve
- Causes of Voltage Distortion
- Distribution of Voltage Sags

Definitions

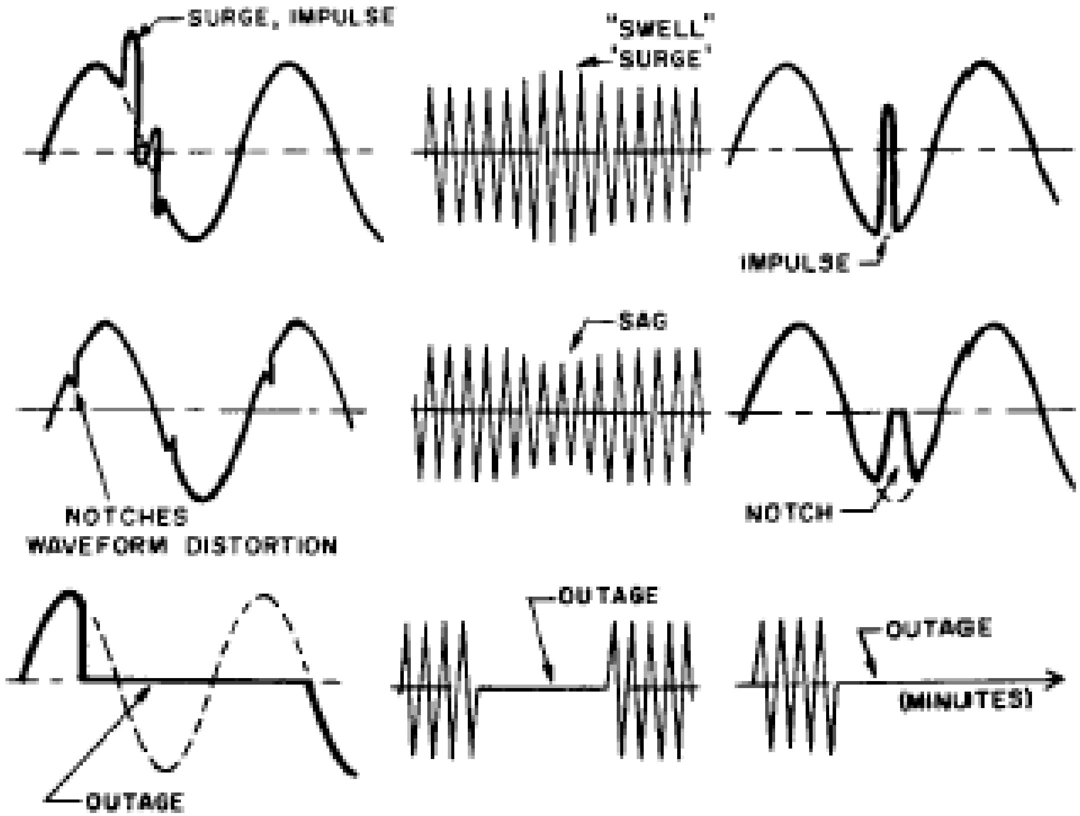


Fig. 1. Graphic definitions of disturbances.

Reference: F. D. Martzloff and T. M. Gruzs, "Power Quality Site Surveys: Facts, Fiction and Fallacies," *IEEE Transactions on Industry Applications*, vol. 24, no. 6, Nov.Dec. 1988, pp. 1005-1018

CBEMA Curve

- Requirement for power for equipment to operate satisfactorily
- Need to correct - over and under voltage

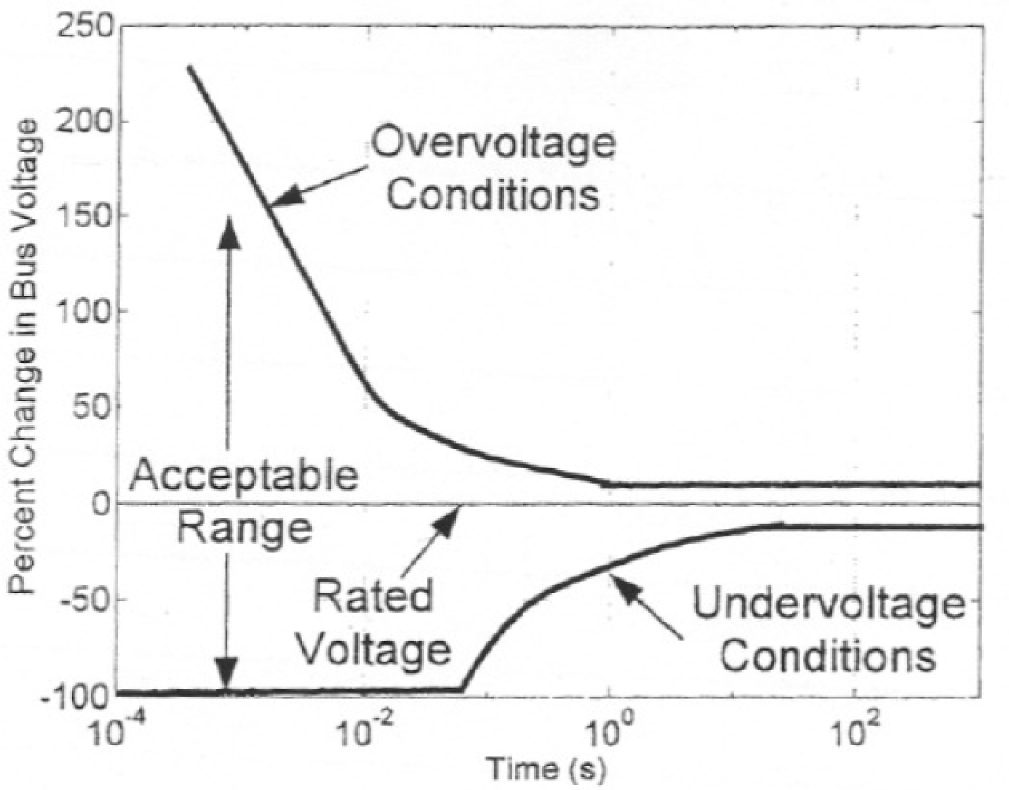
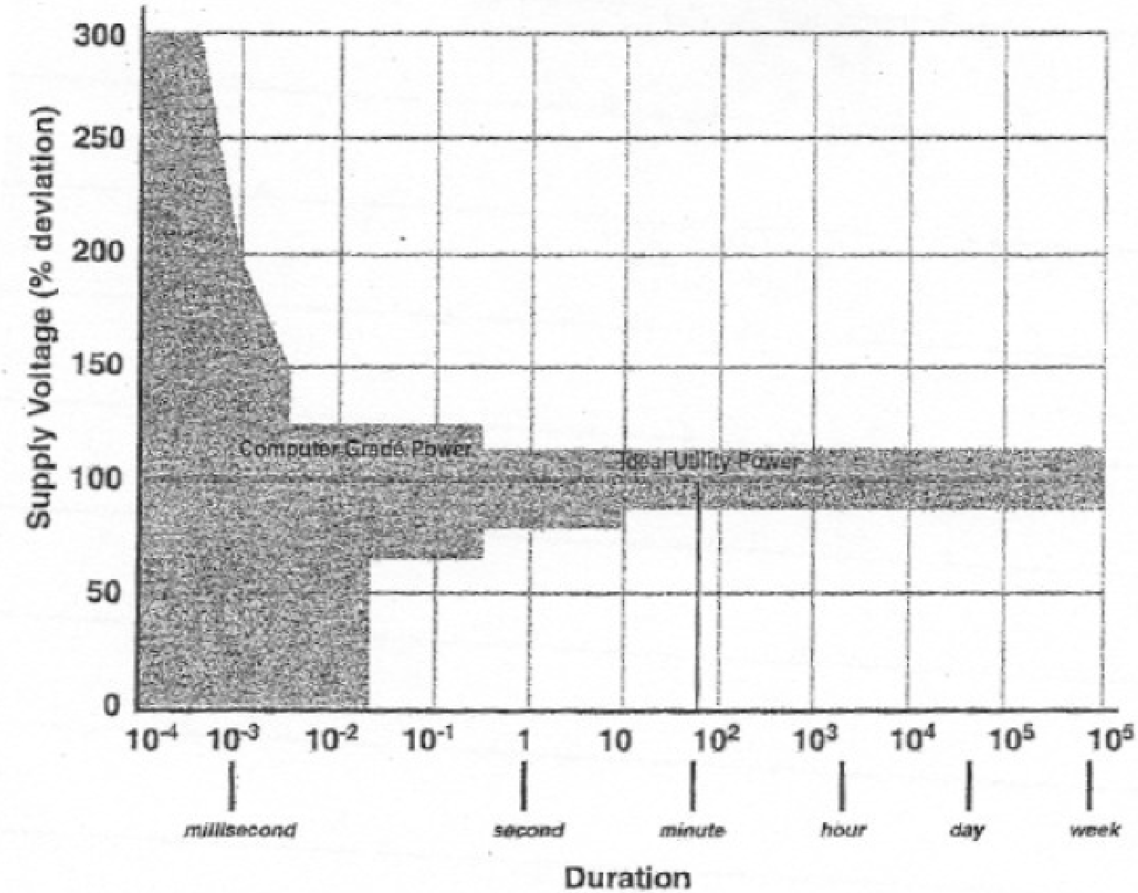


Figure 2.12. The CMEMA curve

Reference: A. Ghosh and G. Ledwich, Power Quality Enhancement Using Custom Power Devices, Kluwer Academic Publishers, Boston, 2002, pp. 40

CBEMA Curve



The CBEMA curve describes the power-quality envelope.

Source: Recommended Power Quality Envelope IEEE 445-1987.

Reference: A. Katz, “Selecting the Right UPS for the Job,” *Electronic Products*, March 2005, pp. 48-49

Causes of Voltage Distortion

- Example: Motor line starting

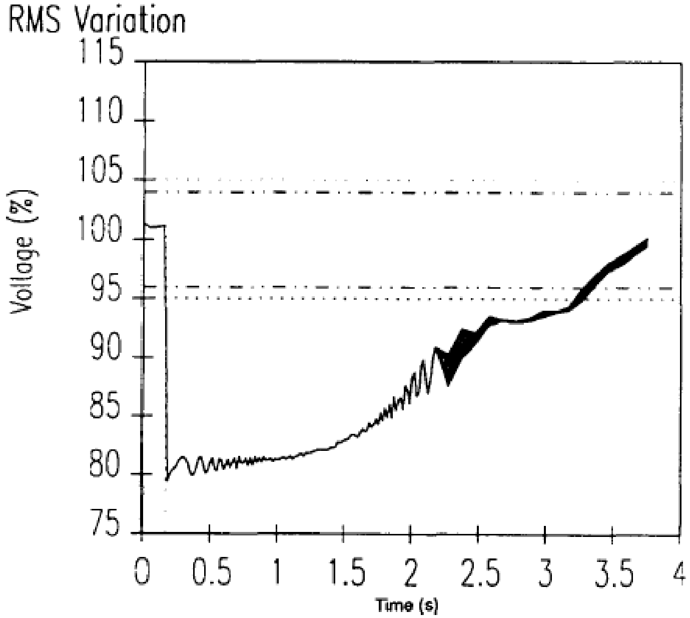


Figure 7—Temporary voltage sag caused by motor starting

Reference: IEEE Standard 1159-1995, “IEEE Recommended Practices for Monitoring Electric Power Quality”

Causes of Voltage Distortion

- Indirect: harmonic current into electrical system

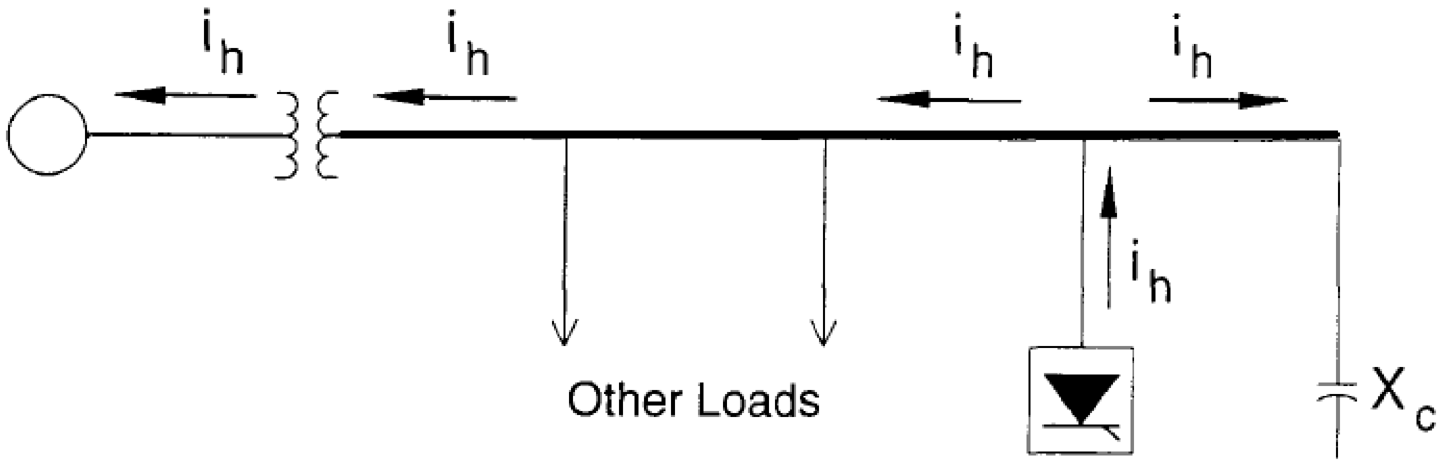


Fig 5.1
Normal Flow of Harmonic Currents

Reference: IEEE Standard 519-1992, "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems," pp. 28

Distribution of Sags

- Rate, depth, duration

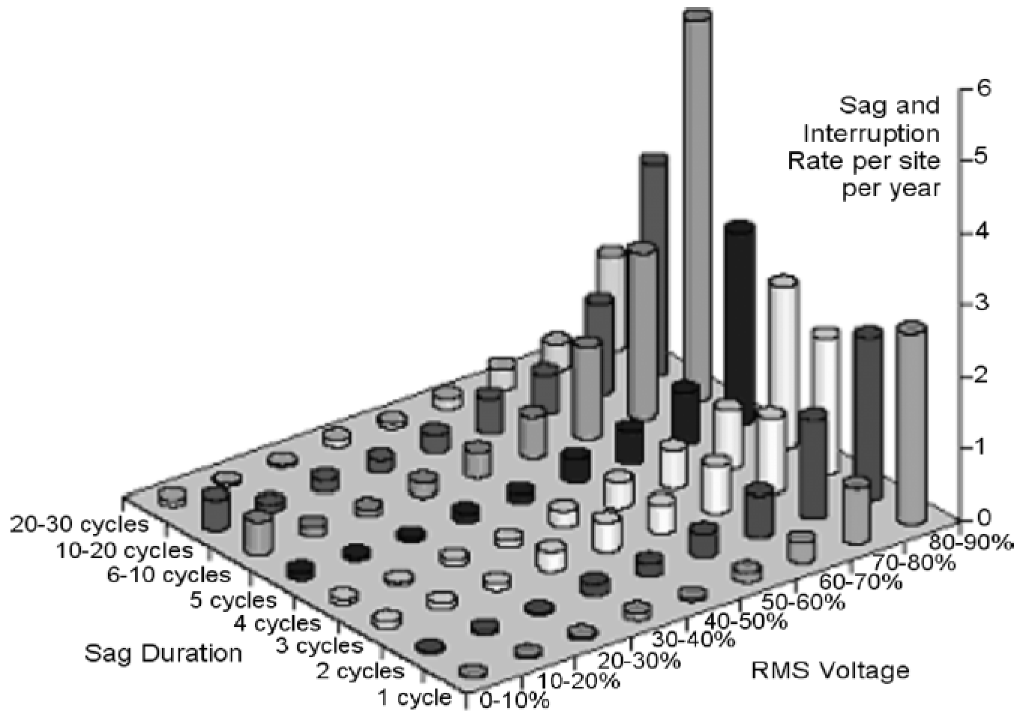
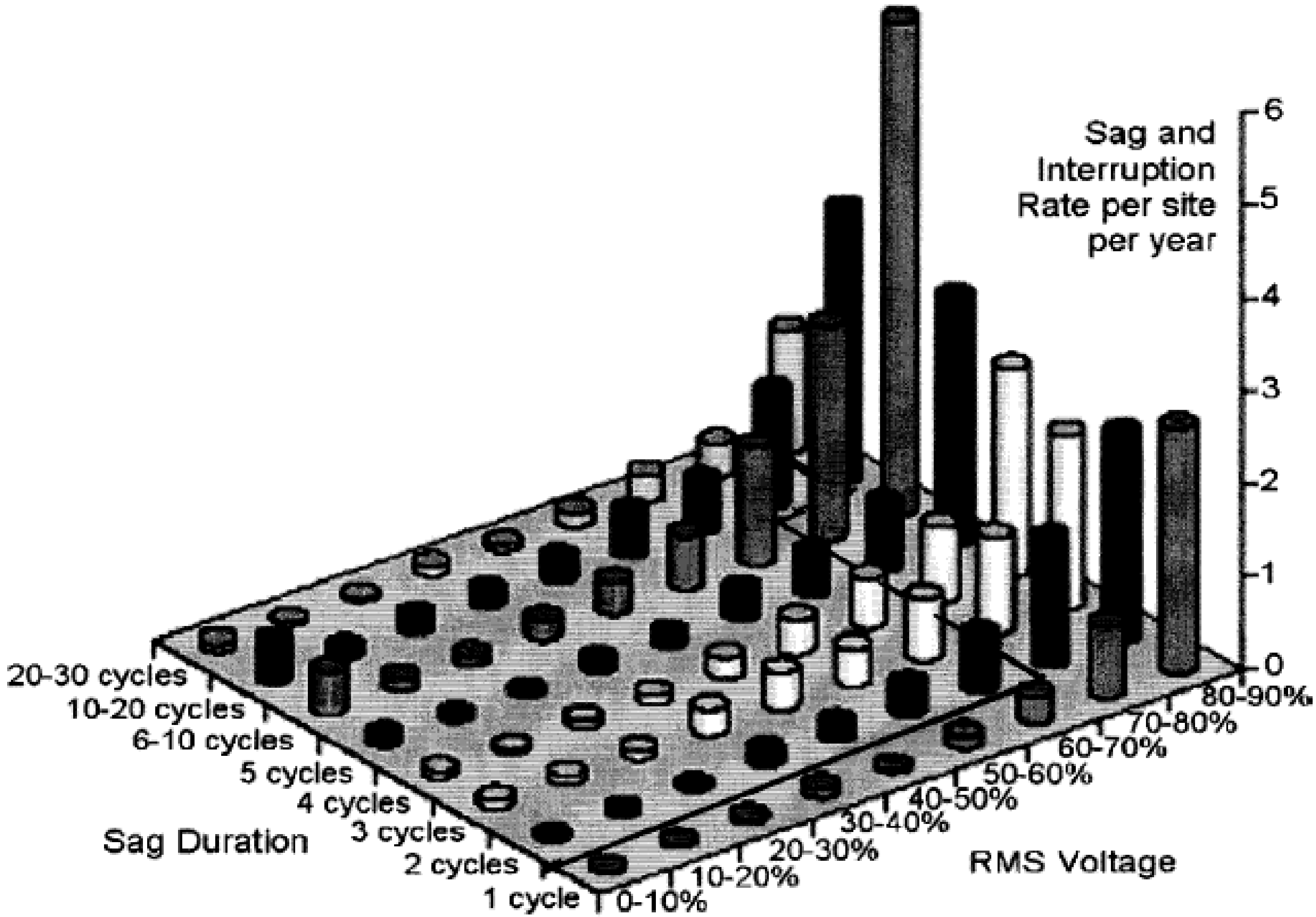


Fig. 16. Distribution of sag and micro-interruption in low-voltage networks in U.S. [29].

Reference: A. T. de Almeida, F. J. T. E. Ferreira and D. Both, "Technical and Economical Considerations in the Application of Variable-Speed Drives with Electric Motor Systems," *IEEE Transactions on Industry Applications*, vol. 41, no. 1, Jan./Feb. 2005, pp. 188-199

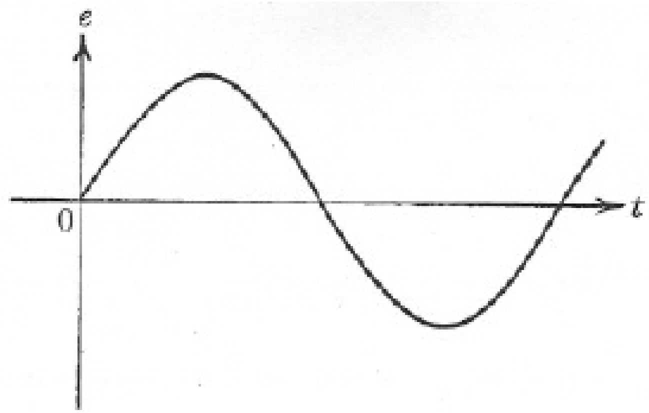
Locus of CBEMA Curve



Harmonics

- Harmonics and Power Quality
- Definitions
- Periodic Waveform - Fourier Analysis
- Harmonic Analysis - IEEE Std. 519
- Resonance

Fundamental Waveforms of Current and Voltage



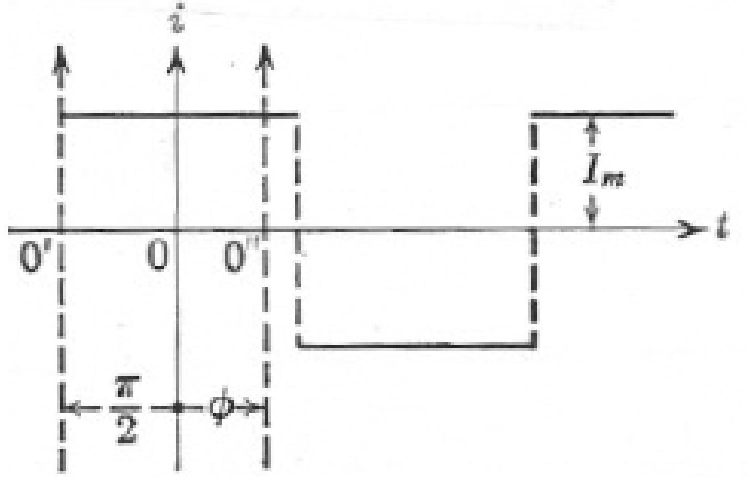


Fig. 2.—Rectangular wave.

Reference: R. H. Frazier, *Elementary Electric-Circuit Theory*, McGraw Hill, New York, 1945, pp. 4, 267

Graphical Illustration of Harmonics of Fundamental Waveforms

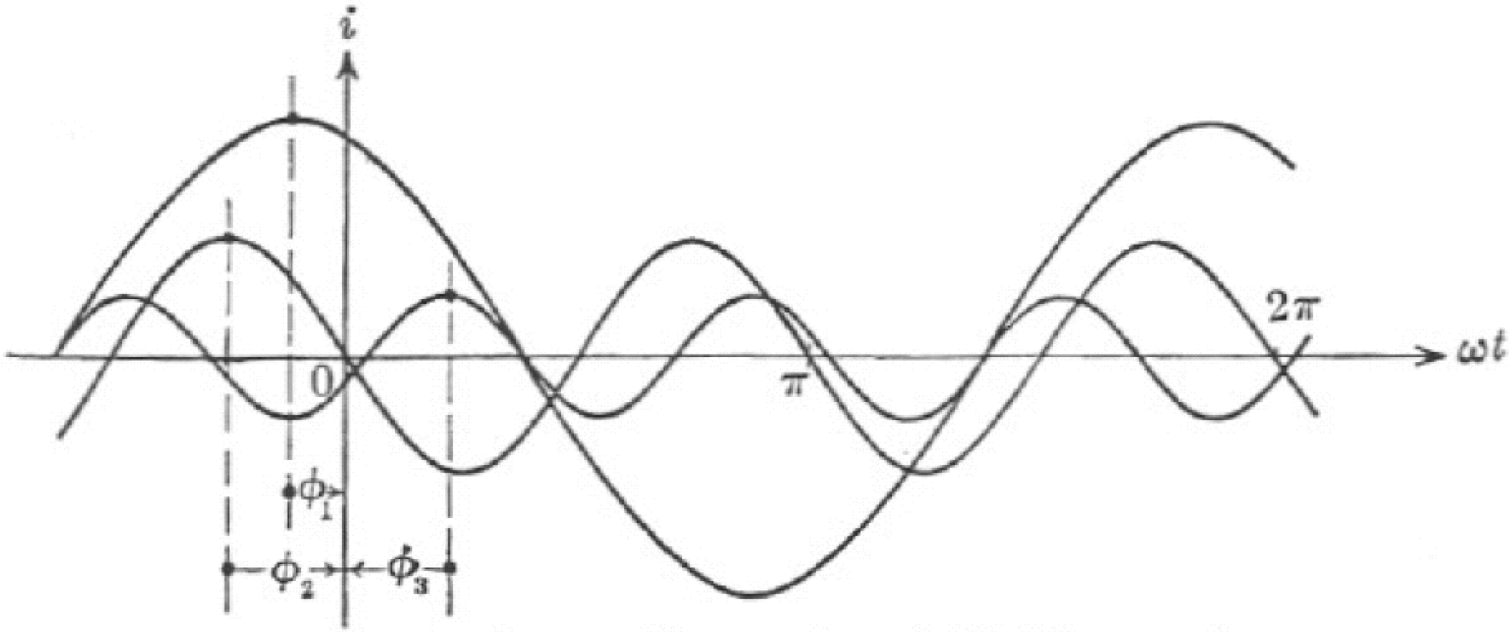


FIG. 4.—Fundamental, second, and third harmonics.

Reference: R. H. Frazier, *Elementary Electric-Circuit Theory*, McGraw Hill, New York, 1945, pp. 269

Fundamental 3-Phase Waveforms and 5th Harmonics

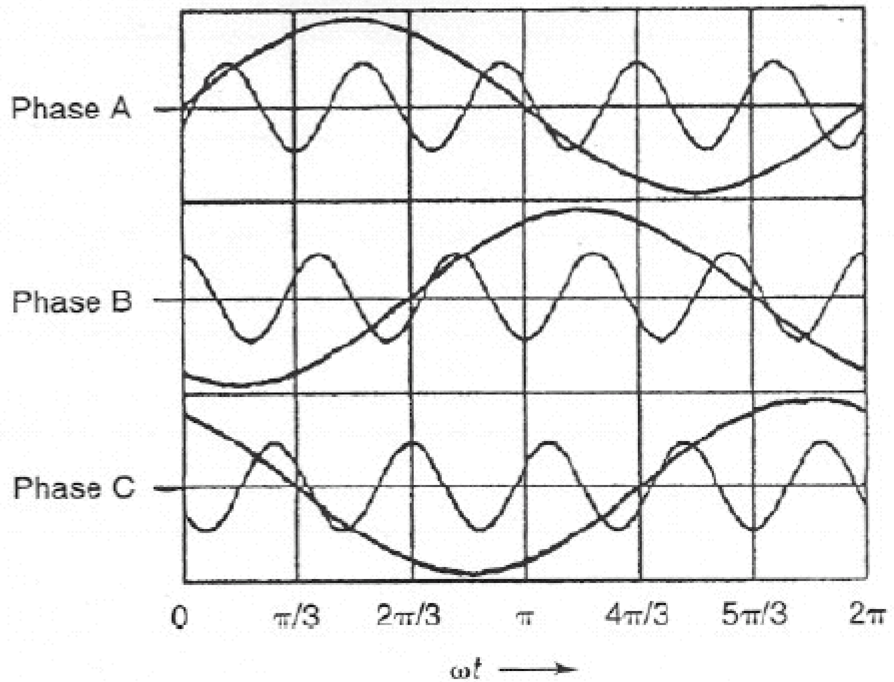


Figure 2-1 Relationships of fundamentals with 5th harmonics at angle 30°.

Reference: D. A. Paice, *Power Electronic Converter Harmonics*, IEEE Press, 1995, pp. 17

Difference --- Second and Third Harmonics

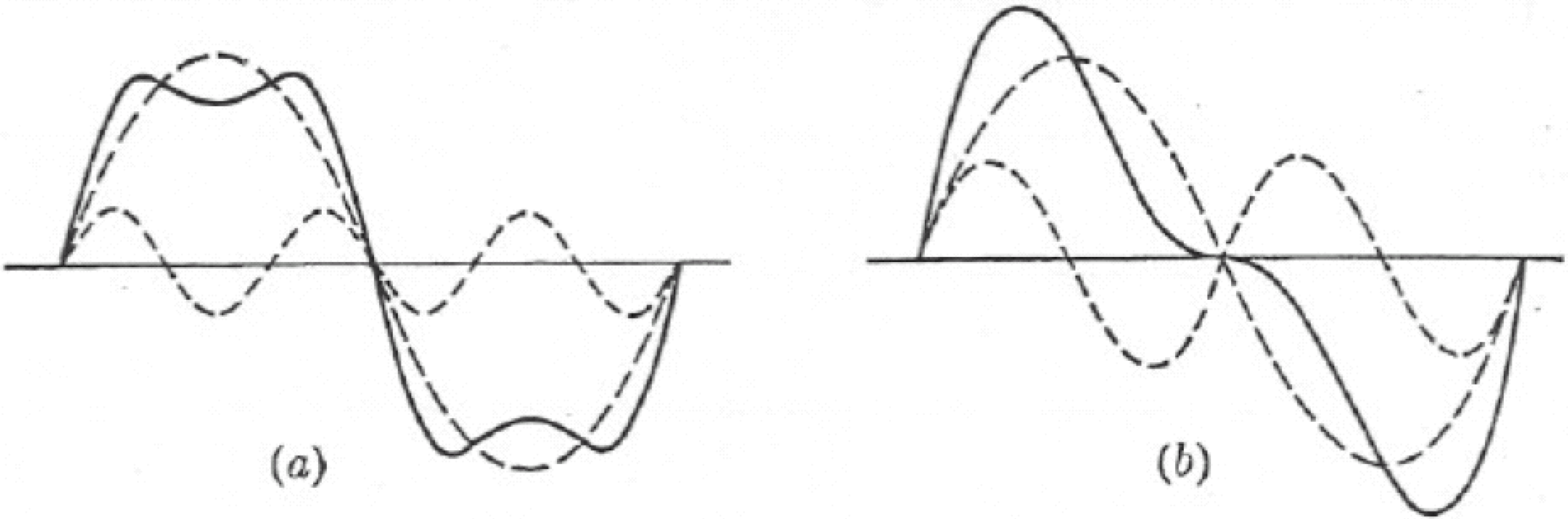


FIG. 9.—Effects of third and second harmonics on symmetry of waves.

Reference: R. H. Frazier, *Elementary Electric-Circuit Theory*, McGraw Hill, New York, 1945, pp. 278

Illustration --- Readout Harmonic Current and Voltage Levels

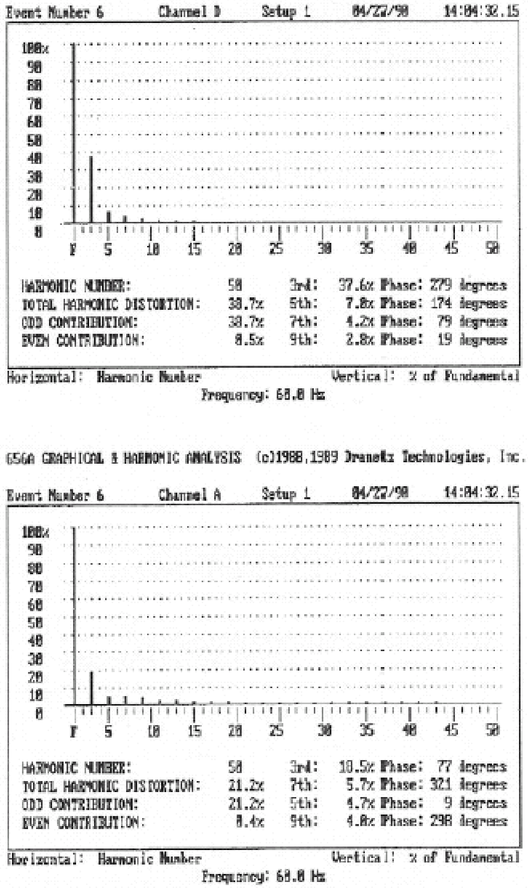


Figure 1-58. Harmonic Analysis: Nonsinusoidal load with high impedance power source, current top, voltage bottom.

Reference: *Dranetz-BMI Field Handbook*, 2003, pp. 64

Model of Industrial Power Svstems

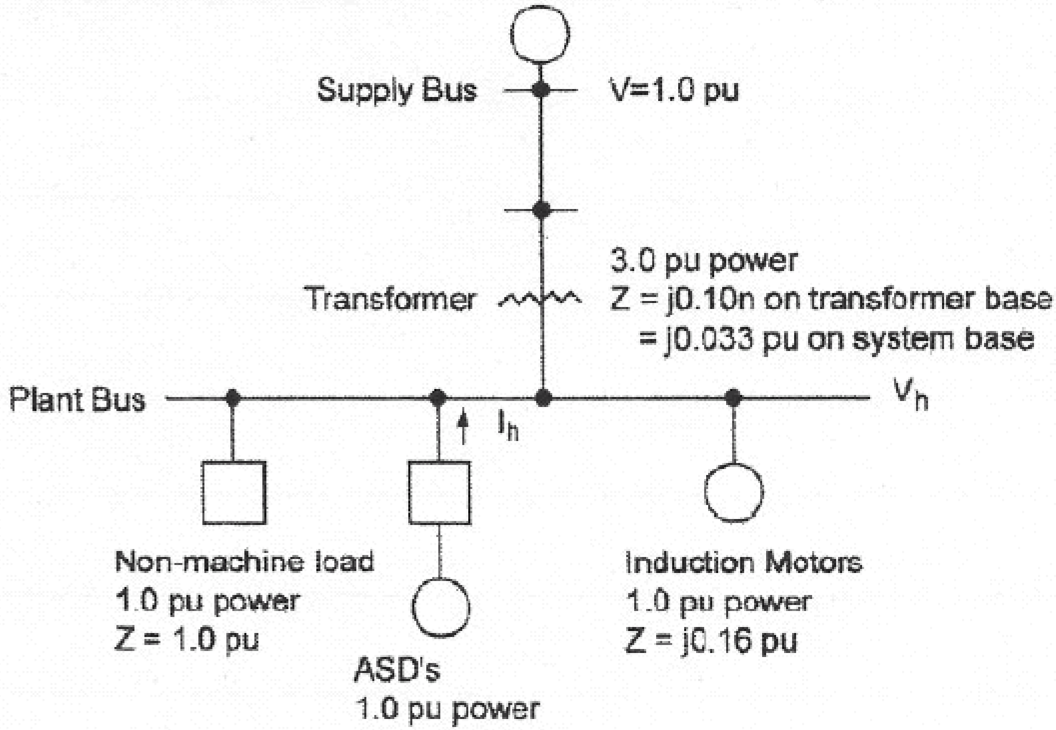


Fig. 2. Model Power System with **(a)** Non-machine Load, 1.0 pu power ; **(b)** ASD's, 1.0 pu power ; **(c)** Direct Connected Induction Motors, 1.0 pu power.

Reference: A. Kusko, "Reduction of Harmonic Voltages by Induction Motors in Industrial Power Systems," *Power Quality Exhibition and Conference*, Nov. 17, 2004, p. 2

Harmonic Equivalent Circuit for Calculating Harmonic Voltage

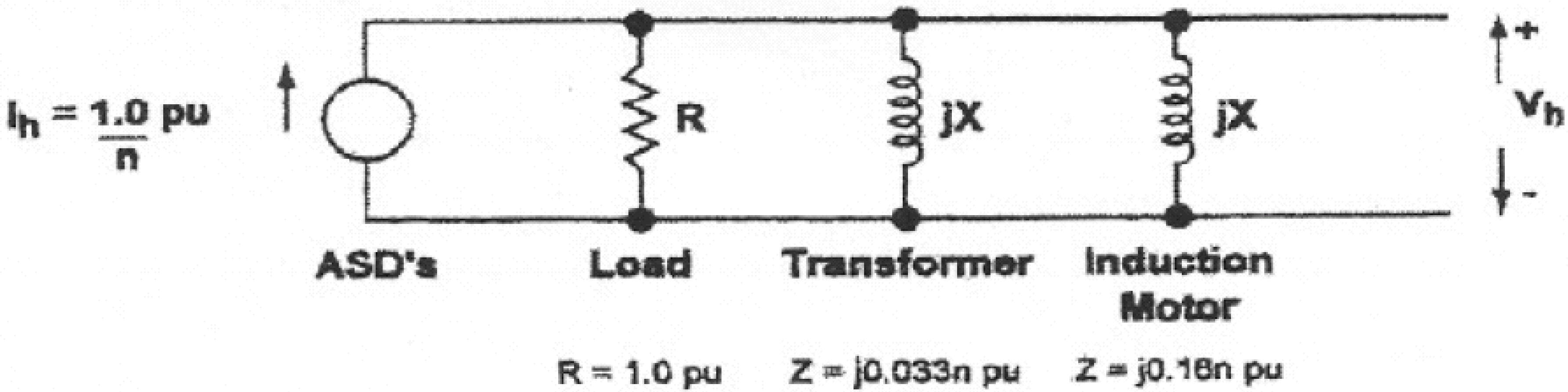


Fig. 3. Equivalent Circuit for the nth Harmonic Current I_h and Voltage V_h

Reference: A. Kusko, "Reduction of Harmonic Voltages by Induction Motors in Industrial Power Systems," *Power Quality Exhibition and Conference*, Nov. 17, 2004, p. 3

Result of Calculation

Table 1
Calculated Harmonic Voltages on Plant Bus

	Condition	Harmonic Order	Voltage, pu
1.	With Induction Motors	5	0.027
2.	Without Induction Motors	5	0.033
3.	All ASD's	5	0.065

Reference: A. Kusko, “Reduction of Harmonic Voltages by Induction Motors in Industrial Power Systems,” *Power Quality Exhibition and Conference*, Nov. 17, 2004, p. 3

Table --- IEEE Std. 519 Voltages

Table 10.1
Basis for Harmonic Current Limits

SCR at PCC	Maximum Individual Frequency Voltage Harmonic (%)	Related Assumption
10	2.5–3.0%	Dedicated system
20	2.0–2.5%	1–2 large customers
50	1.0–1.5%	A few relatively large customers
100	0.5–1.0%	5–20 medium size customers
1000	0.05–0.10%	Many small customers

Reference: IEEE Standard 519-1992, "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems," pp. 76

Table --- IEEE Std. 519 Currents

Table 10.3
Current Distortion Limits for General Distribution Systems
(120 V Through 69 000 V)

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{sc}/I_L	<11	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h$	TDD
<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

Even harmonics are limited to 25% of the odd harmonic limits above.

Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

*All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.

where

I_{sc} = maximum short-circuit current at PCC.
I_L = maximum demand load current (fundamental frequency component) at PCC.

Reference: IEEE Standard 519-1992, "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems," pp. 78

Conditions for Resonance

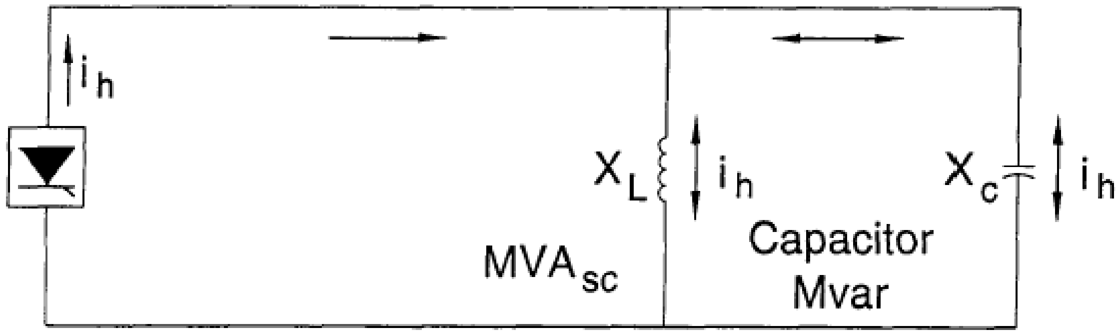


Fig 8.2
Simple Circuit for Hand Calculations

The most important calculation for this circuit is the resonant frequency. This is given by

$$h_r = \sqrt{\frac{MVA_{sc}}{Mvar_{cap}}} = \sqrt{\frac{X_c}{X_{sc}}} \quad \text{(Eq 8.1)}$$

where

h_r	is the resonant frequency as a multiple of the fundamental frequency
MVA_{sc}	is the short-circuit duty at the point of study
$Mvar_{cap}$	is the capacitor rating at the system voltage
X_c	is the capacitive reactance of the capacitor bank at fundamental frequency
X_{sc}	is the short-circuit reactance at the substation

Reference: IEEE Standard 519-1992, "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems," pp. 56