Power Quality
Notes 2-2 (AK)

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Review

- Voltage distortion
- CBEMA curve
- Harmonics
- Calculation of harmonic voltages
- IEEE Std. 519

Class #2 - Hour #2 (4/12/05) Harmonic Current Effects

- Sources of harmonic currents
- Case study, plastic extrusion plant
- Case study, GE diagnostic imaging system
- IEEE Paper, “Effects of Harmonics on Equipment”
- Resonance, capacitors

Sources of Harmonic Currents

- Static power converter, ASD, source of harmonic current

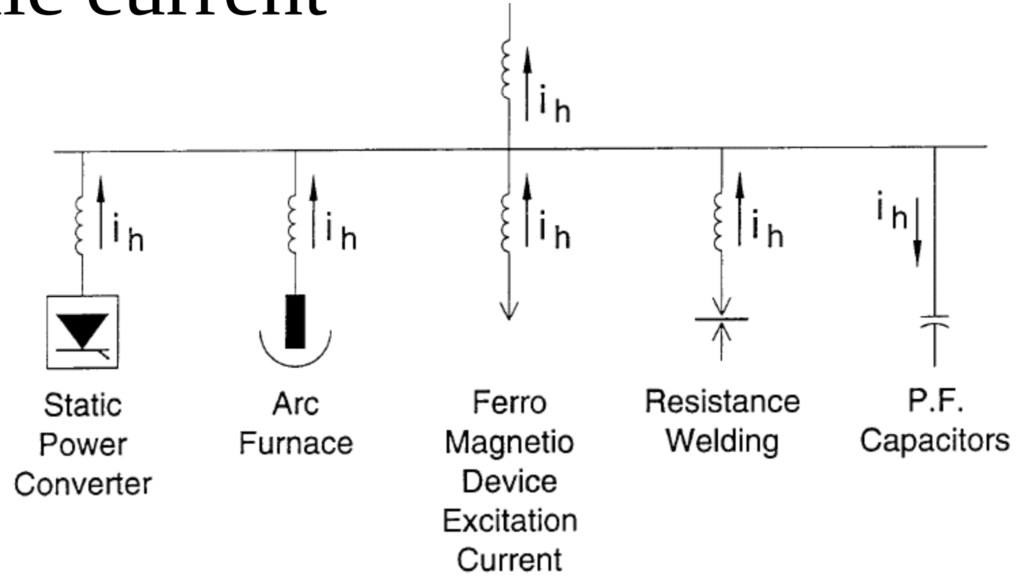


Fig 8.1
Modeling Nonlinear Loads by Current Sources

Reference: IEEE Standard 519-1992, "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems," pp. 55

Case Study: "Power Harmonic Problems at a Plastic Extrusion Plant"

- Original: utility transformer, 300 kVA
- Extruder, thyristor DC drive, 250 hp
- Poor power factor, 0.57

Reference: Nosh Medora and Alex Kusko, "Power Harmonic Problems at a Plastic Extrusion Plant," *IEEE IAS Annual Conference*, October 1995

Power Measurements

TABLE 1
POWER MEASUREMENTS PERFORMED
AT PLASTIC EXTRUSION PLANT

Transformer: 300-kVA 13.8 kV to 480 V
Extruder: 250-HP Thyristor DC Adjustable Speed Drive

Measured Parameter	Phase A
Line Voltage (l-l)	468 V
Line Current (I_L)	490 A
Real Power (P)	226 kW
Reactive Power (Q)	326 kvar
Apparent Power (S)	397 kVA
Power Factor (p.f.)	0.57

Reference: Nosh Medora and Alex Kusko, "Power Harmonic Problems at a Plastic Extrusion Plant," *IEEE IAS Annual Conference*, October 1995

Thyristor DC Drive Harmonics

TABLE 2
HARMONIC CURRENTS PRESENT IN INPUT CURRENT TO A TYPICAL STATIC POWER CONVERTER IN PER-UNIT OF THE FUNDAMENTAL CURRENT [2]

Converter Pulses	Harmonic Order							
	5	7	11	13	17	19	23	25
6	0.175	0.110	0.045	0.029	0.015	0.010	0.009	0.008

Reference: Nosh Medora and Alex Kusko, "Power Harmonic Problems at a Plastic Extrusion Plant," *IEEE IAS Annual Conference*, October 1995

Impedance Diagram --- 300 kvar Capacitor

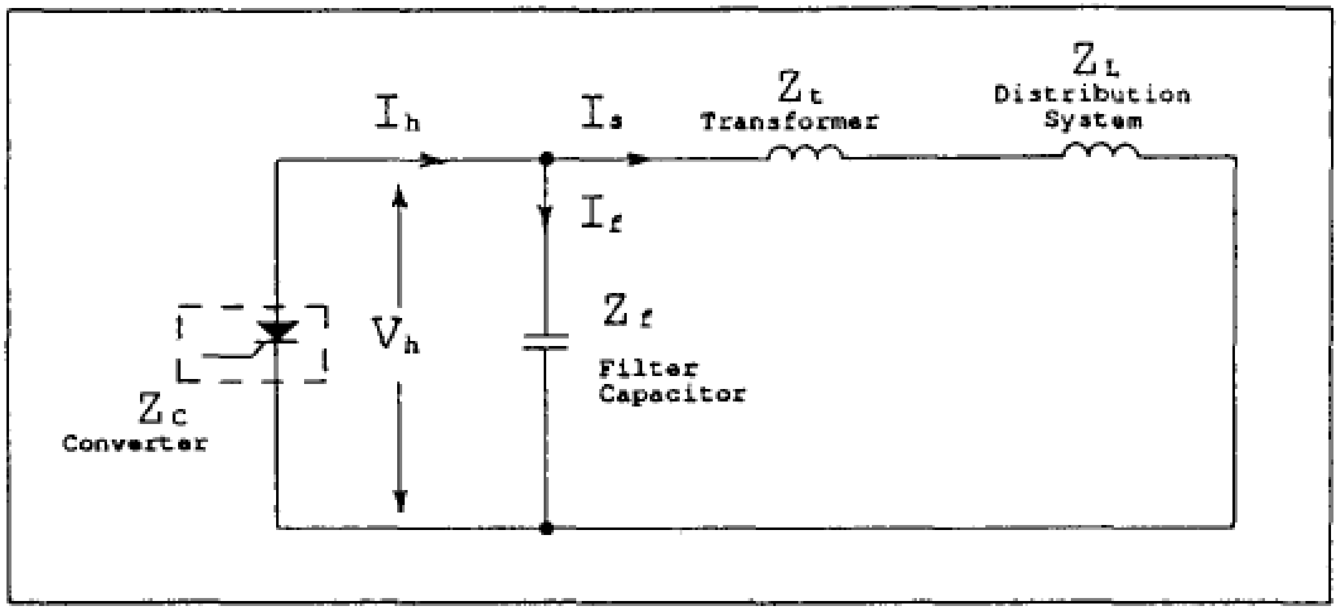


Fig. 3. Impedance Diagram of Power System [2]

Reference: Nosh Medora and Alex Kusko, "Power Harmonic Problems at a Plastic Extrusion Plant," *IEEE IAS Annual Conference*, October 1995

Waveforms: Drive, Transformer, Capacitor Current. Fifth Harmonic Resonance

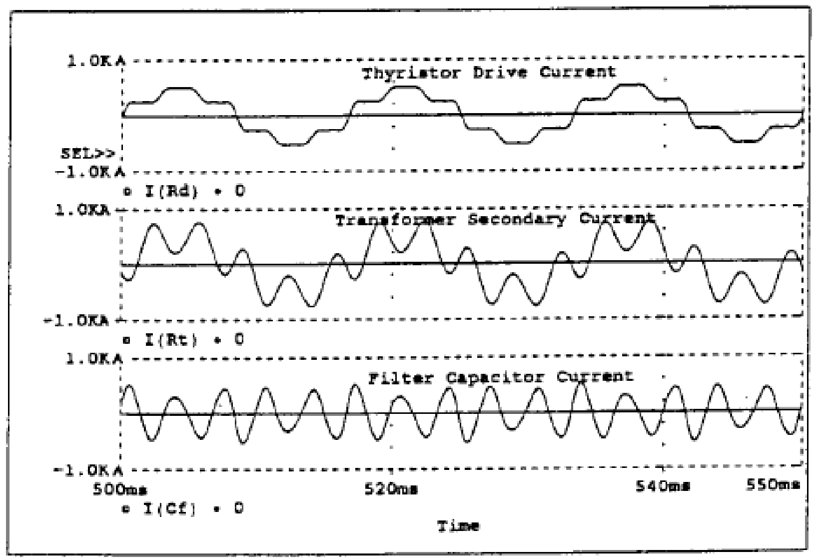


Fig. 7a. Thyristor Drive Current, Transformer Secondary Current, and Filter Capacitor Current vs. Time, No Series Reactor

Reference: Nosh Medora and Alex Kusko, "Power Harmonic Problems at a Plastic Extrusion Plant," *IEEE IAS Annual Conference*, October 1995

Solutions to Harmonic Problem

- Do not install capacitors
- Install series reactor tuned to 5th harmonic
- Install larger, lower reactance, transformer
- Change drive to 12-pulse converter

Reference: Nosh Medora and Alex Kusko, "Power Harmonic Problems at a Plastic Extrusion Plant," *IEEE IAS Annual Conference*, October 1995

Reactor Tuned to Fifth Harmonic: PSPICE Model

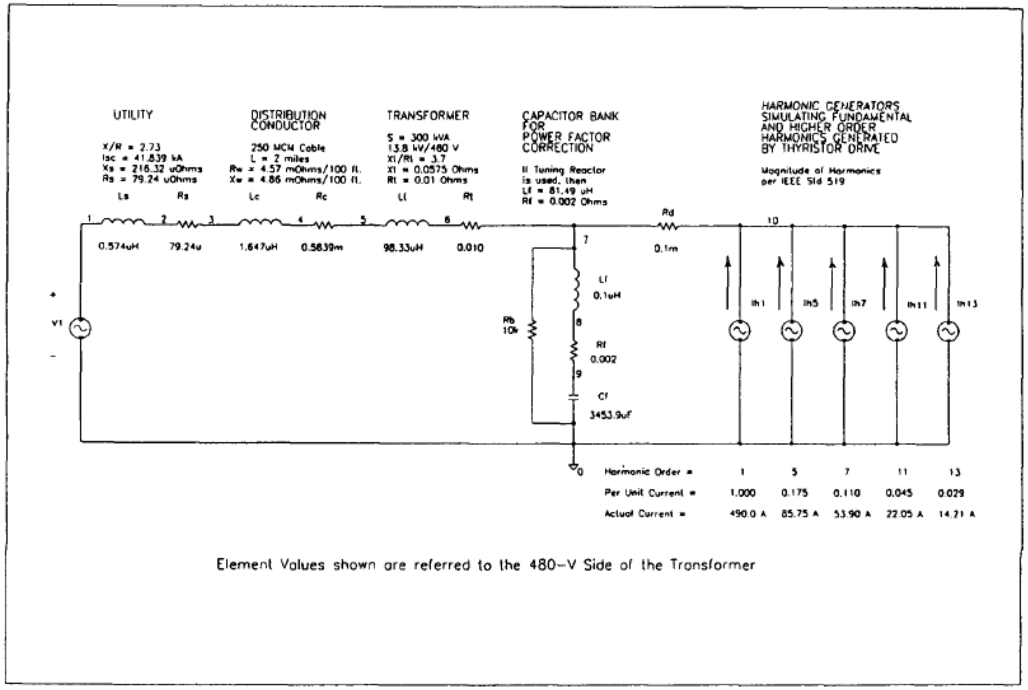


Fig. 4. One-Line Diagram of Electric Power System at Plastics Extrusion Plant

Reference: Nosh Medora and Alex Kusko, "Power Harmonic Problems at a Plastic Extrusion Plant," *IEEE IAS Annual Conference*, October 1995

Waveforms: Drive, Transformer, Capacitor Current. Series Reactor Tuned to Fifth Harmonic

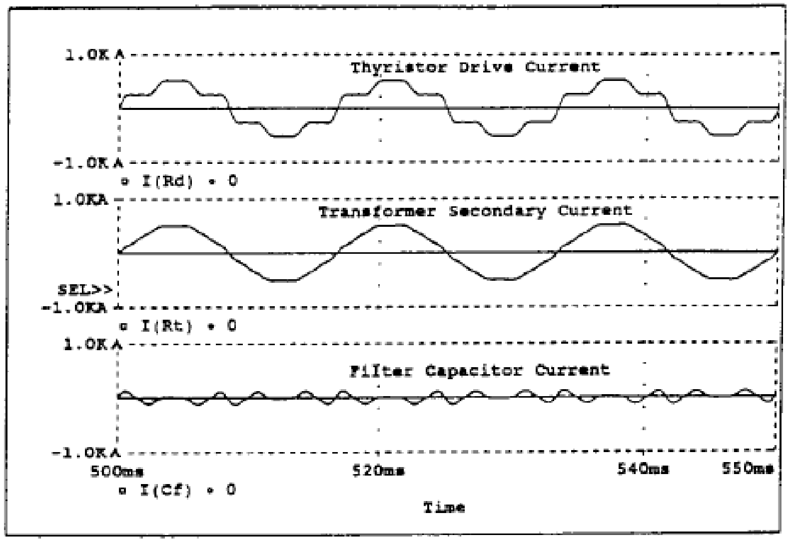


Fig. 7b. Thyristor Drive Current, Transformer Secondary Current, and Filter Capacitor Current vs. Time for Series Reactor Tuned to 5th Harmonic

Reference: Nosh Medora and Alex Kusko, "Power Harmonic Problems at a Plastic Extrusion Plant," *IEEE IAS Annual Conference*, October 1995

Case Study, “Low Cost Power Monitoring of Diagnostic Imaging Systems”

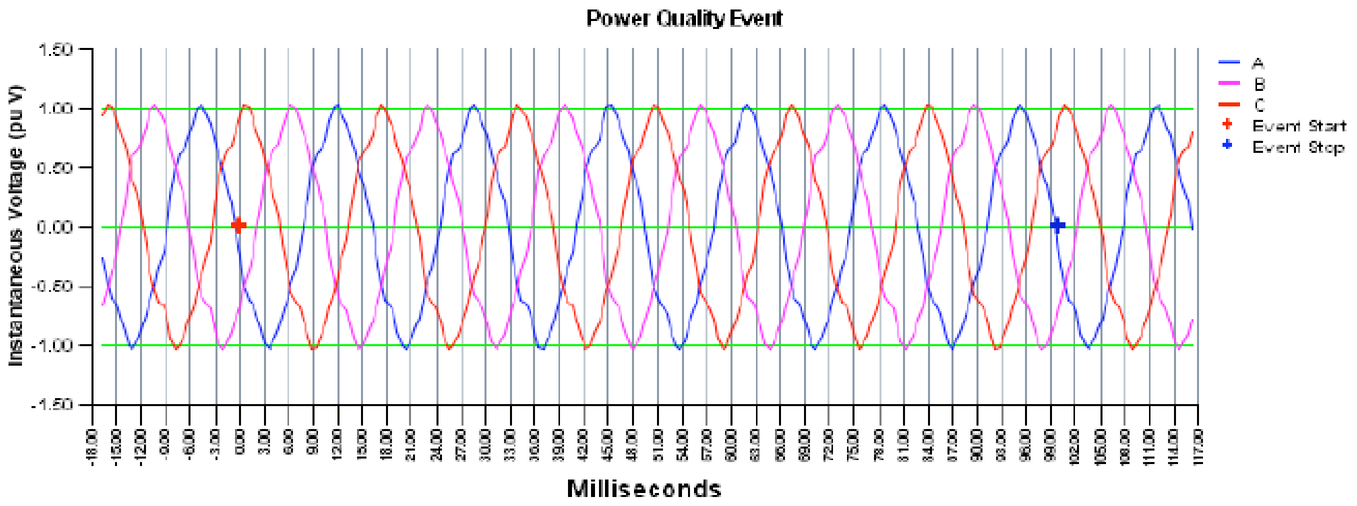
- Require reliable and consistent power quality to insure proper operation
- Installed 40 “I-Sense” monitors to record power quality events
- Monitored three-phase voltages
- Printed out magnitude and duration of events on CBEMA format

Reference: D. A. Rush, “Low Cost Power Monitoring of Diagnostic Imaging Systems,: *Power Quality Exhibition and Conference,* Chicago IL, November 16-18, 2004

Case #1: Steady State Line Voltages

- Note: distortion of all three-phase voltages
- Corrected within facility

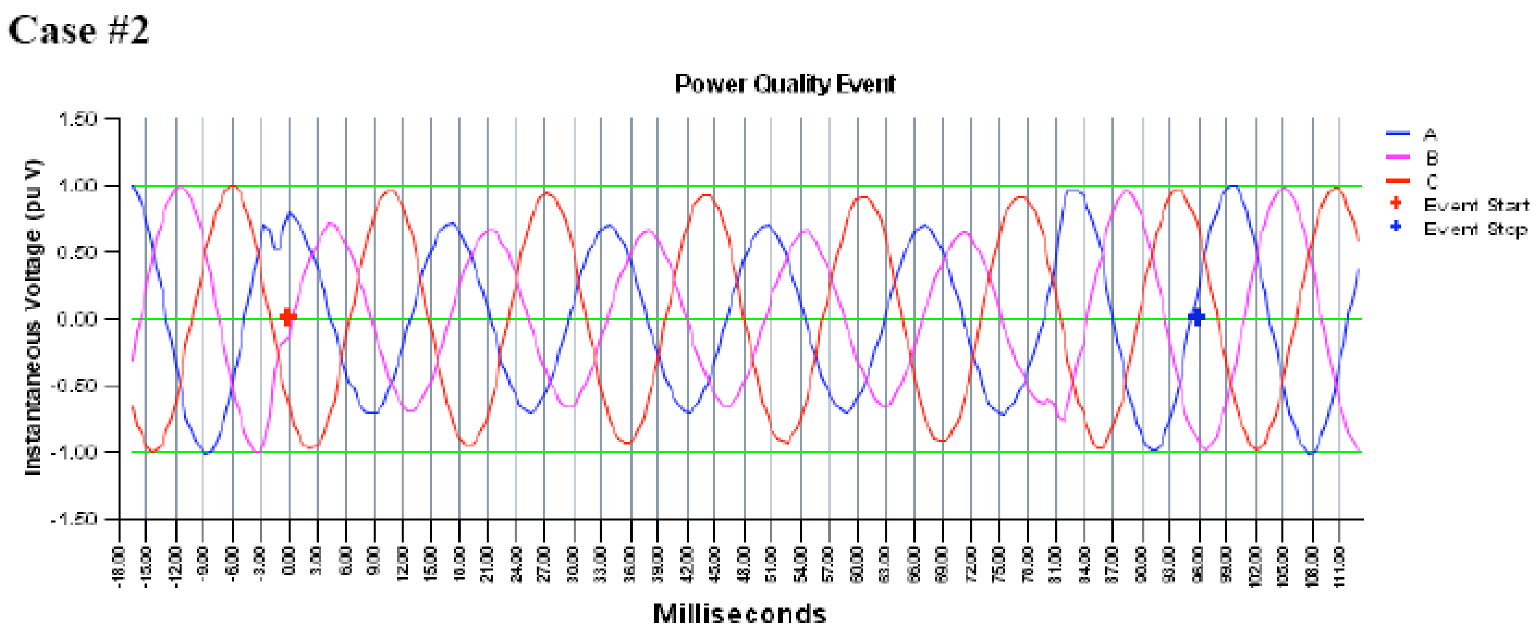
Case #1



Reference: D. A. Rush, "Low Cost Power Monitoring of Diagnostic Imaging Systems,: *Power Quality Exhibition and Conference*, Chicago IL, November 16-18, 2004

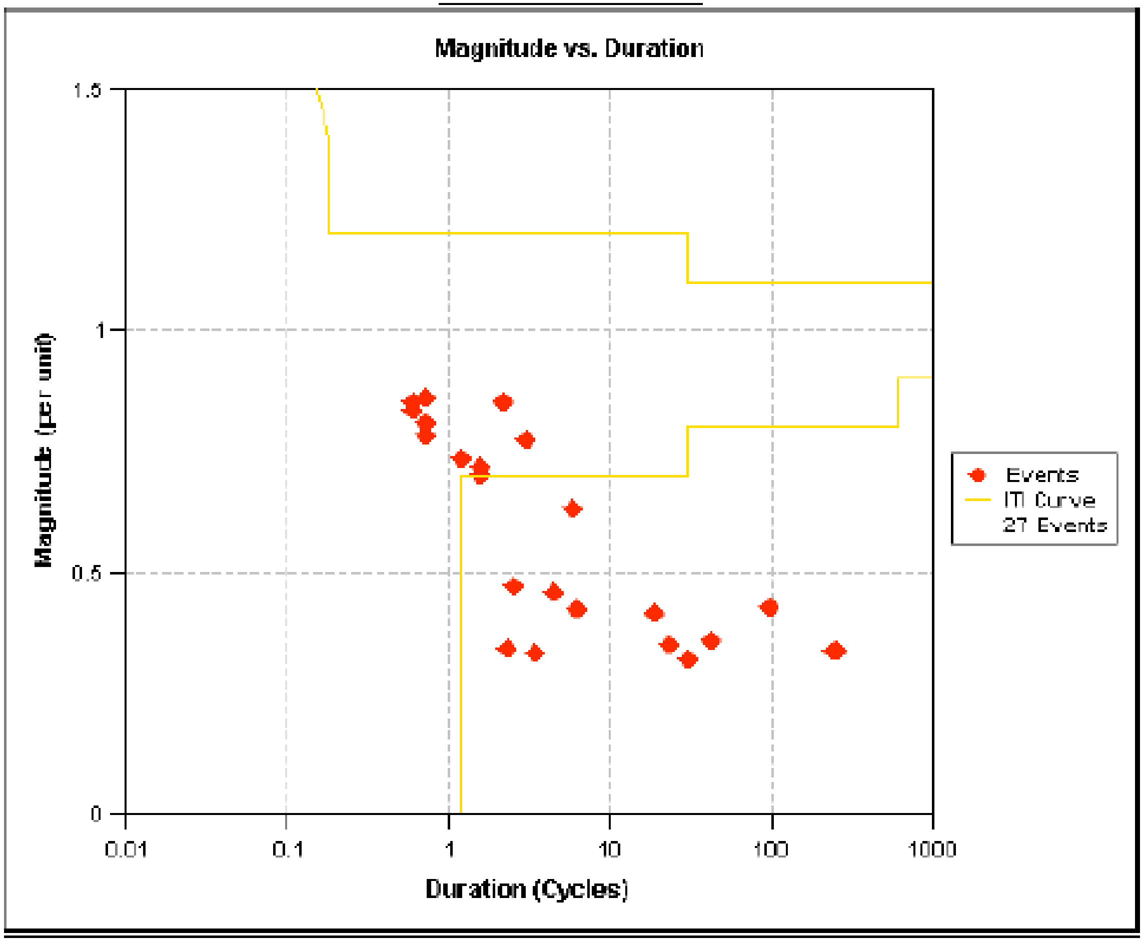
Case #2: Sags in Three-Phase Line Voltages

- Note: voltage sags in two of the phase voltages
- Problem on utility feeder



Reference: D. A. Rush, "Low Cost Power Monitoring of Diagnostic Imaging Systems,: *Power Quality Exhibition and Conference,* Chicago IL, November 16-18, 2004

Case #2: Outage Events on CBEMA Curve

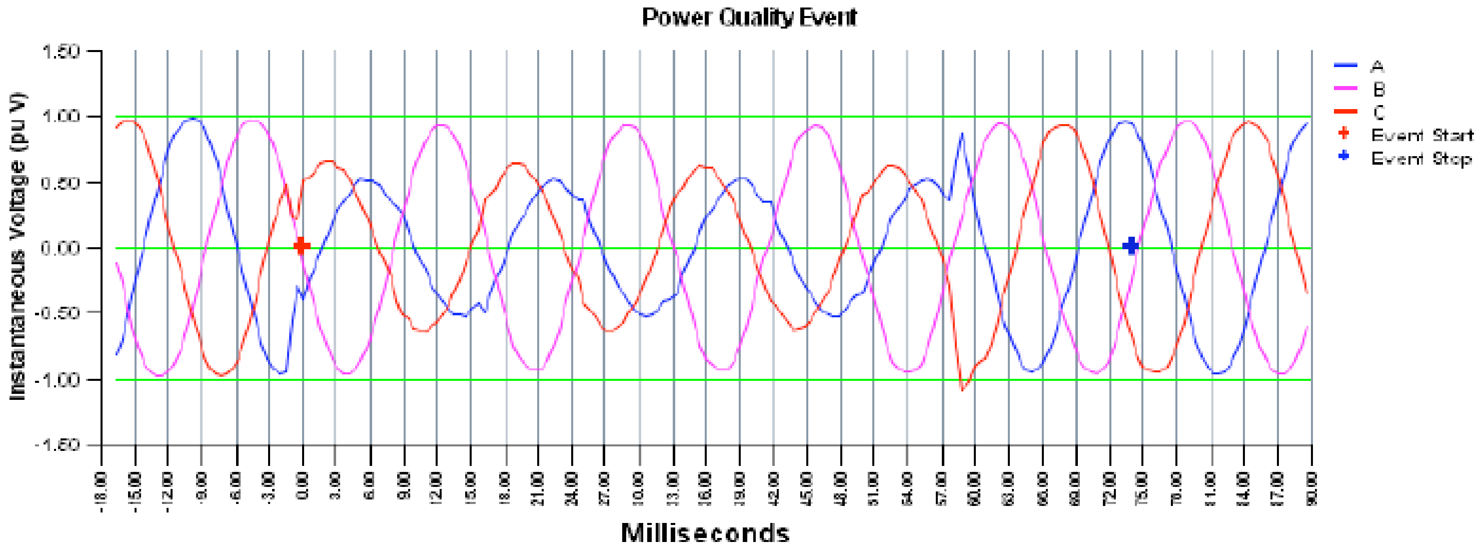


Reference: D. A. Rush, "Low Cost Power Monitoring of Diagnostic Imaging Systems,: *Power Quality Exhibition and Conference*, Chicago IL, November 16-18, 2004

Case #3: Sags in Three-Phase Line Voltages

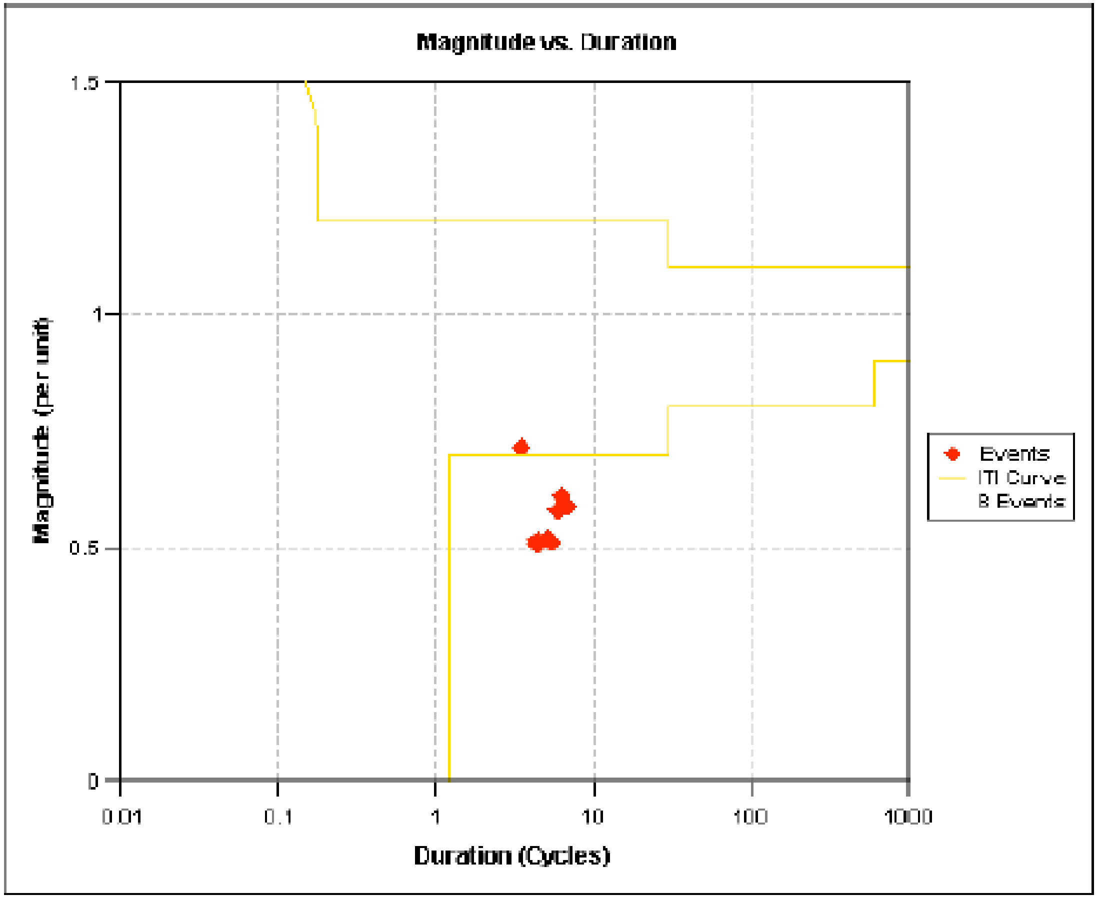
- Note: utility distribution line fault cleared in 4 cycles

Case #3



Reference: D. A. Rush, “Low Cost Power Monitoring of Diagnostic Imaging Systems,: *Power Quality Exhibition and Conference*, Chicago IL, November 16-18, 2004

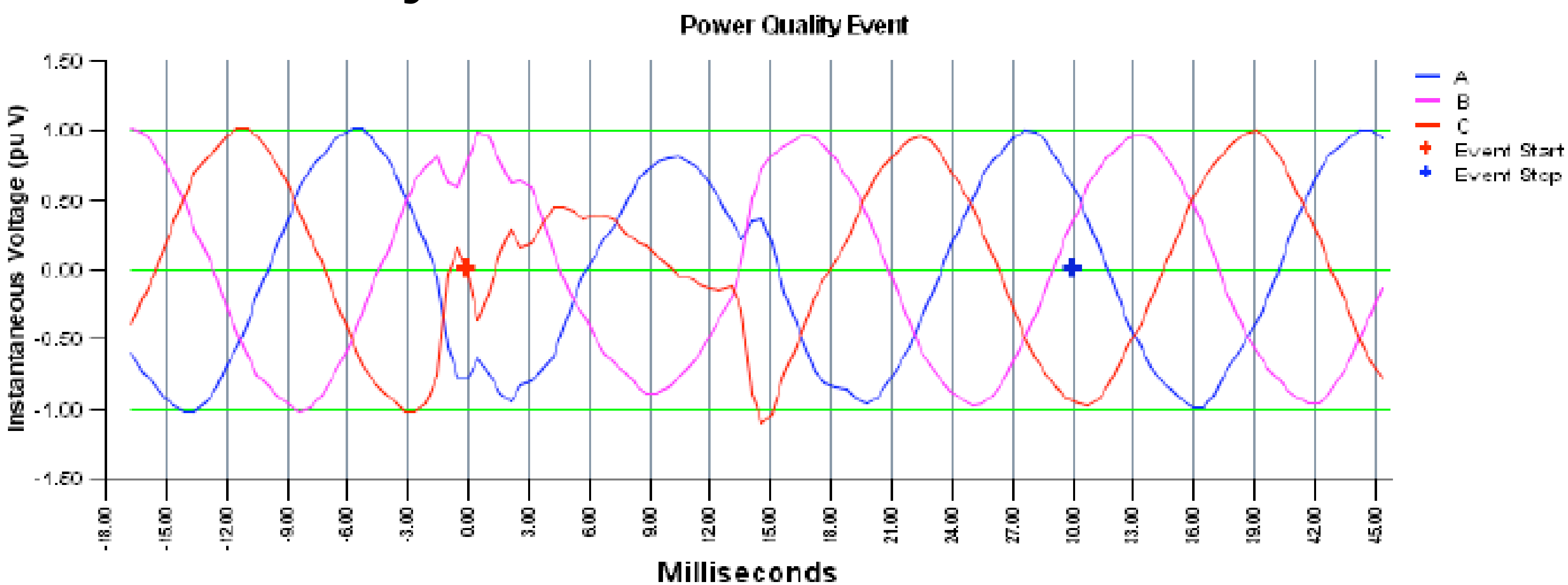
Case #3: Outage and Clearing Events on CBEMA Curve



Reference: D. A. Rush, "Low Cost Power Monitoring of Diagnostic Imaging Systems,: *Power Quality Exhibition and Conference*, Chicago IL, November 16-18, 2004

Case #4: Capacitor Bank Switching

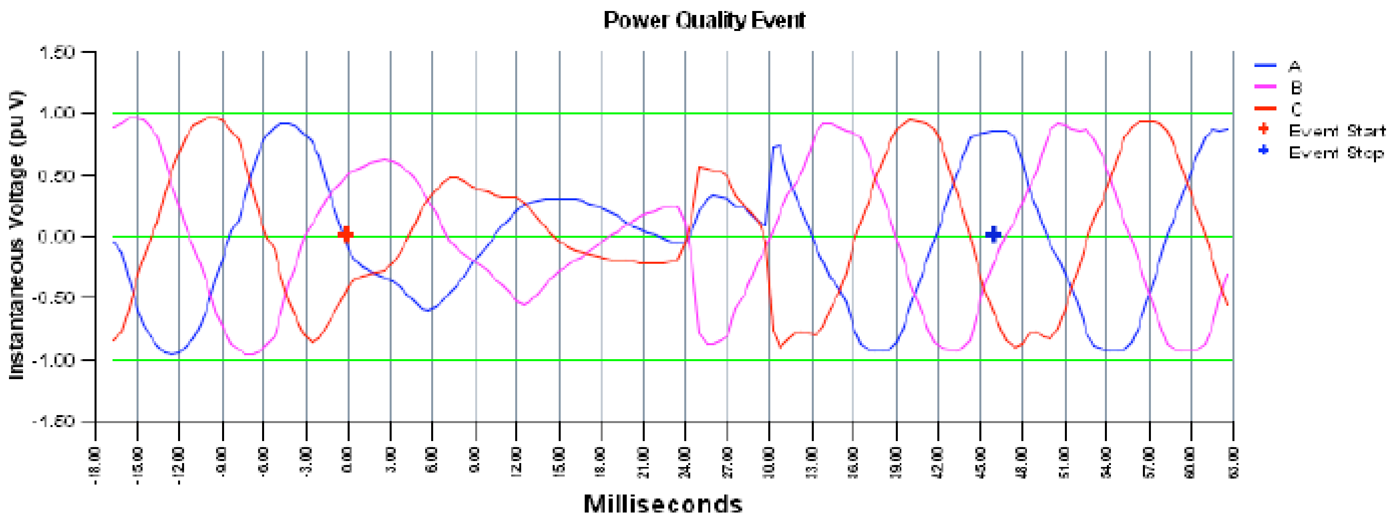
- Note: distortion of all three line voltages lasts about one cycle



Reference: D. A. Rush, "Low Cost Power Monitoring of Diagnostic Imaging Systems,: *Power Quality Exhibition and Conference*, Chicago IL, November 16-18, 2004

Case #5: Transfer of Load From Utility to Backup Generator

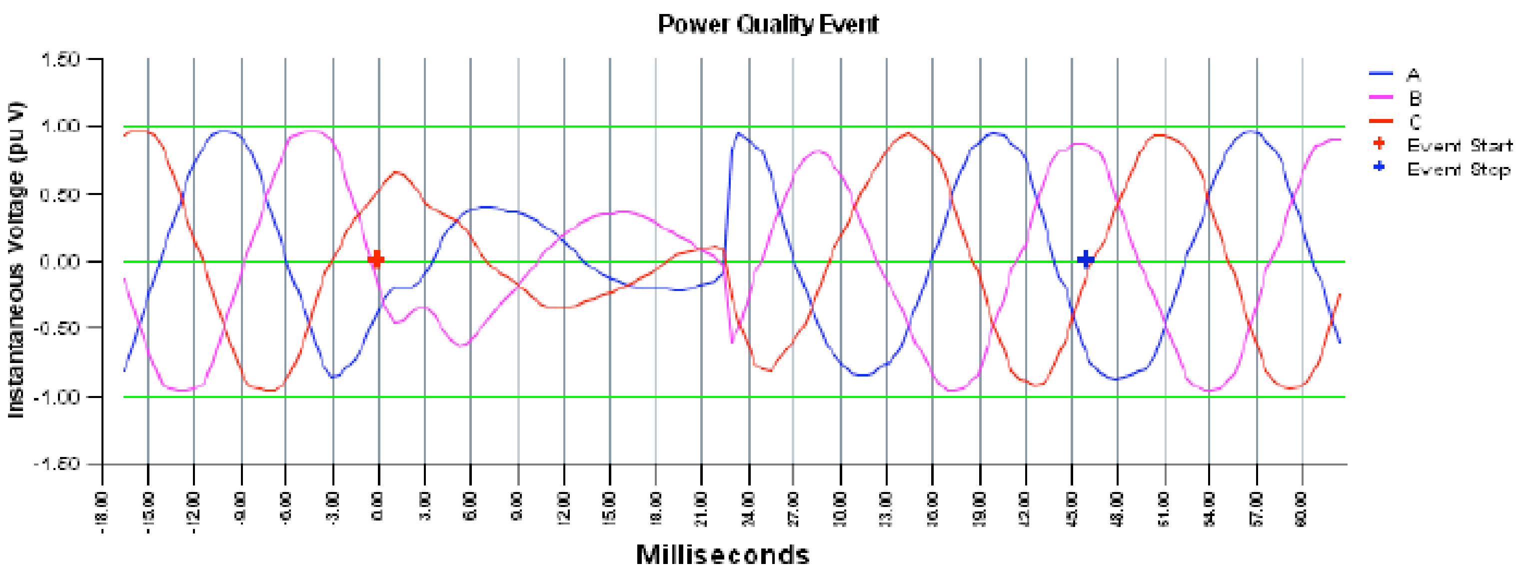
- Note: Generator already up to speed and voltage
- Transfer takes two cycles. Voltages outside CBEMA curve. Generator voltage distorted.



Reference: D. A. Rush, “Low Cost Power Monitoring of Diagnostic Imaging Systems,: *Power Quality Exhibition and Conference*, Chicago IL, November 16-18, 2004

Case #5: Transfer of Load From Backup Generator to Utility

- Note: transfer takes two cycles to achieve steady utility voltage



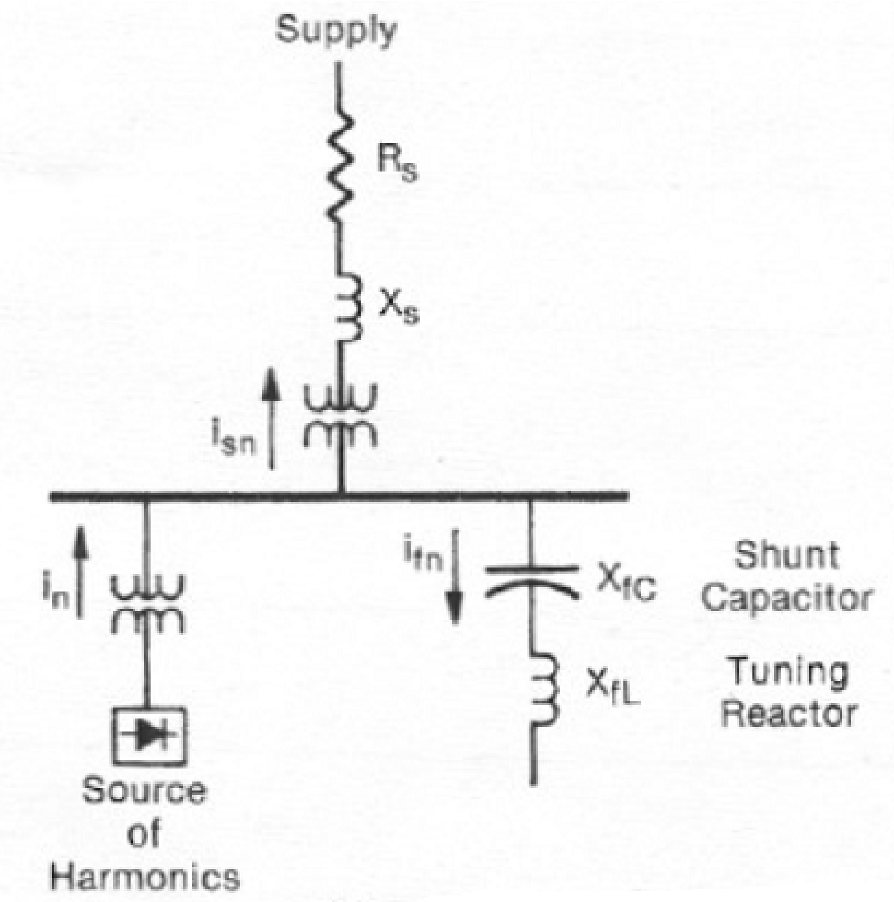
Reference: D. A. Rush, “Low Cost Power Monitoring of Diagnostic Imaging Systems,: *Power Quality Exhibition and Conference*, Chicago IL, November 16-18, 2004

Effects of Harmonics on Equipment

- Adjustable speed drives (ASD)
- Capacitors
- Circuit breakers and fuses
- Conductors
- Electronic equipment
- Lighting
- Meters
- Protective relaying
- Rotating machines
- Telephone interference
- Transformers

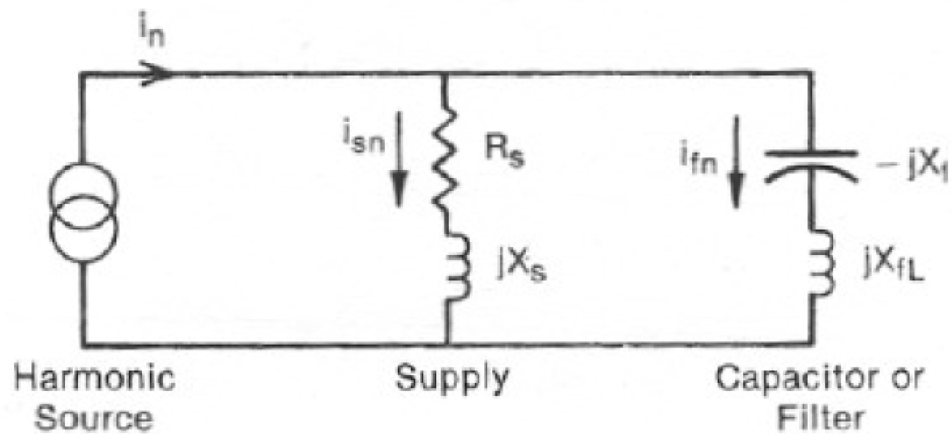
Reference: "Report of the IEEE Task Force on the Effects of Harmonics on Equipment," *IEEE Transactions on Power Delivery*, April 1993, pp. 672-680

Resonance: Model of Power System



Reference: T. J. E. Miller, *Reactive Power Control in Electric Systems*, John Wiley, pp. 339

Resonance Equivalent Circuit



$i_{sn} = \rho_s i_n$

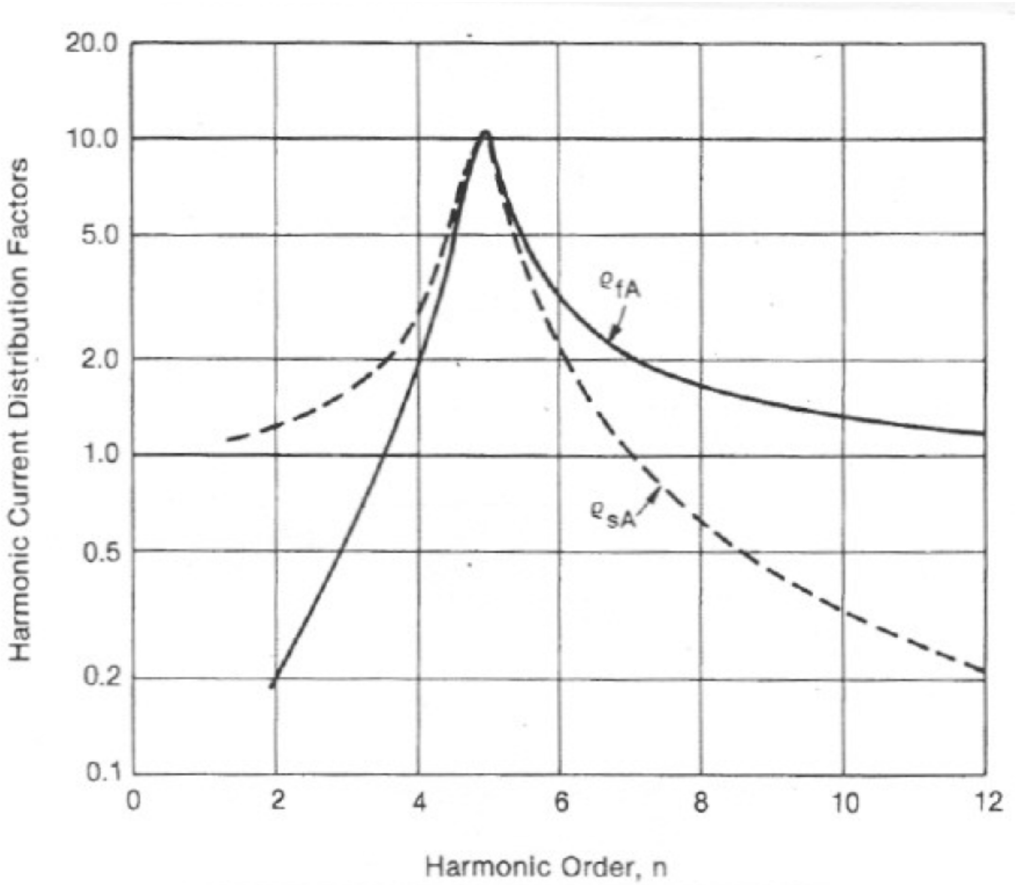
$i_{fn} = \rho_f i_n$

ρ_s = supply distribution factor

ρ_f = capacitor or filter distribution factor

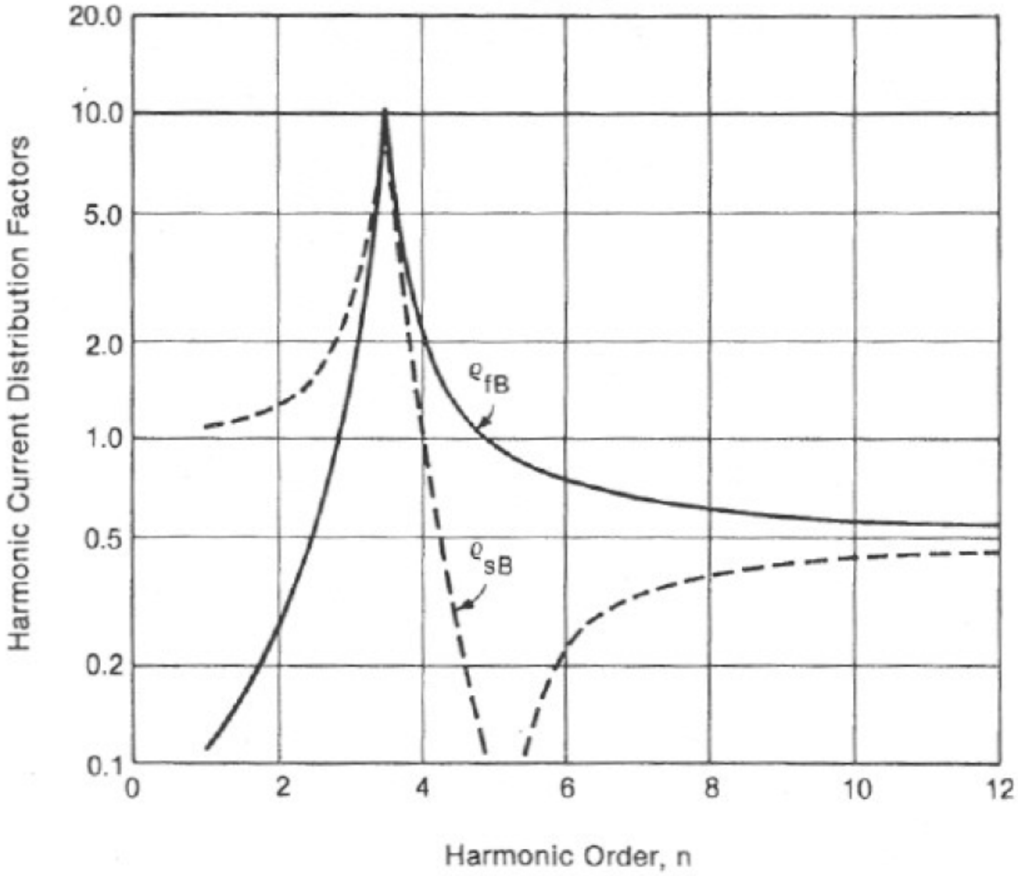
Reference: T. J. E. Miller, *Reactive Power Control in Electric Systems*, John Wiley, pp. 339

Resonance: Distribution Factor, No Reactor



Reference: T. J. E. Miller, *Reactive Power Control in Electric Systems*, John Wiley, pp. 341

Resonance: Distribution Factor, with Reactor



$\rho_{fB} \rightarrow 1$ at $n = 5$

$\rho_{sB} \rightarrow 0$ at $n = 5$

Reference: T. J. E. Miller, Reactive Power Control in Electric Systems, John Wiley, pp. 341