Power Quality
Notes 3-1 (AK)

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Review

- Sources of harmonic current
- Case studies: Plastic Plant, GE Imaging Systems
- Effects of harmonics on equipment
- Capacitors, resonance

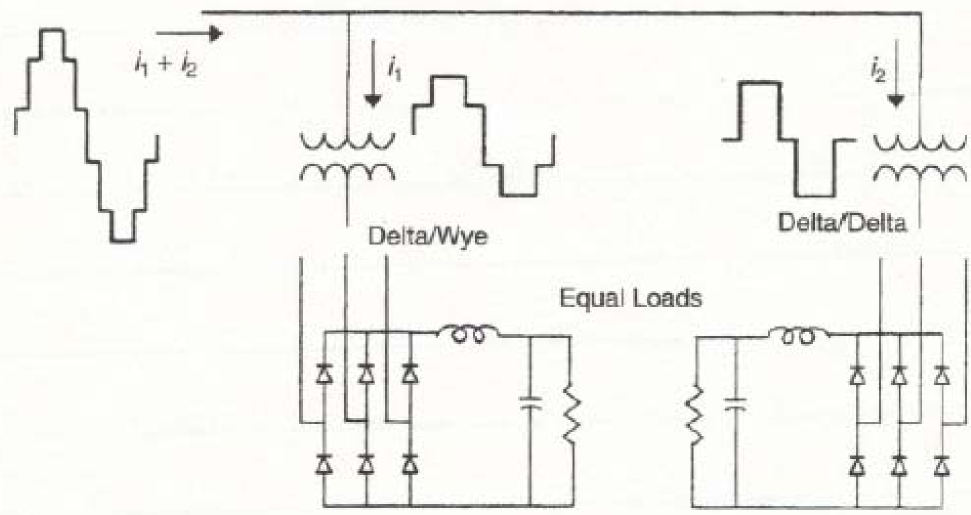
Correction for Power Quality Problems

- 12-pulse converters
- Power-harmonic filters
- Uninterruptible power supplies (UPS)
- Special transformers

12-Pulse Converters

- Apply to AC to DC converters
- DC motor drives (Examples: elevators, extruders)
- AC motor drives (Examples: ASDs)
- Eliminate 5th, 7th harmonics from line current
- Eliminate 360 Hz ripple in DC voltage

Separate 6-Pulse Converters Phase Shifted AC Inputs



$$i_1(\omega t)\,\alpha\,\frac{2\sqrt{3}}{\pi}\left(\cos\omega t - \frac{\cos 5\omega t}{5} + \frac{\cos 7\omega t}{7} - \frac{\cos 11\omega t}{11}\cdots\right)$$

$$i_2(\omega t)\,\alpha\,\frac{2\sqrt{3}}{\pi}\left(\cos\omega t + \frac{\cos 5\omega t}{5} - \frac{\cos 7\omega t}{7} - \frac{\cos 11\omega t}{11}\cdots\right)$$

Figure 3-1 Two separate 6-pulse converters combine to draw 12-pulse current from the power system.

Reference: D. A. Paice, Power Electronics Converter Harmonics, IEEE Press, 1995, pp. 27

Combined 6-Pulse Converters Phase Shifted AC Inputs

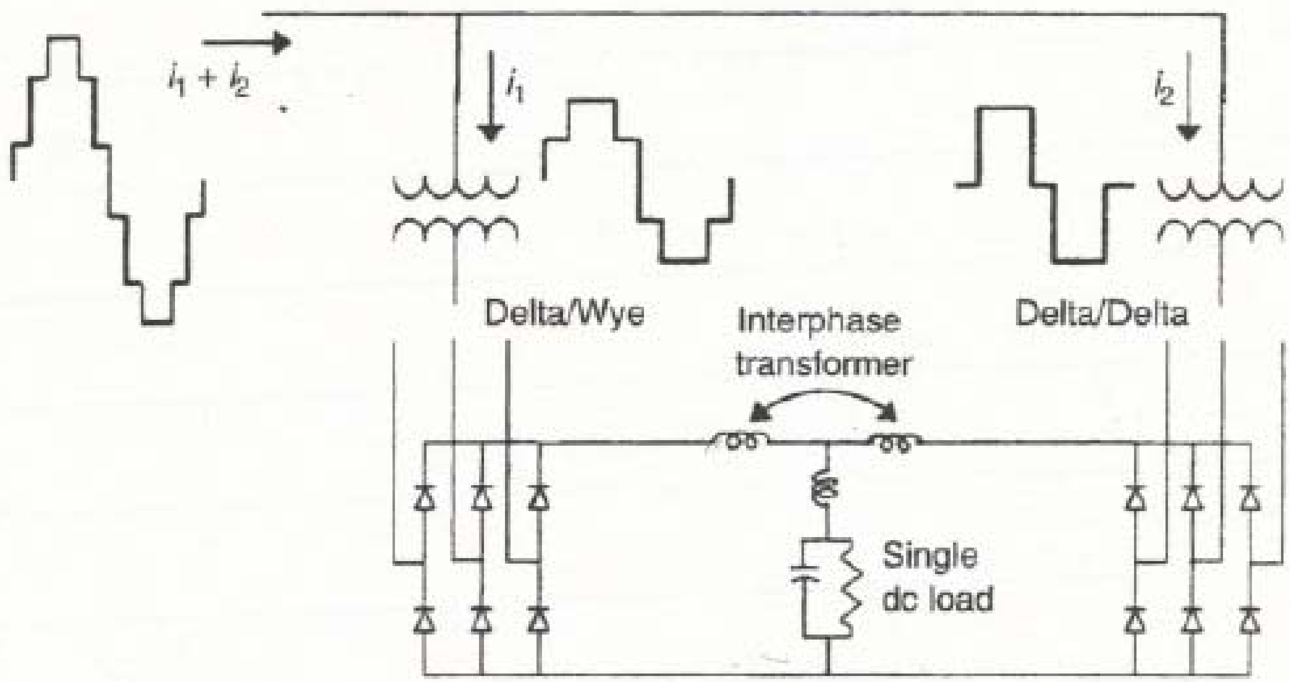


Figure 3-2 Two 6-pulse converters combine within a single equipment and single dc load for continuous 12-pulse operation.

Reference: D. A. Paice, *Power Electronics Converter Harmonics*, IEEE Press, 1995, pp. 27

Basic 6-Pulse Converter DC Motor Drive

- DC motor under regeneration (braking)
- Energy returned to line

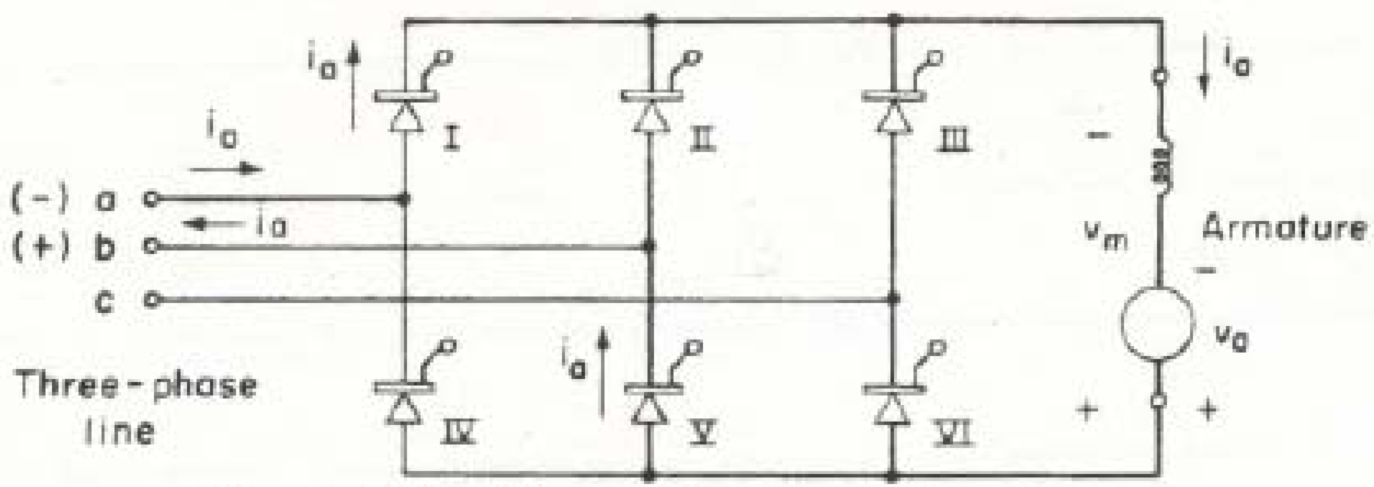


Figure 5.4 Three-phase complete bridge.

Reference: A. Kusko, _Solid-State DC Motor Drives_, MIT Press, 1969, pp. 63

Control Characteristic for 6-Pulse DC Motor Drive

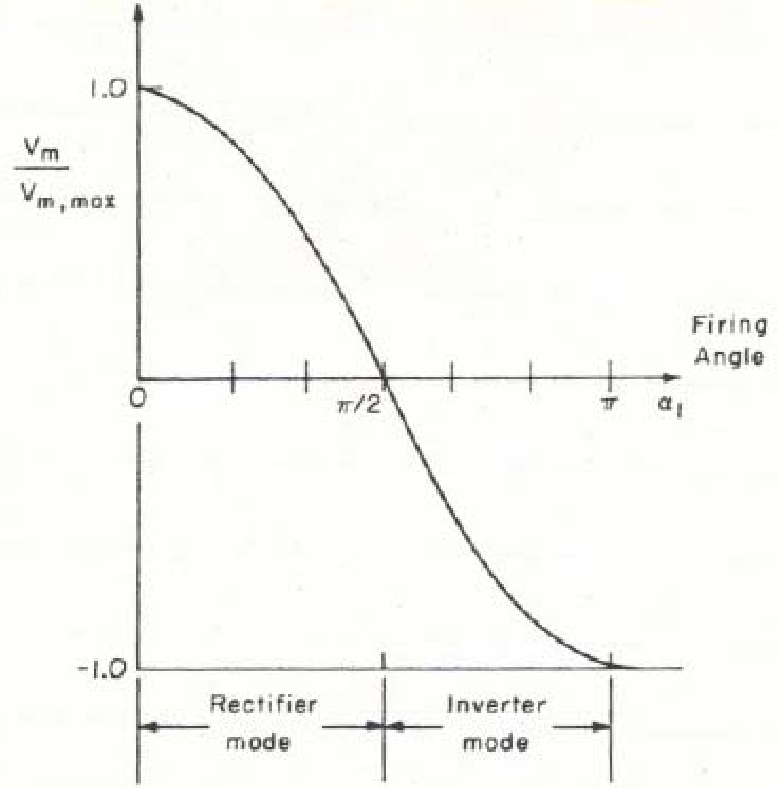


Figure 5.5 Voltage-firing angle characteristic of complete bridge, inductive load.

Reference: A. Kusko, *Solid-State DC Motor Drives*, MIT Press, 1969, pp. 63

Waveform of Line Current and Line Voltage, 6-Pulse DC Motor Drive

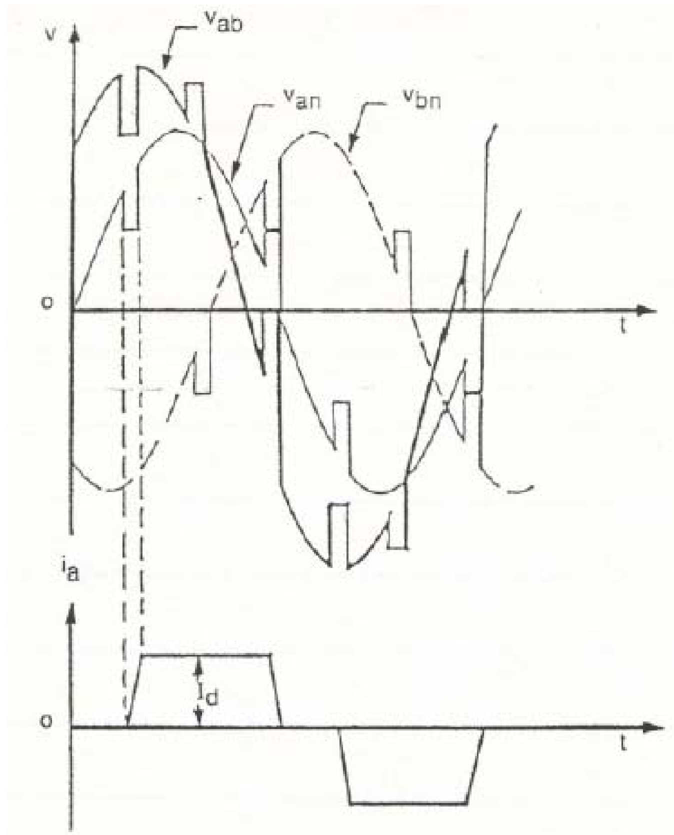


Figure 3 — Waveforms of line current, line-line and line-neutral voltage of a 6-pulse converter for a dc-motor drive

Reference: A. Kusko and S. M. Peeran, "Application of 12-Pulse Converters," *Elevator World*, February 1992, pp. 33-43

Fundamental and Harmonic Components of Line Current, 6-Pulse Converter

- Note: increase in source (line) reactance reduces harmonic amplitude

Source reactance X_s pu	Harmonic Components, I_n/I_{10} pu 1st	5th	7th	11th	13th	Rms harmonics pu
0	1.0	0.200	0.140	0.091	0.076	0.27
0.05	0.997	0.188	0.125	0.065	0.047	0.24
0.10	0.994	0.172	0.108	0.044	0.027	0.21

Figure 4 — Fundamental and Harmonic Components of the Line Current for 6-Pulse Converter as a Function of the Source Reactance X_s

Reference: A. Kusko and S. M. Peeran, "Application of 12-Pulse Converters," *Elevator World*, February 1992, pp. 33-43

Case Study: 12-Pulse DC motor Elevator Drive (Schindler)

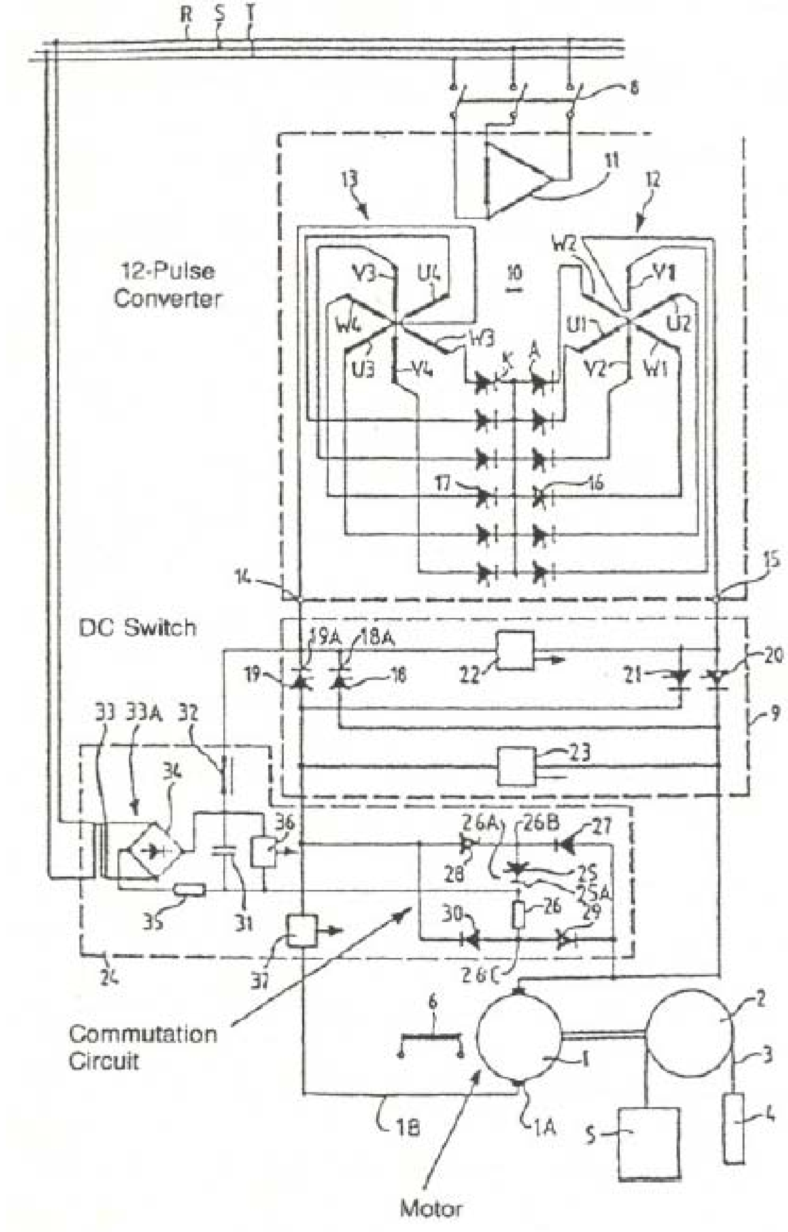


Figure 15 — Diagram of 12-pulse elevator drive

Reference: A. Kusko and S. M. Peeran, "Application of 12-Pulse Converters," *Elevator World*, February 1992, pp. 33-43

Case Study: Equipment for 12-Pulse DC Motor Elevator Drive

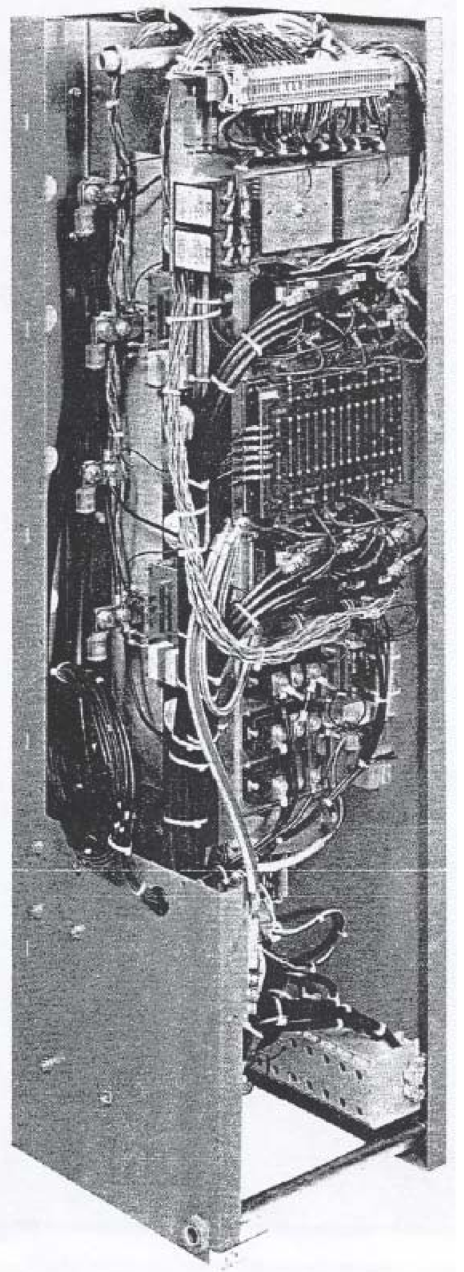


Figure 17 —
Power module subassembly

Reference: A. Kusko and S. M. Peeran, "Application of 12-Pulse Converters," *Elevator World*, February 1992, pp. 33-43

Case Study: Equipment for 12-Pulse DC Motor Elevator Drive

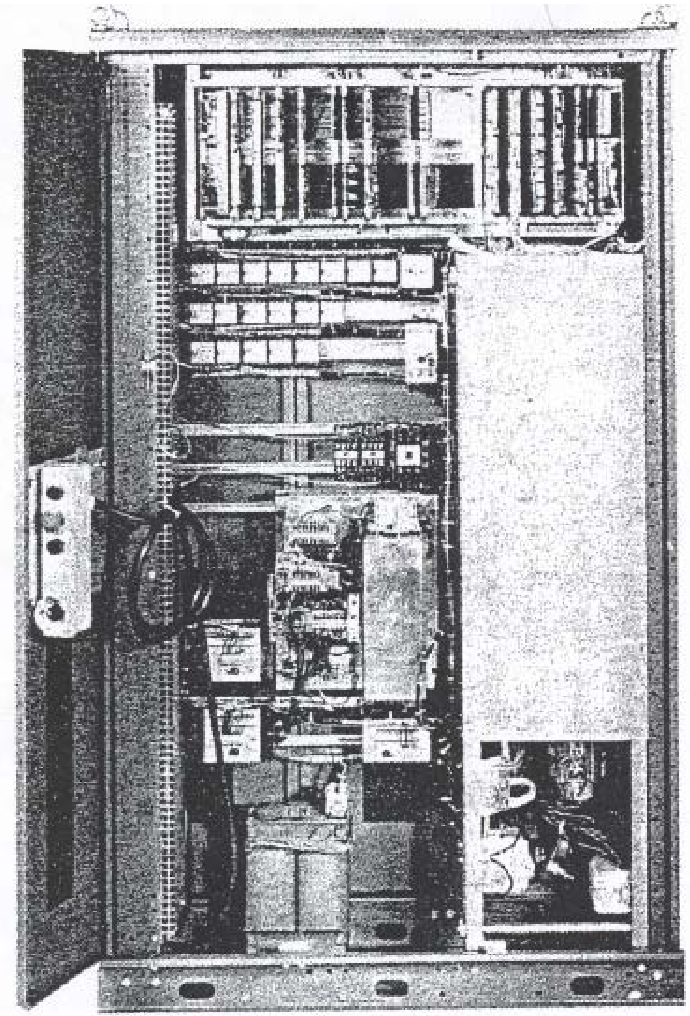
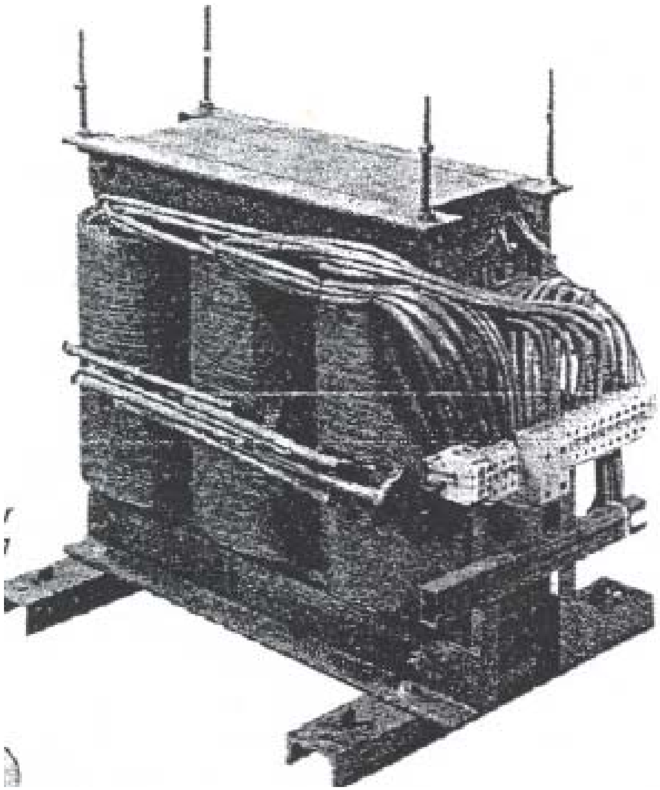


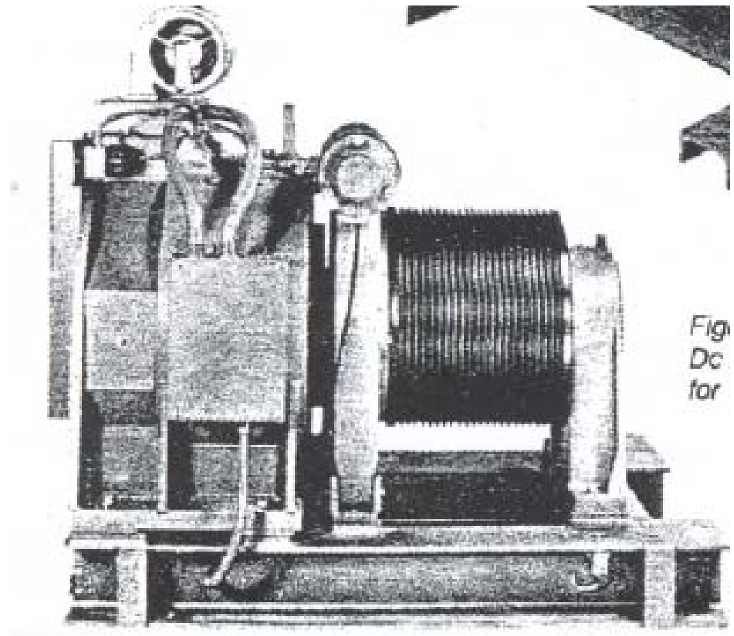
Figure 16 — Power controller cabinet and input module cabinet

Reference: A. Kusko and S. M. Peeran, "Application of 12-Pulse Converters," *Elevator World*, February 1992, pp. 33-43

Case Study: Equipment for 12-Pulse DC Motor Elevator Drive



- Double zig-zag transformer



- DC elevator motor

Reference: A. Kusko and S. M. Peeran, “Application of 12-Pulse Converters,” *Elevator World*, February 1992, pp. 33-43

Case Study: Waveforms of Line Voltage and Line Current for 12-Pulse DC Motor Elevator Drive

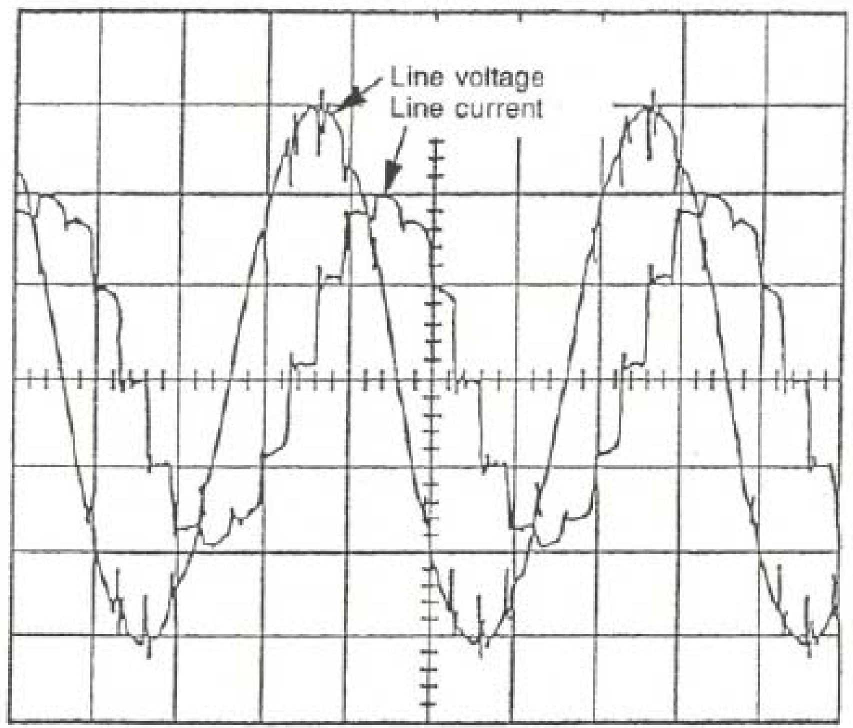


Figure 21 — Waveforms of supply voltage and line current for the 12-pulse converter of Figure 15

Reference: A. Kusko and S. M. Peeran, "Application of 12-Pulse Converters," *Elevator World*, February 1992, pp. 33-43

Case Study: 1750 HP Boiler Feed Pump ASD

- 12-pulse input, 12-pulse output to 1750 HP induction motor

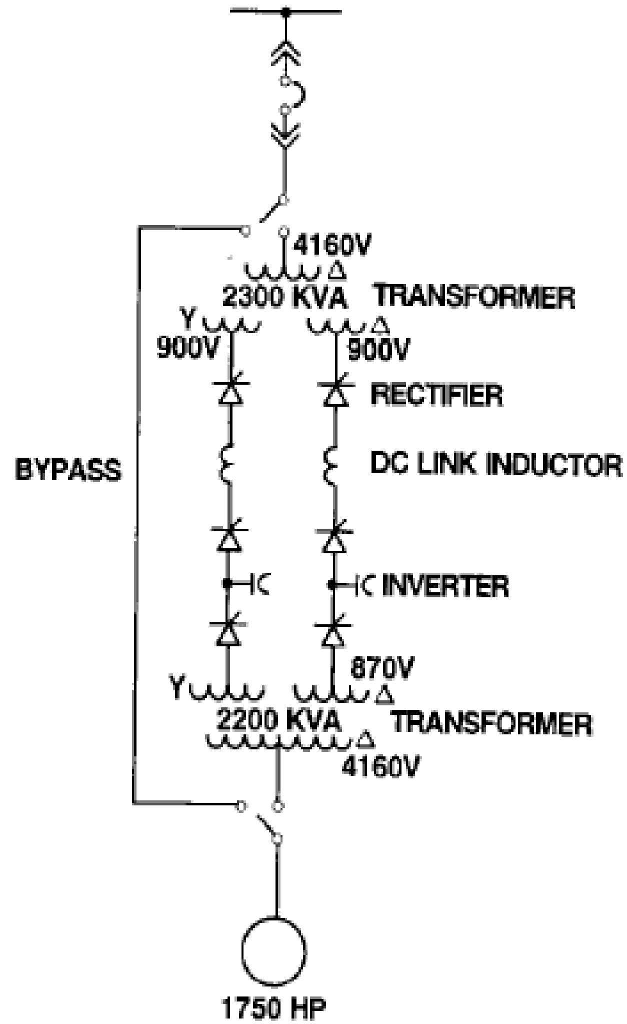


Figure 1
12-Pulse Input, 12-Pulse Output, Current-Source ASD
Ft. Churchill Plant, Unit 1

Reference: J. A. Oliver and B. B. Banerjee, “Power Measurement and Harmonic Analysis of Large Adjustable Speed Drives,” *IEEE Transactions on Energy Conversion*, vol. 3, no. 2, June 1988, pp. 384-390

1750 HP 12-Pulse Input and Output ASD, Current and Voltage Waveforms

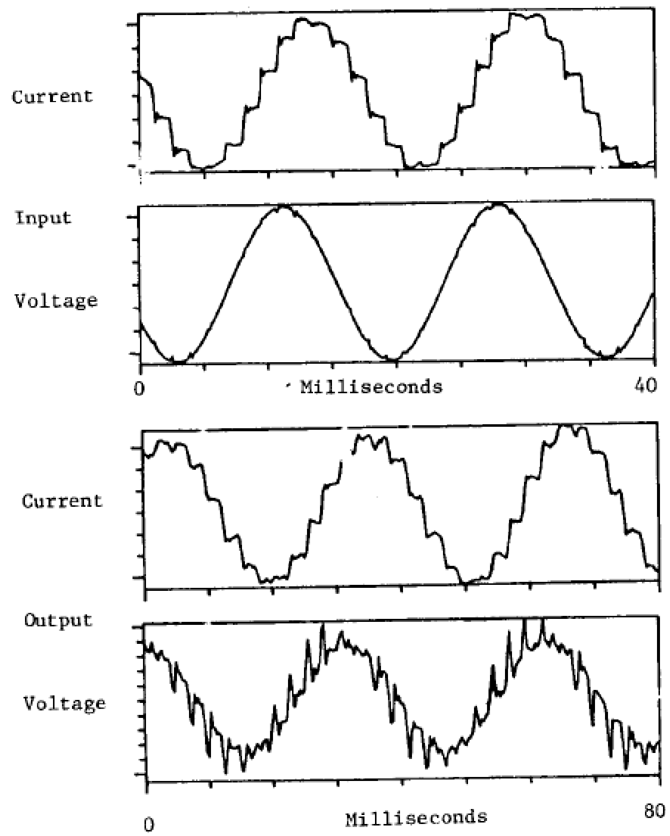


Figure 6
Input And Output Currents and Voltage For
Ft. Churchill Plant, Unit 1
ASD at 30 Hz Output

Reference: J. A. Oliver and B. B. Banerjee, "Power Measurement and Harmonic Analysis of Large Adjustable Speed Drives," *IEEE Transactions on Energy Conversion*, vol. 3, no. 2, June 1988, pp. 384-390

1750 HP 12-Pulse Input and Output ASD, Current and Voltage Harmonic Spectra

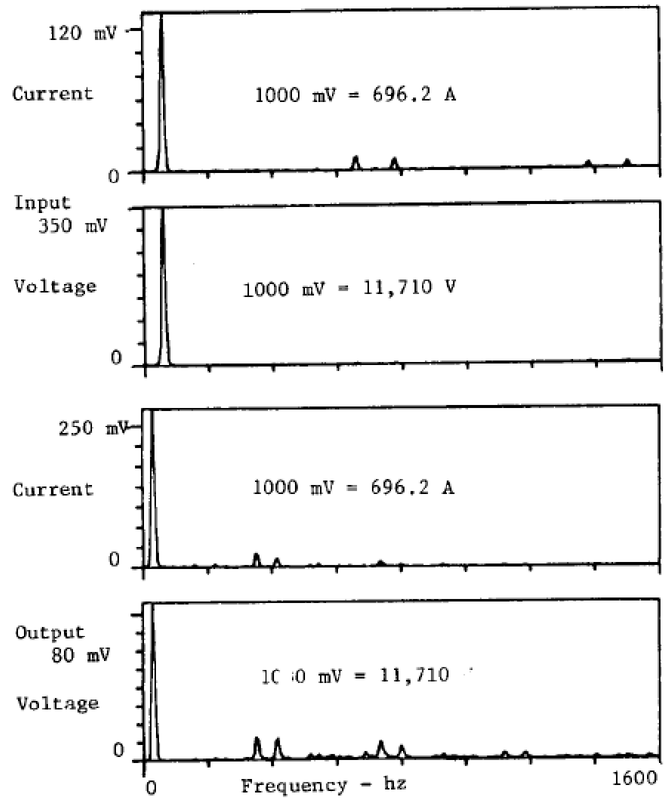


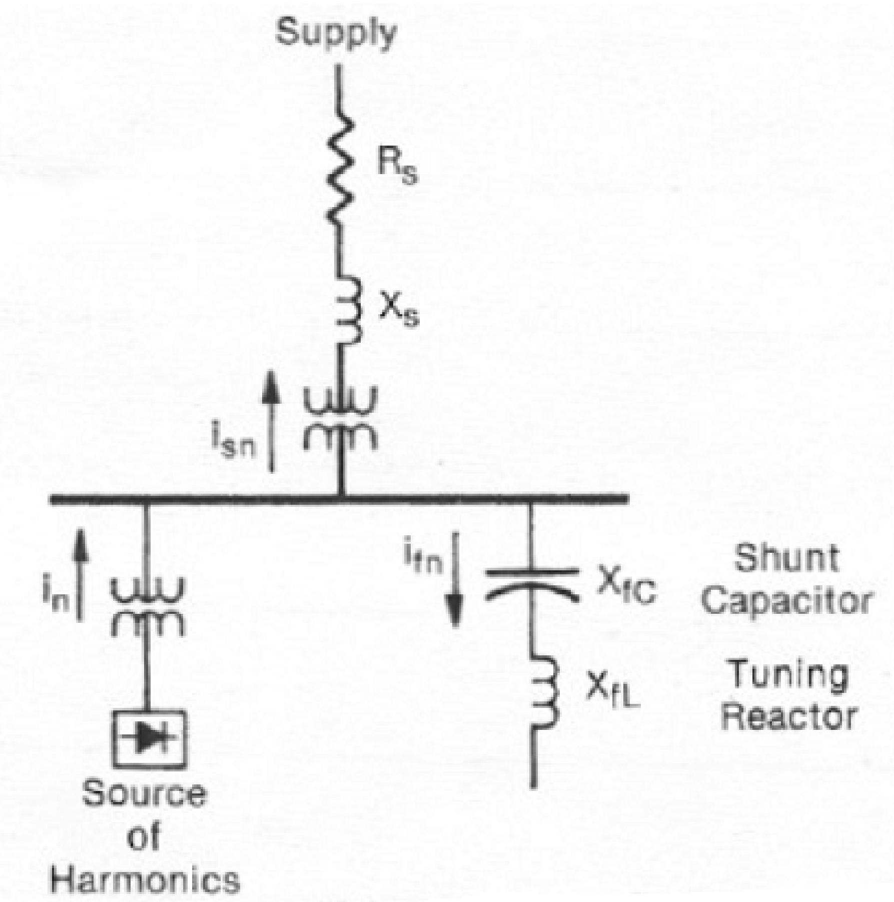
Figure 7
Fourier Analysis of Currents and Voltage of Figure 6

Reference: J. A. Oliver and B. B. Banerjee, "Power Measurement and Harmonic Analysis of Large Adjustable Speed Drives," *IEEE Transactions on Energy Conversion*, vol. 3, no. 2, June 1988, pp. 384-390

Power Harmonic Filters --- Purpose

- Divert harmonic currents produced by converters and other non-linear loads from power factor capacitors
- Divert harmonic currents from feeding back to utility supply system
- Minimize harmonic voltages at site

Power Harmonic Filter: Model of Power System



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

Power Harmonic Filters: Possible Locations in System

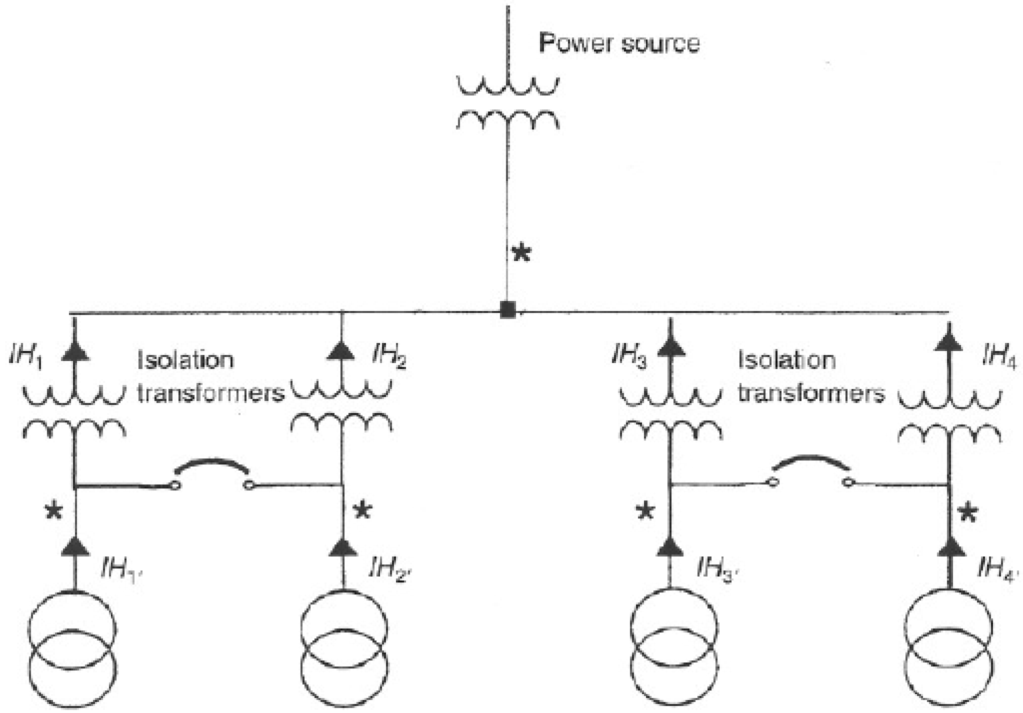


Figure 8-6 Power system with dispersed harmonic sources (* marks possible shunt filter locations).

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

Power Harmonic Filter: Tuned to Five Harmonic Frequencies

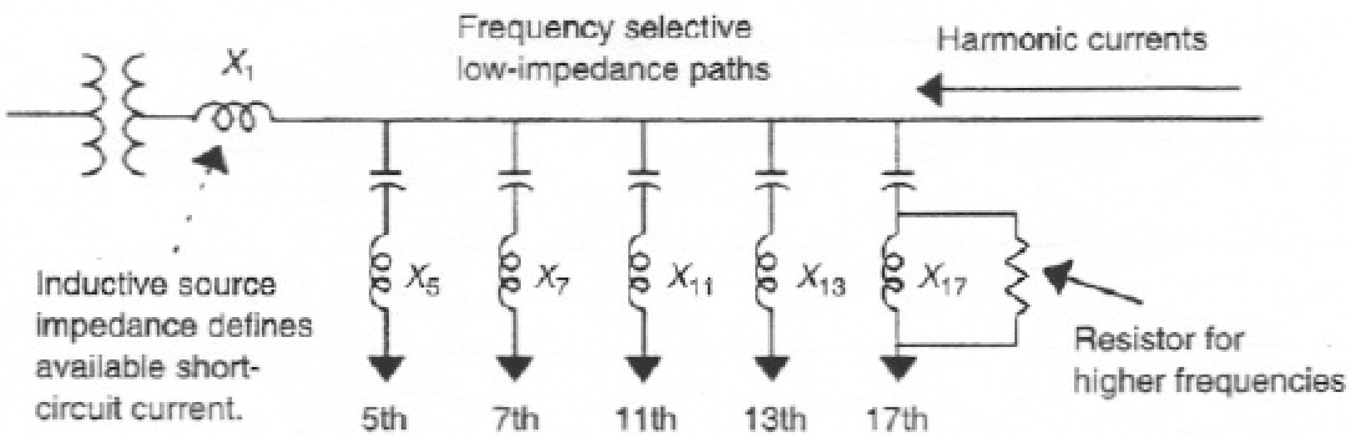


Figure 8-7 Arrangement of multiple parallel path filters using series-tuned harmonic "traps."

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

Power Harmonic Filter: Impedance Seen by Harmonic Currents

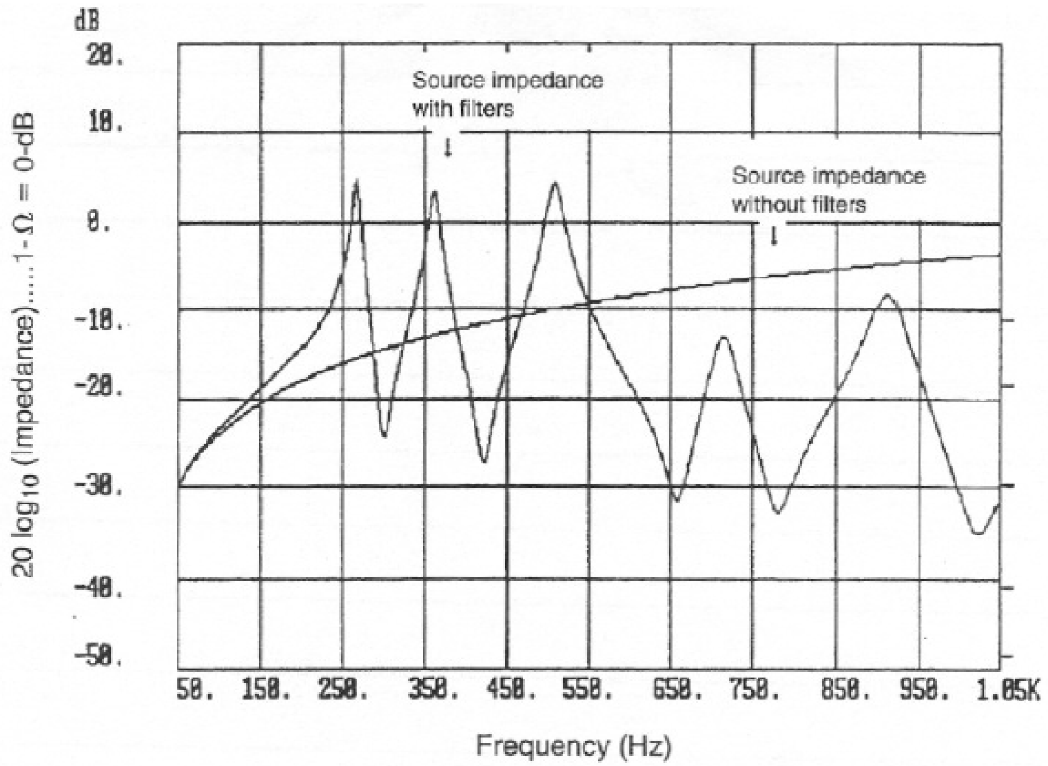


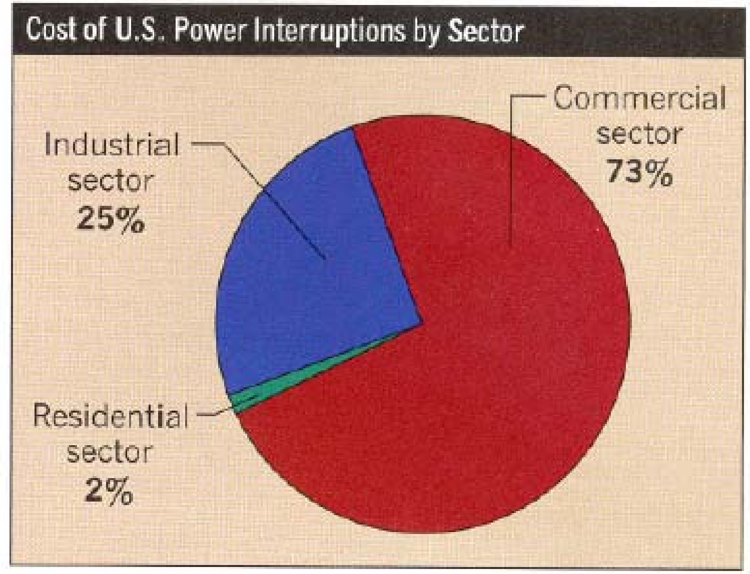
Figure 8-8 Typical impedance "seen" by harmonic currents for the type of filter shown in Figure 8-7. *Note: System power loads will reduce peaks caused by parallel resonance.*

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

MARKET WATCH

Annual Cost of Power Interruptions Estimated at $80 Billion—Maybe

In the wake of 2003's Northeast blackout, researchers have focused their attention on investing to improve the grid, but a new study asserts that more information is needed before people start reaching into their pocketbooks. Researchers Kristina Hamachi-LaCommare and Joe Eto of the Lawrence Berkeley National Laboratory report that electrical power outages and blackouts cost the nation about $80 billion a year, but they caution that a lack of information makes it difficult to be completely sure. Using the best available data, the researchers estimate that the commercial sector accounts for $57 billion of the approximate $80 billion worth of annual losses, the industrial sector accounts for roughly $20 billion, and residential accounts for $1.5 billion. However, uncertainties in the available data on power interruptions could mean the true costs of interruptions could be higher or lower by tens of billions of dollars, the researchers say. "Given the high stakes involved in decisions regarding who should invest how much to improve the grid, it's imperative that we rely on the best possible information on one of the key expected benefits from these investments, namely improvements in electricity reliability," Eto says. The researchers have called for a national effort to collect better information on these costs; they recommend that the utility industry and its regulators expand the collection of data on power interruptions and power quality.



Reference: *EC&M*, March 2005, pp. 10

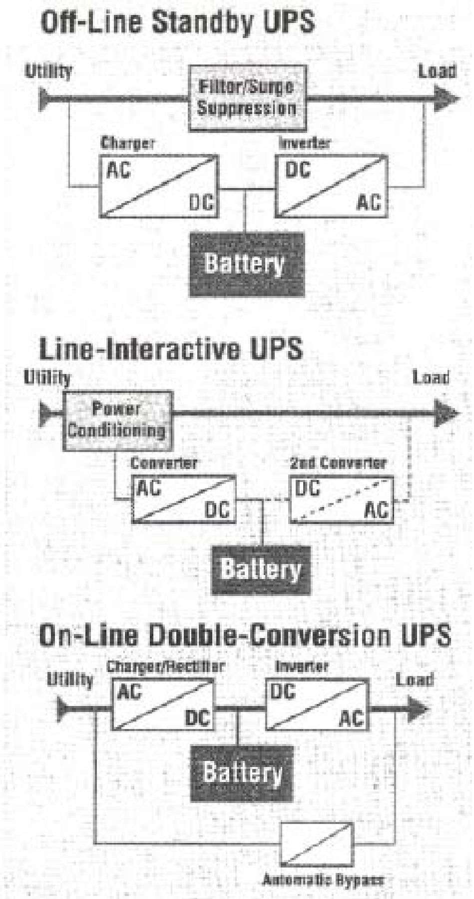
Uninterruptible Power Supplies (UPS) Purpose

- Provide continuous power to the load in the face of line voltage disturbances and outages
- Present high power factor to the the supply line
- Isolate non-linear loads from the line

Types of UPS

- Static (semiconductor) inverter
- Rotary (generator)
- Alternate feeder (transfer switch)

Three Types of UPS Packages



There are three basic UPS technologies.

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

UPS: Engine Generator Alone

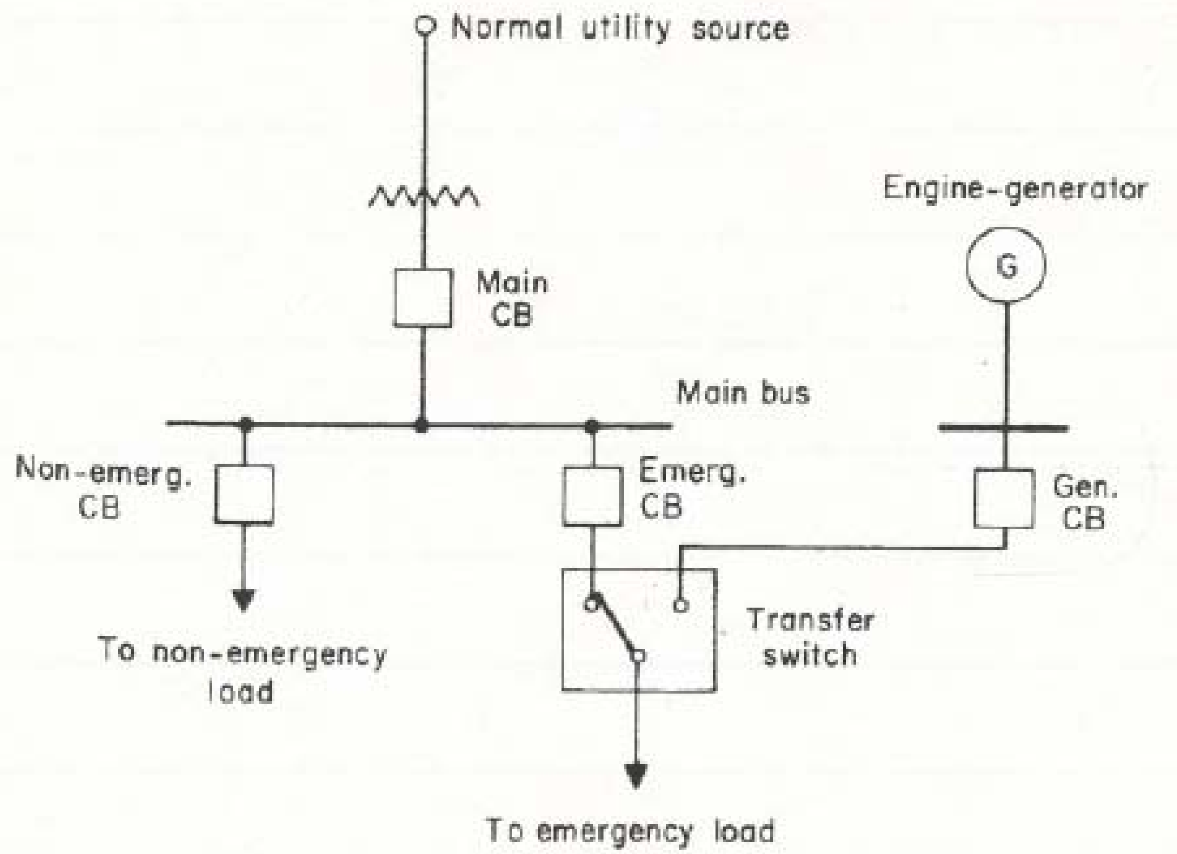


Figure 2.2 Emergency engine-generator system with a transfer switch.

Reference: A. Kusko, *Emergency Standby Power Systems*, McGraw Hill, 1989

UPS: Static Inverter

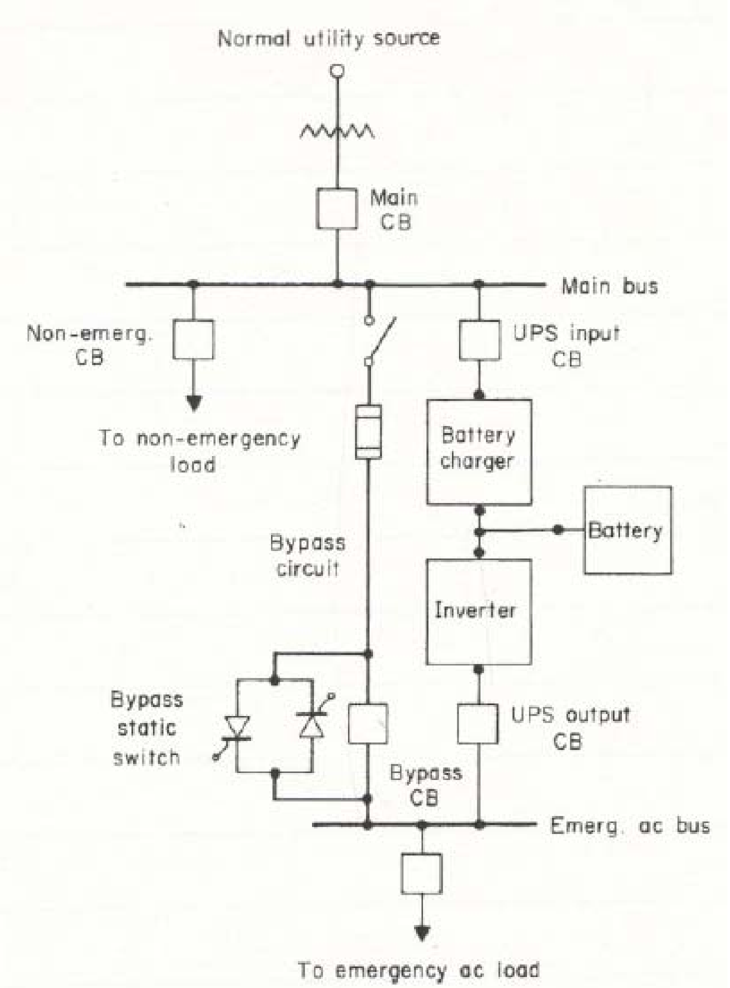


Figure 2.3 Emergency system with a static UPS.

Reference: A. Kusko, *Emergency Standby Power Systems*, McGraw Hill, 1989

UPS: Alternate Feeder

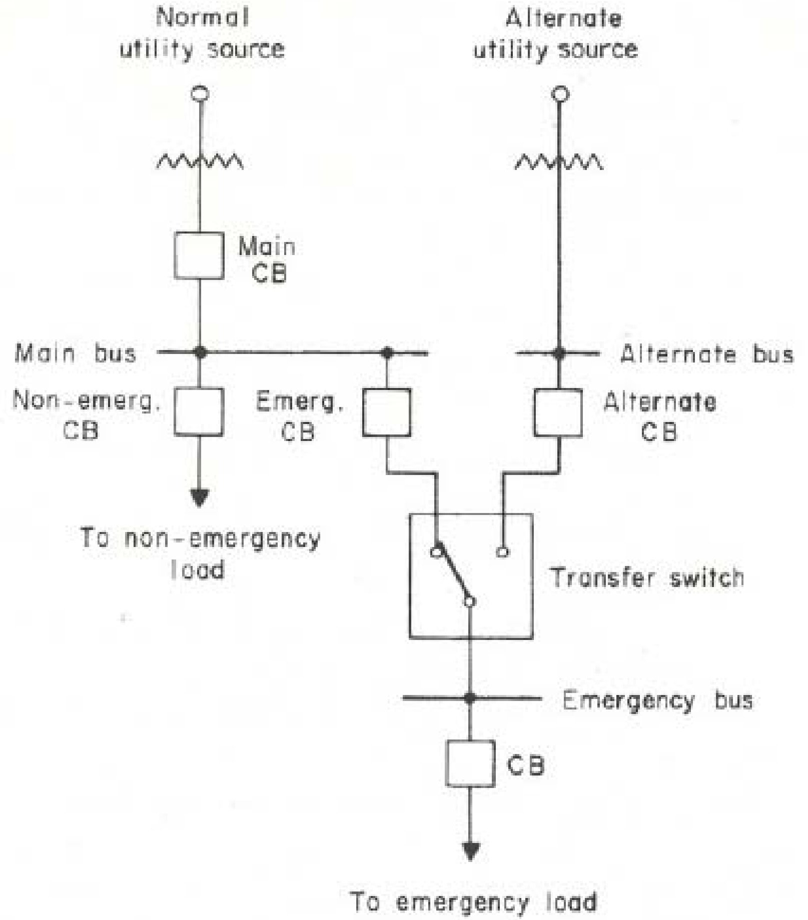


Figure 2.4 Emergency system with an alternate utility service.

Reference: A. Kusko, Emergency Standby Power Systems, McGraw Hill, 1989

UPS: Rotary (Pillar) Circuit

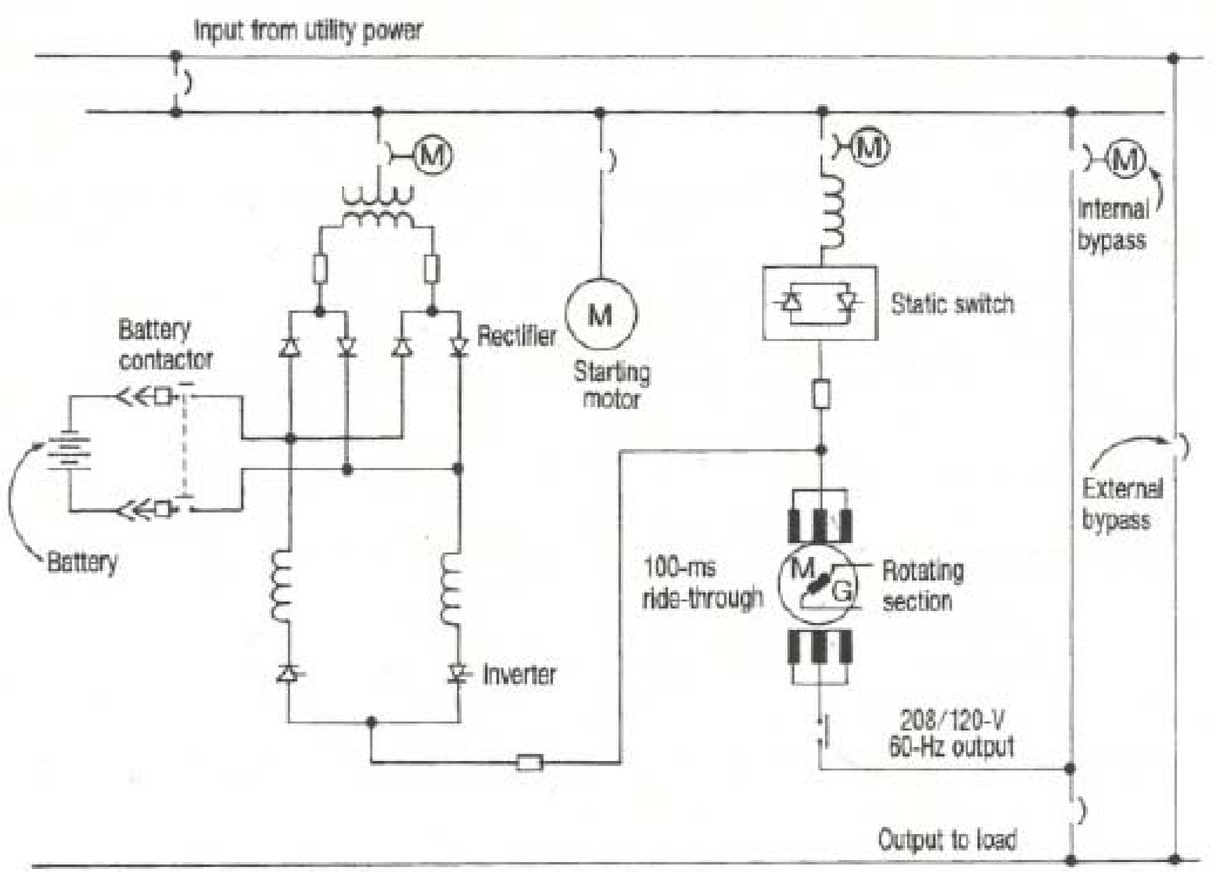


FIGURE 17.7 Improved hybrid UPS. (Courtesy *EC&M Magazine.*)

Reference: D. C. Griffith, *Uninterruptible Power Supplies*, Marcel Dekker, 1989

UPS: Rotary (Pillar) Machine

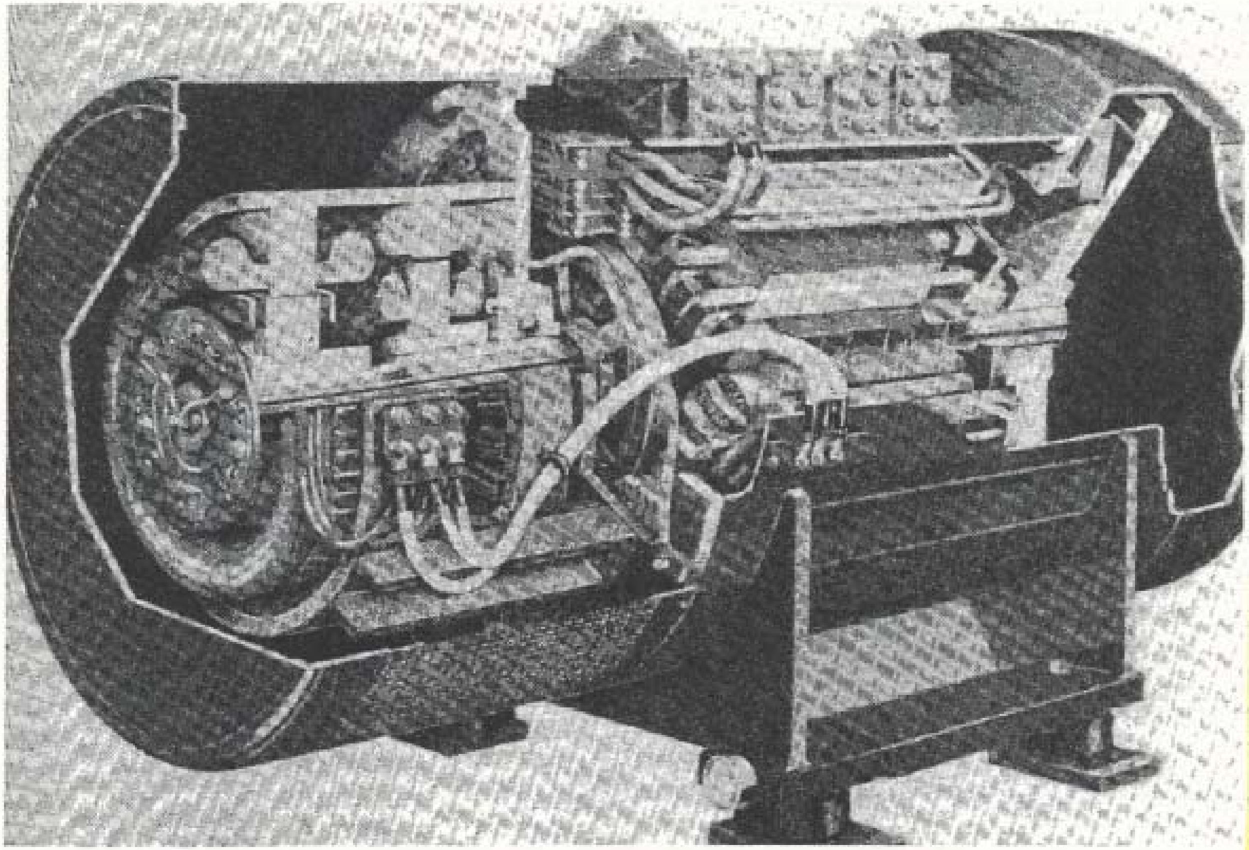


FIGURE 17.6 Improved hybrid UPS MG with common stator. (Courtesy Pillar.)

Reference: D. C. Griffith, _Uninterruptible Power Supplies_, Marcel Dekker, 1989

Transformers for Correction of Voltage Deviation and Harmonic Currents

- Tap changing --- automatic, slow
- Buck/boost --- fixed ratio (example ± 10%)
- Constant voltage (Sola) --- continuous, range 75-115 percent line voltage
- Phase shifting --- eliminate 5th and 7th harmonic currents from line
- Neutral grounding --- eliminate 3rd harmonic from neutral