platts

Distribution Transformer Efficiency

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Why Does Transformer Efficiency Matter?

- First cost isn't the whole story.
- Most transformers are >95% efficient.
- Transformers are energized 24/7.
- A little efficiency improvement goes a long way.
- On average, transformers are in service for 30 years
- Higher efficiency models minimize life-cycle costs.

The Environmental Cost of Transformer Losses

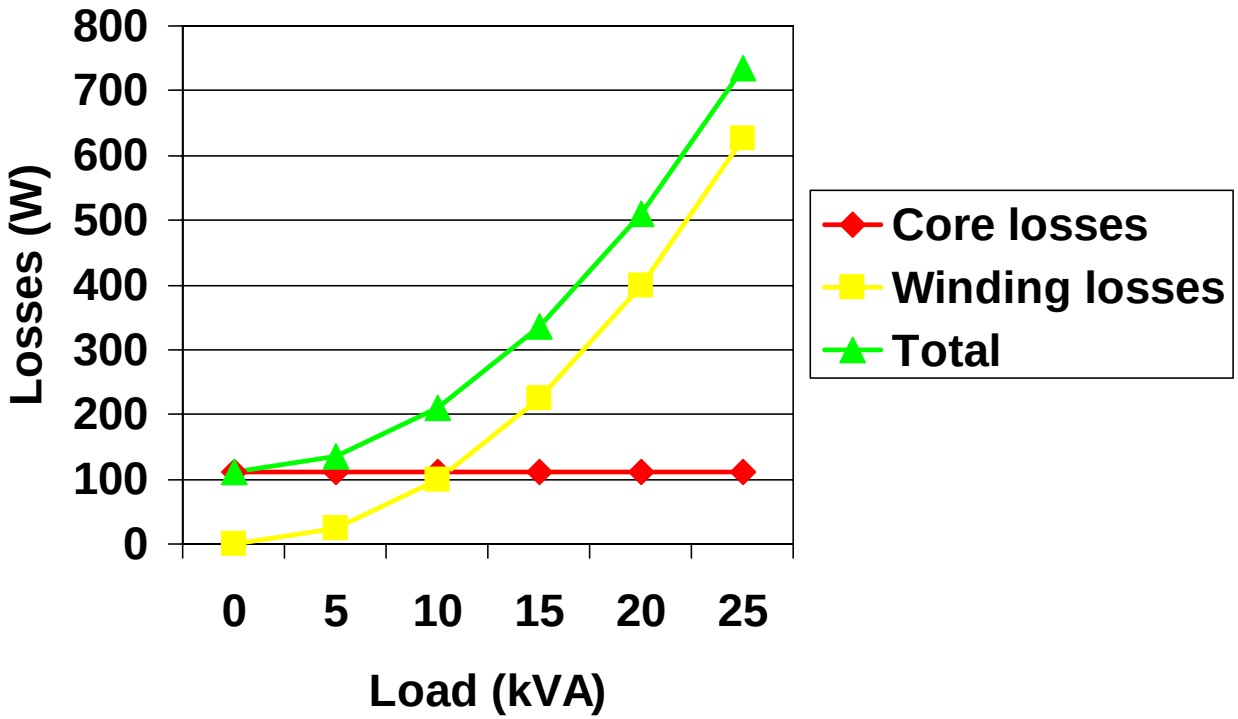
According to the U.S. Environmental Protection Agency, transformer losses:

- Waste >2% of total U.S. generation, about 61 billion kWh/year.

- Are responsible for 45 million tons of CO2 emissions—equivalent to the annual emissions of 6.0 million cars.

Transformer Loss Mechanisms

- Core Losses
- Winding Losses



Core Losses

- Independent of load level.

- Occur whenever the transformer is energized.

- Types of losses:
  - Hysteresis
  - Eddy current
  - Other (~1% of total losses)
    - Magnetizing current I^2R losses
    - Stray eddy current losses
    - Dielectric losses

Winding Losses

- I^2R losses
  proportional to square of load.

- Winding eddy current losses
  (10-15% of I^2R losses)

The Big Tradeoff

Transformer design is a tradeoff between:

- Core losses
- Winding losses
- Weight
- Size
- Cost

Improvements in one of these often come at the expense of another.

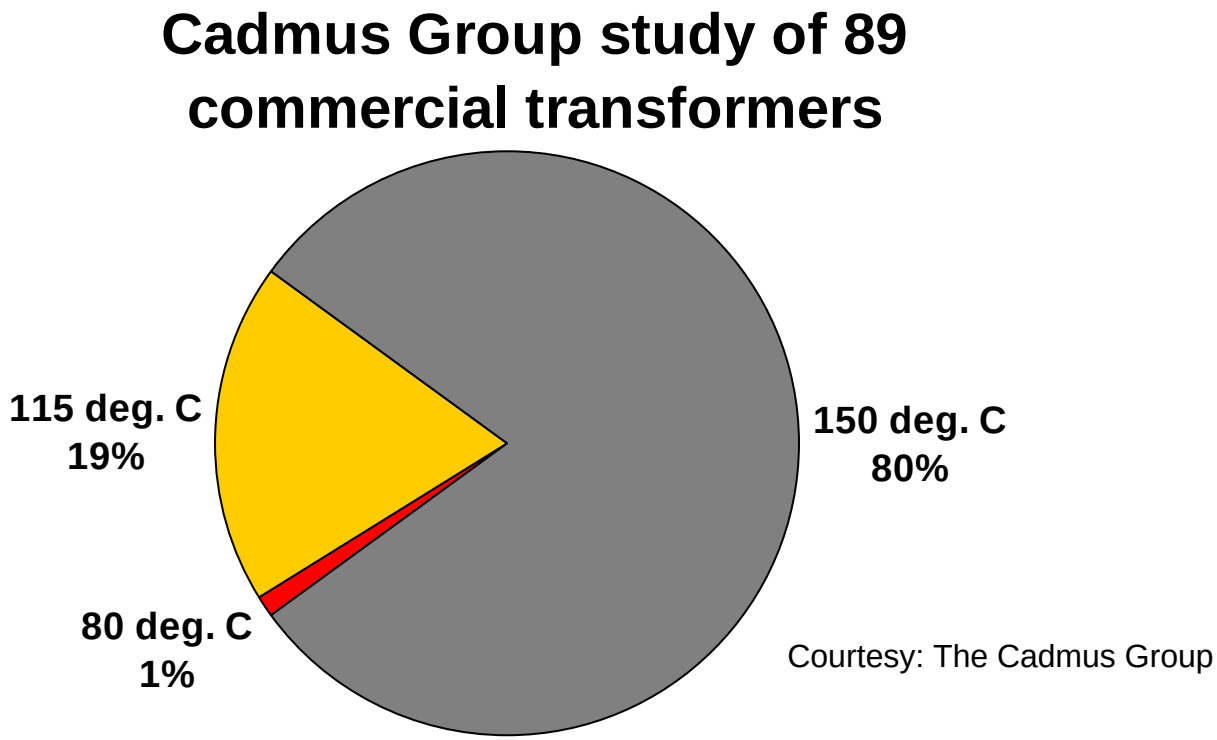
Standard Efficiency Distribution Transformers

Standard transformers are differentiated by their full-load temperature rise: 80° C, 115° C, or 150° C

KVA	Cost ($)		Core Losses (W)		Winding Losses (W @ full load)	
	80° C	**150° C**	**80° C**	**150° C**	**80° C**	**150° C**
45	$1,501	$705	290	335	825	1,923
75	$2,412	$998	485	505	1,410	2,571
112.5	$2,460	$1,475	819	853	984	2,678

About 233,000 low voltage (<1,200 Vac primary) distribution transformers are sold annually to commercial and industrial customers.

Lowest First Cost Dominates the Market



Courtesy: The Cadmus Group

- 43 buildings in Massachusetts
- Office, manufacturing, retail, hospitals, schools

High-Efficiency Transformers

National Electrical Manufacturers Association (NEMA) established it's TP-1 standard in 1996:

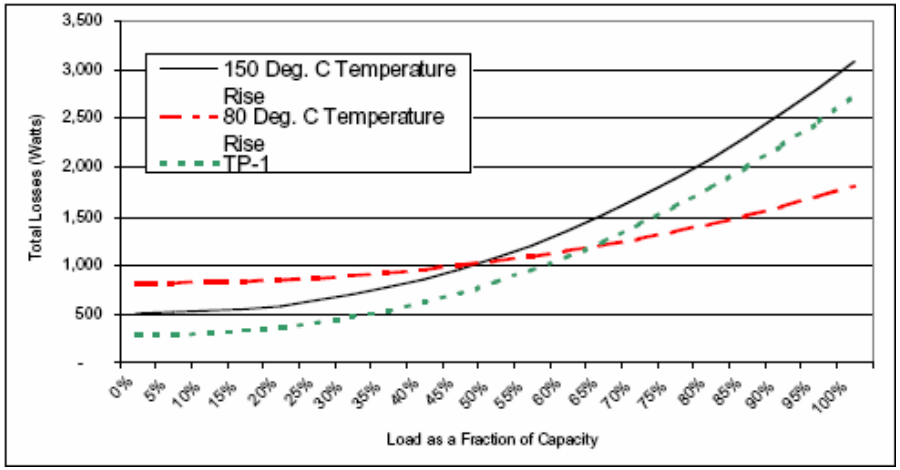
- Defines high efficiency transformers.
- Levels set to provide a 3-year payback on average.
- TP-1 adopted by DOE/EPA ENERGY STAR program.
- Currently 36 manufacturers, 870 qualifying models.

NEMA's TP-1 Standard

Single-phase transformers				Three-phase transformers			
KVA	Baseline efficiency	TP-1	Reduction in losses (%)	KVA	Baseline efficiency	TP-1	Reduction in losses (%)
15	96.7	97.7	29.4	15	95.7	97	29.4
25	97.2	98	29.4	30	96.5	97.5	29
37.5	97.3	98.2	33.1	45	97	97.7	23.4
50	97.4	98.3	33.7	75	97.3	98	24.7
75	97.8	98.5	30.7	112.5	97.6	98.2	23.5
100	97.9	98.6	33.8	150	97.9	98.3	19.3
167	98.1	98.7	31.5	225	98.1	98.5	19
250	98.3	98.8	30.2	300	98.3	98.6	18.1
333	98.3	98.9	34	500	98.4	98.7	16.4
500	98			750	98.6	98.8	13
667	98.3			1000	98.7	98.9	13.1
833	98.4			1500	98.8		
				2000	98.9		
				2500	99		

Efficiency Depends on Load Level

Total losses versus load for three 75 kVA transformers



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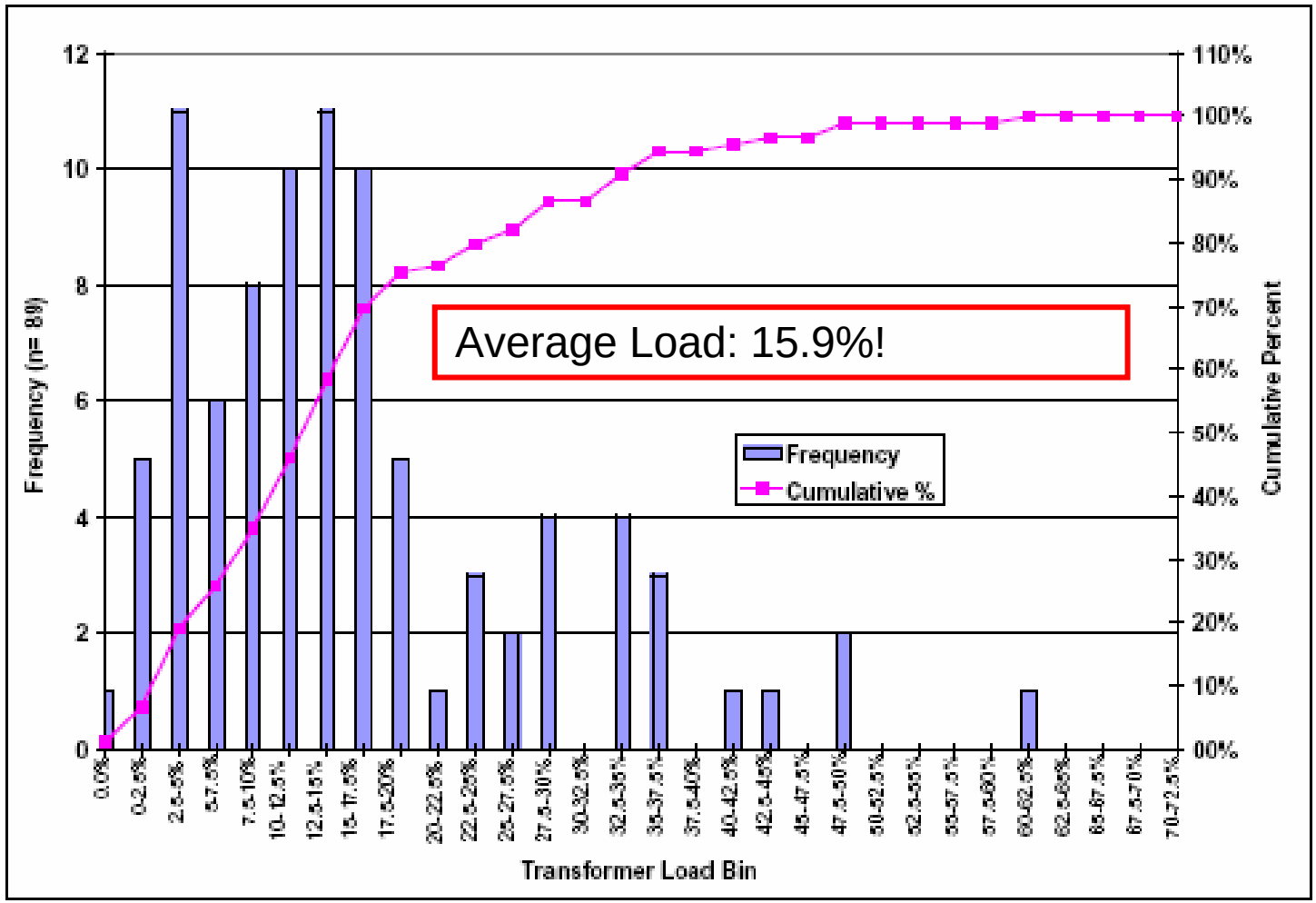
- TP-1 models optimized for 35% of capacity.
- 80° C model minimizes load losses, better above 65% of capacity
- 150° C model minimizes core losses, better than 80° C model below 45% of capacity.
- Most distribution transformers operate below 35% of nameplate capacity most of the time.

Cadmus Data on Average Transformer Load Levels



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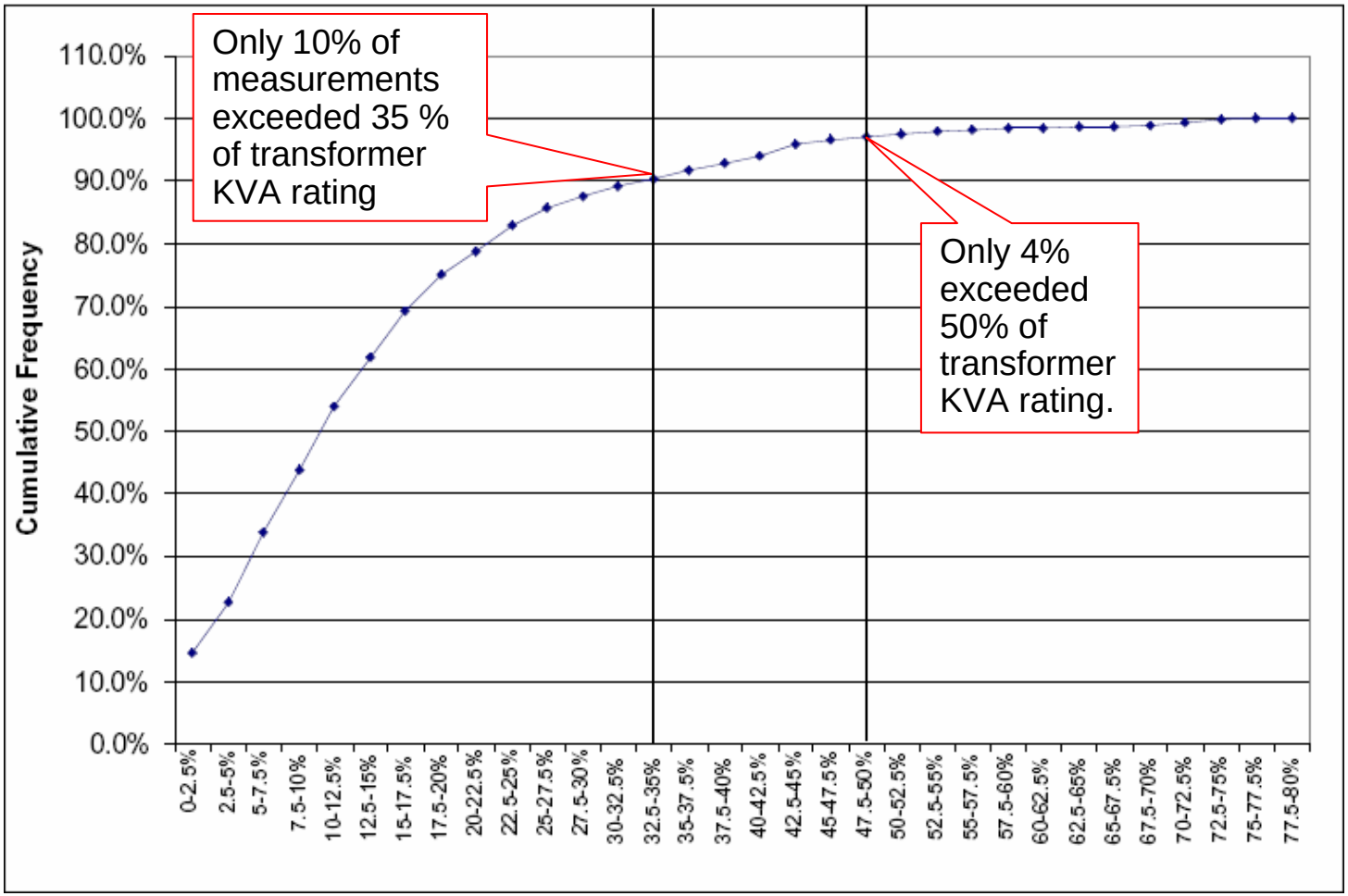
Cadmus Data on 10-minute Load Measurements



Courtesy: The Cadmus Group

Sometimes Downsizing is the Better Choice

Transformer	Total losses	Purchase price	Cost of losses	Premium	Annual savings	Payback	Life Cycle Cost*
75 KVA 150C	6,133	$998	$393	**baseline**			$5,422
75 KVA 80C	5,181	$2,412	$332	$1,414	$61	23.2	$6,150
75 KVA Energy Star	3,537	$2,109	$226	$1,111	$167	6.7	$4,653

A 75 KVA transformer with a 20% average load vs. a 45 KVA transformer with a 33% average load (identical load):

- 75 KVA Energy Star minimizes losses.

Resources for Purchasing Decisions

- TP-1/Energy Star Qualifying models:

http://www.energystar.gov/ia/products/prod_lists/transformers_prod_list.xls

- Transformer Efficiency Calculator:

http://www.energystar.gov/index.cfm?c=ci_transformers.pr_ci_transformers

- American Council for an Energy Efficient Economy:

http://www.aceee.org/ogeece/ch5_trans.htm

- Consortium for Energy Efficiency:

http://www.cee1.org/ind/trnsfm/trnsfm-main.php3

Harmonic Problem? What Harmonic Problem?

Harmonics are everywhere.

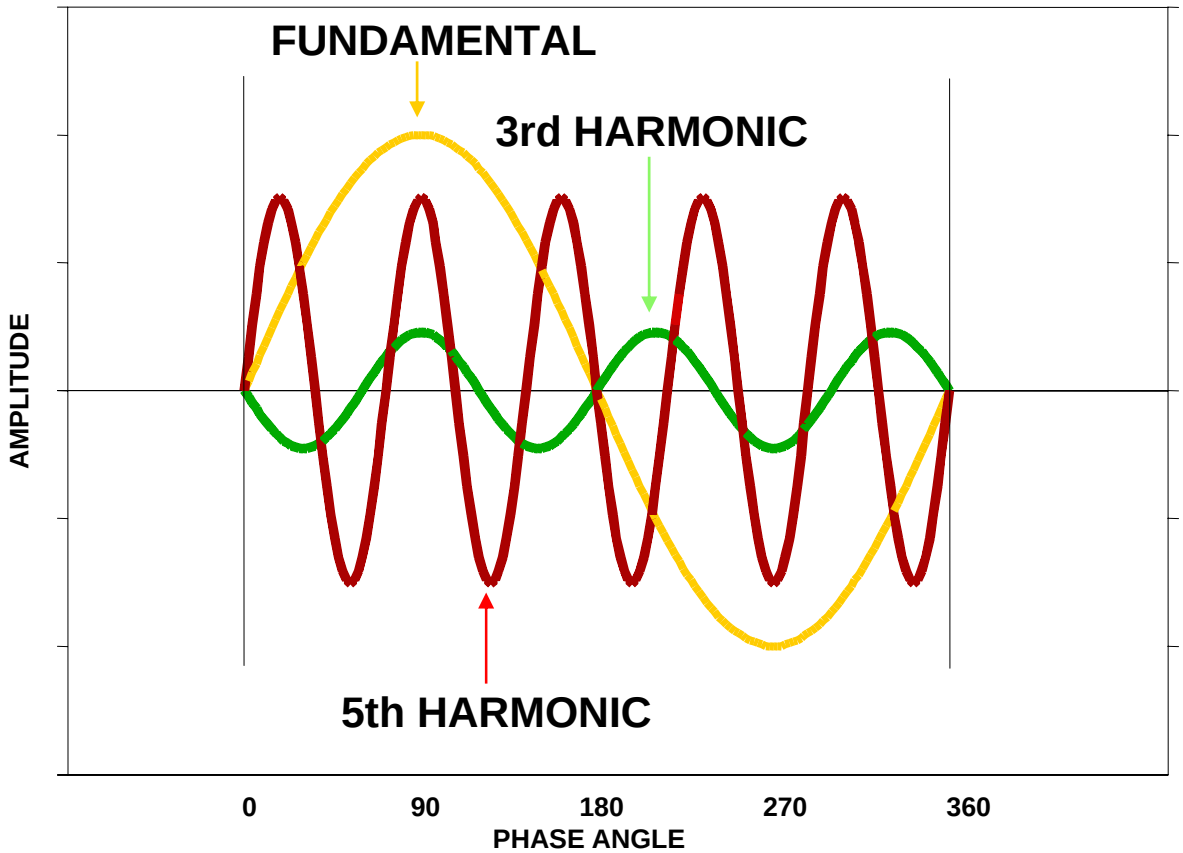
- Caused by single- and three-phase electronics.

- Waste energy, limit distribution system capacity, distort voltage, cause high neutral currents, can cause breaker trips or malfunction of sensitive equipment.

- ***They're rarely a problem.***

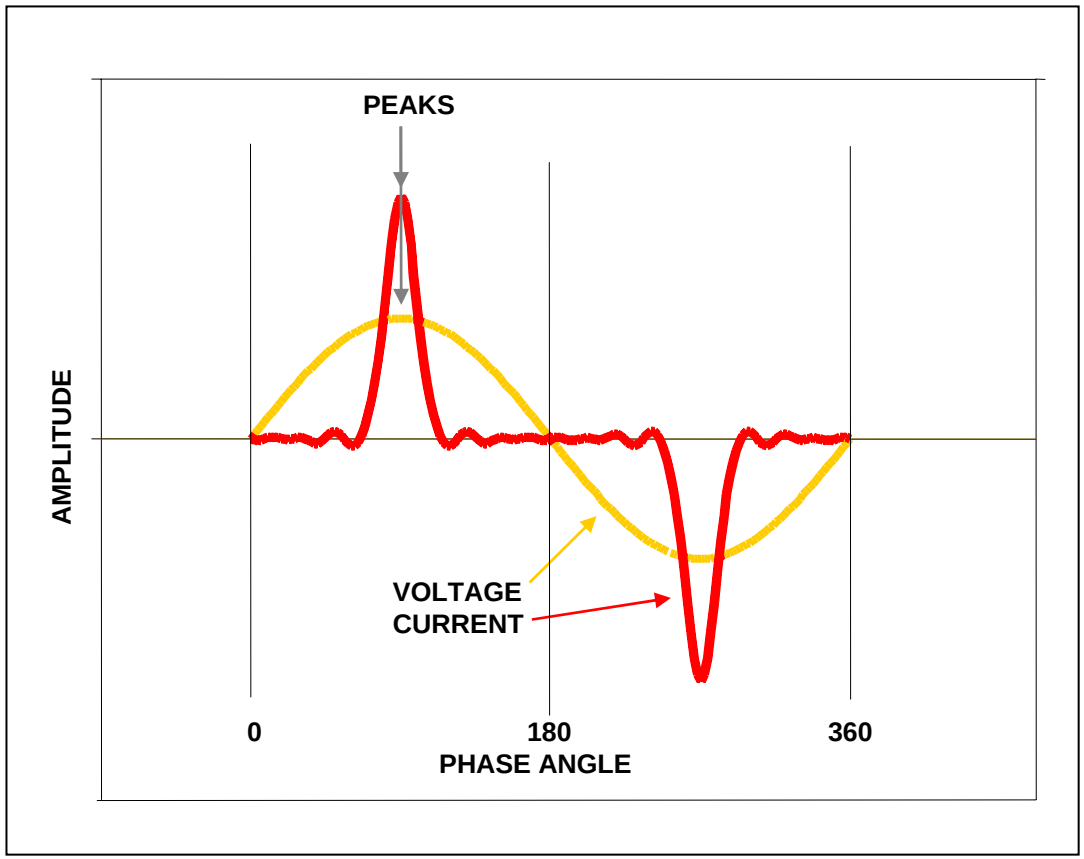
What are Harmonics?

Harmonics are simply electronic waveforms that oscillate at multiples of the fundamental frequency



Voltage and Current for a Non-linear Load

- These are current and voltage waveforms for computer power supply, a Non-linear Load.
- The current waveform is a totally different shape from the voltage waveform.



You Know You've got a Harmonics Problem When…

- Transformer temperature >= rated rise well below rated load.
- Crest factor (V_{peak}/V_{rms}) is below 1.4.
- Terminal screws, conductor insulation discolored at panel.
- Neutral current is high and exceeds imbalance of phase currents.

Solutions for Harmonics

Harmonic Mitigating Transformers:

- Special windings that attenuate harmonics
- Effective at and upstream of transformer.
- Price premium from 35 to 200%.
- Manufacturers:
  - Powersmiths International Corp.
  - Mirus International Inc.
  - Power Quality International
  - The Delta Group

Solutions for Harmonics

K-Rated Transformers:

- "Beefed-up" to handle harmonics.
- Don't attenuate harmonics, just better able to radiate the additional heat.
- 40%-60% price premium
- All major manufacturers offer them

Solutions for Harmonics

Doubling the Neutral:

- Harmonics from single-phase electronics add in the neutral—can exceed neutral's ampacity.

- Doubling the neutral treats the symptom, does nothing about disease.

Solutions for Harmonics

Harmonic Suppression System from Harmonics Ltd.:

- Suppresses harmonics from single phase loads only.
- Virtually eliminates 3rd harmonic (180 Hz).
- Connects at transformer, but works throughout distribution system.
- www.harmonicslimited.com.

The Federal Transformer Efficiency Standard Process

- 1992: Energy Policy Act
- 1997: DOE determination
- July ’04 NOPR:
  - Efficiency testing procedure
  - Efficiency standard
- Implementation: 2007???

Questions?