Understanding and Troubleshooting Real-World Power Quality Problems

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Class Content

- Introduction to power quality (PQ)
- Causes of poor PQ and impact of application
- PQ characteristics
- Tools for monitoring PQ
- Case studies

PQ Involves Voltage and Current Characteristics

Poor PQ refers to changes in an electric power supply that can cause equipment to fail, misoperate, or degrade

Noisy Transformers

Overheated Equipment

Blown Fuses

What Is the Cost of Poor PQ?

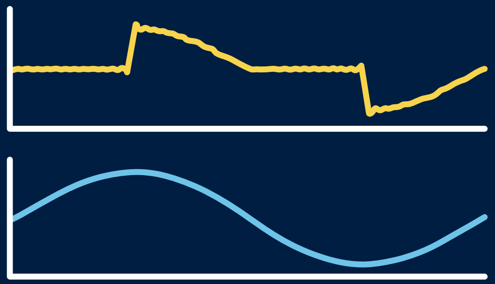
Equipment failures, misoperations, and degradation

Power frequency	Pass
Supply voltage variations	Pass
Flicker	Pass
Supply voltage unbalance	Pass
Harmonics	Fail
Rapid voltage changes	Concern
Voltage dips and interruptions	Concern
Temporary overvoltages	Pass

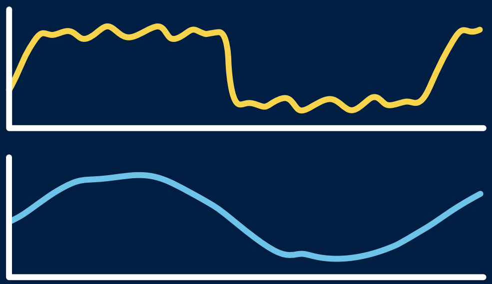
PQ Problems Can Affect Metering Accuracy

ANSI C12.20-2015, Accuracy Class 0.1 Adds Tests

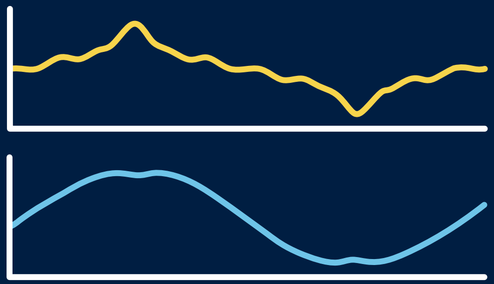
Test 39
90° Phase-Fired Waveform



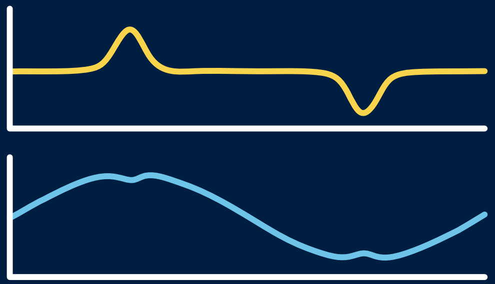
Test 40
Quadriform Waveform



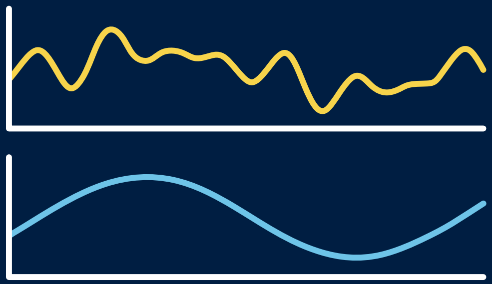
Test 41
Peaked Waveform



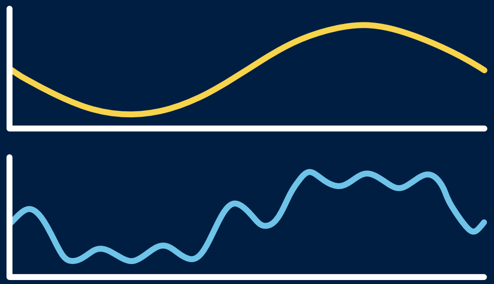
Test 42
Pulse Waveform



Test 43
Multiple Zero-Crossing



Test 44
Multiple Zero-Crossing



Several Factors Affect PQ

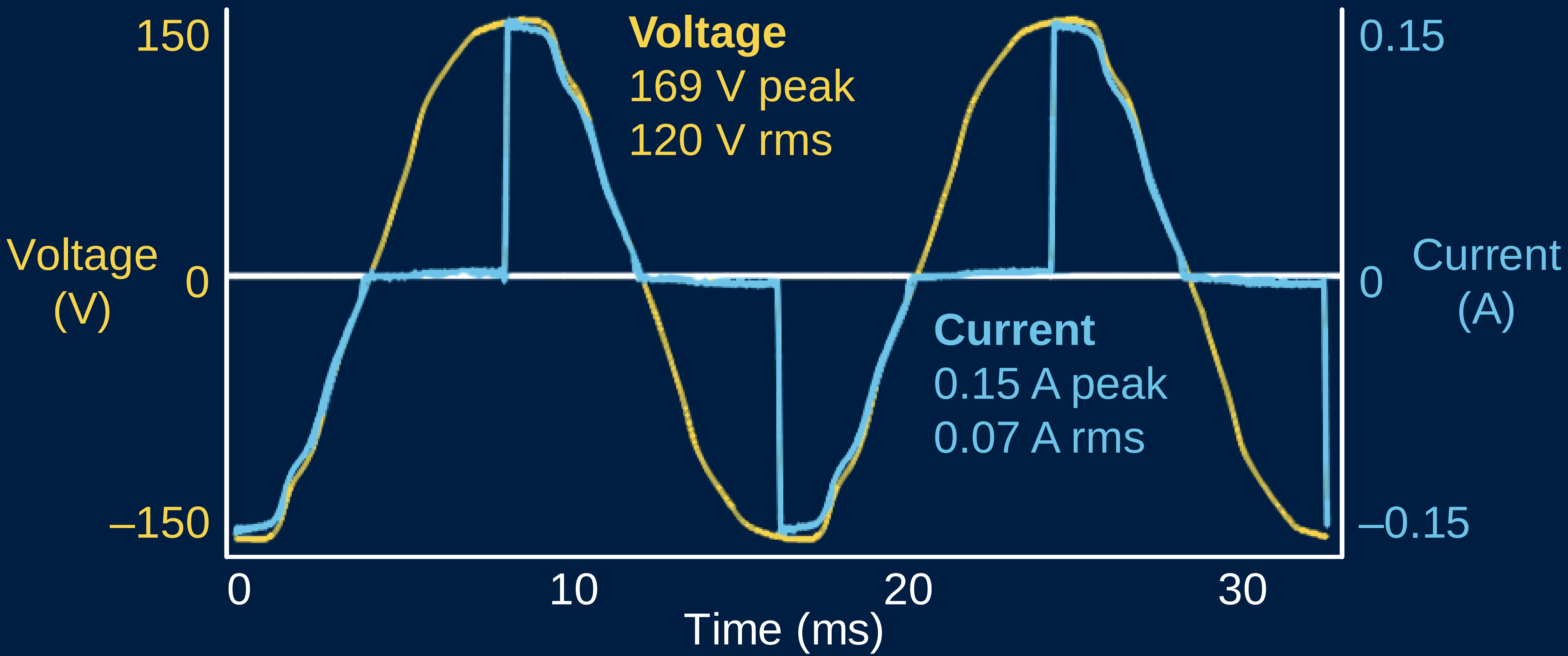
Nonlinear Loads

Large Load Changes

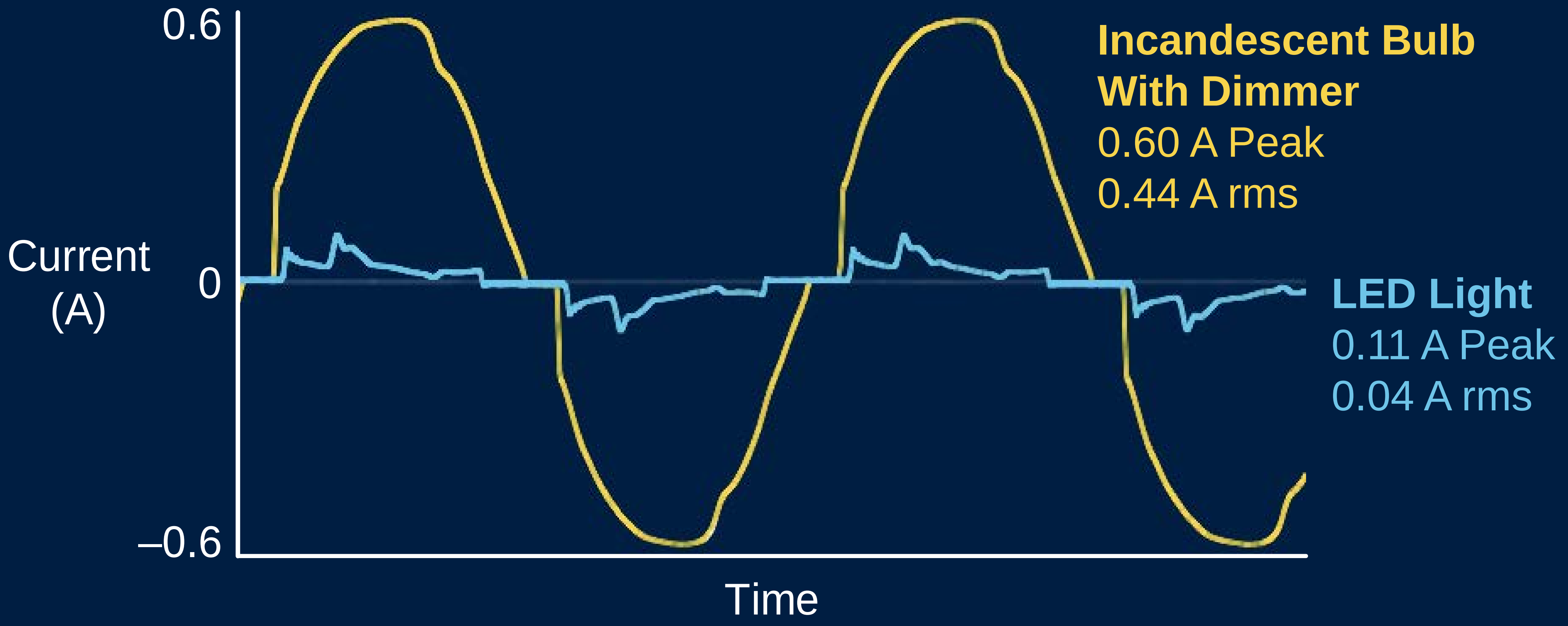
Faults

Nonlinear Loads Distort Waveforms

Incandescent Bulb With Dimmer



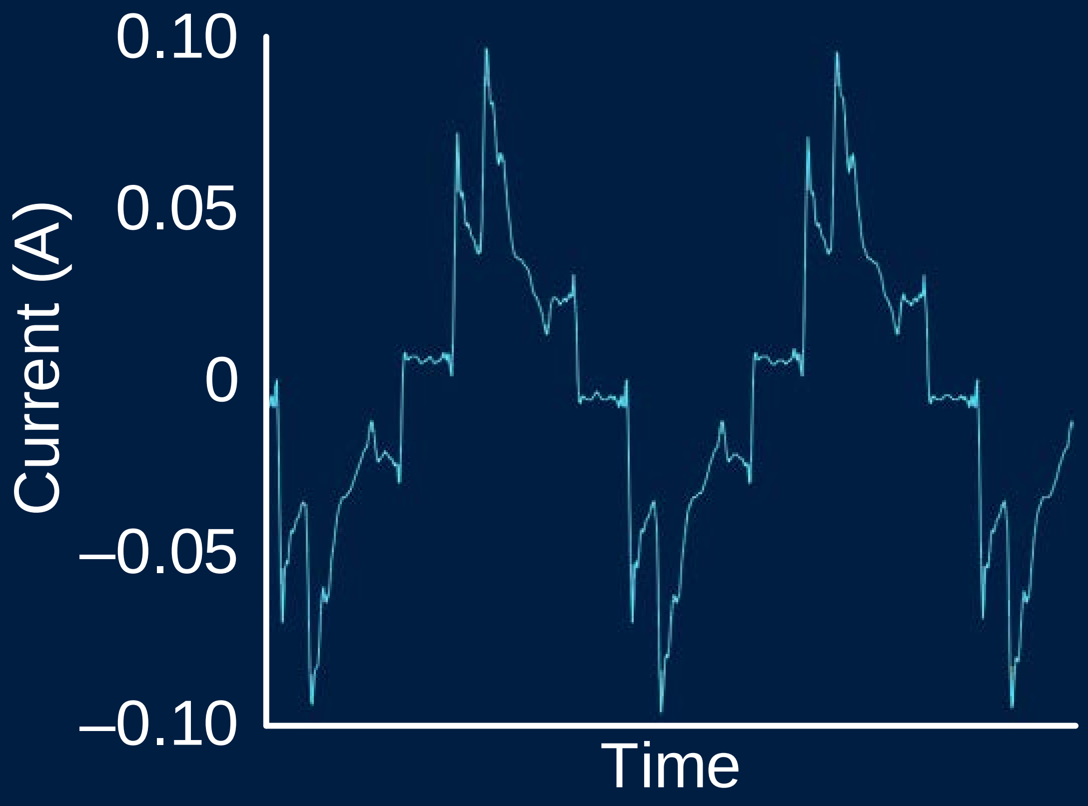
LED Lights Provide Energy Efficiency But Distort Waveforms



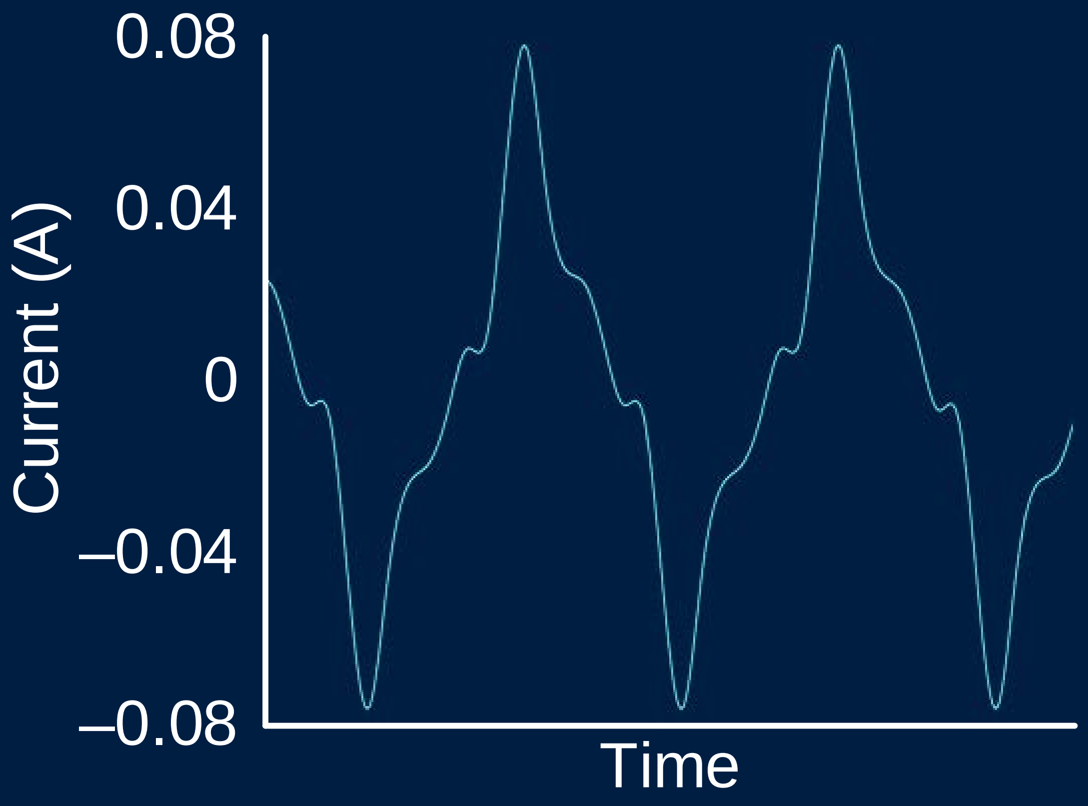
High Sampling Rates Accurately Capture Waveform Content

LED Light Bulb Waveforms

8 kHz – 0% Error

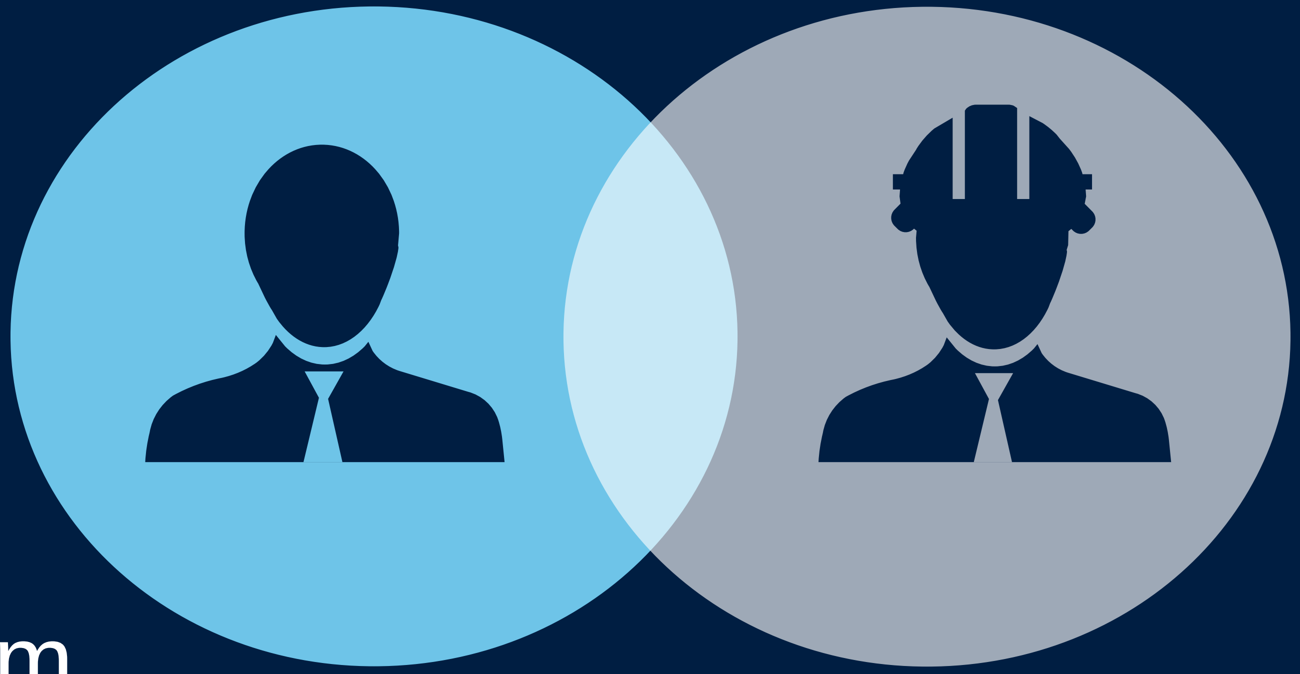


1 kHz – 2.2% Error



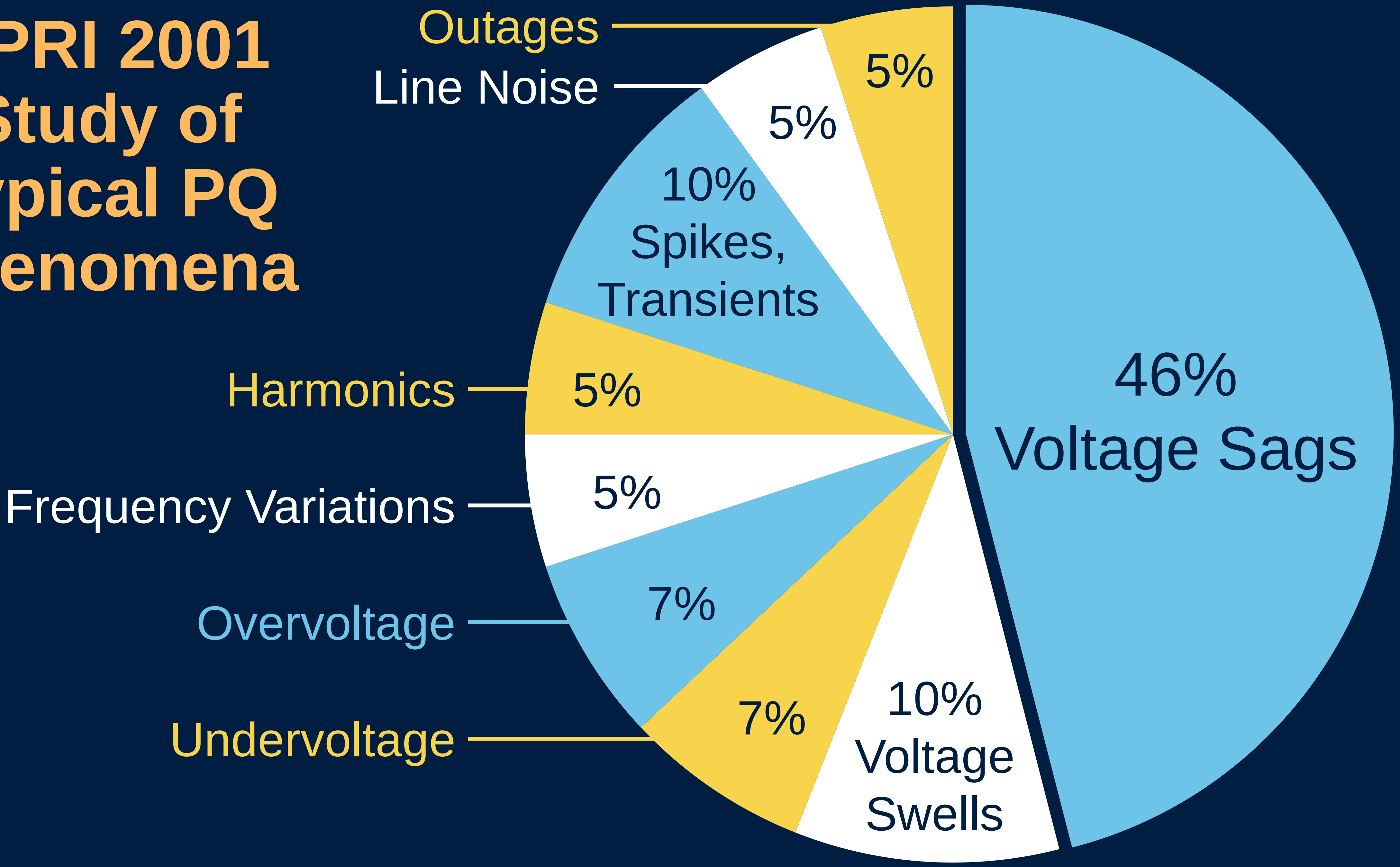
Customer and Utility Share Responsibility

- Customer limits current distortion
- System owner or operator limits voltage distortion by modifying supply system impedance characteristics

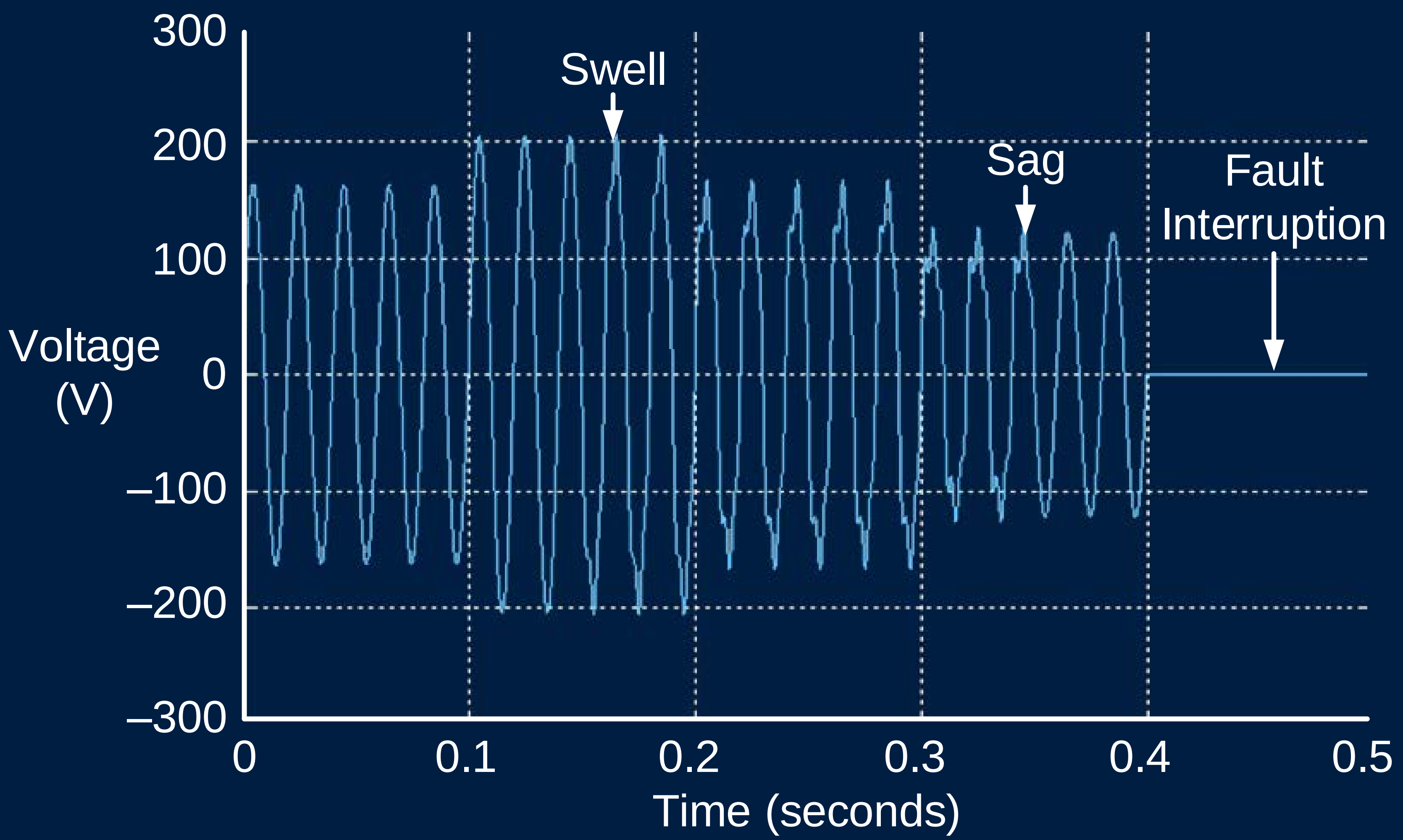


IEEE 519-2014 applies to point of common coupling

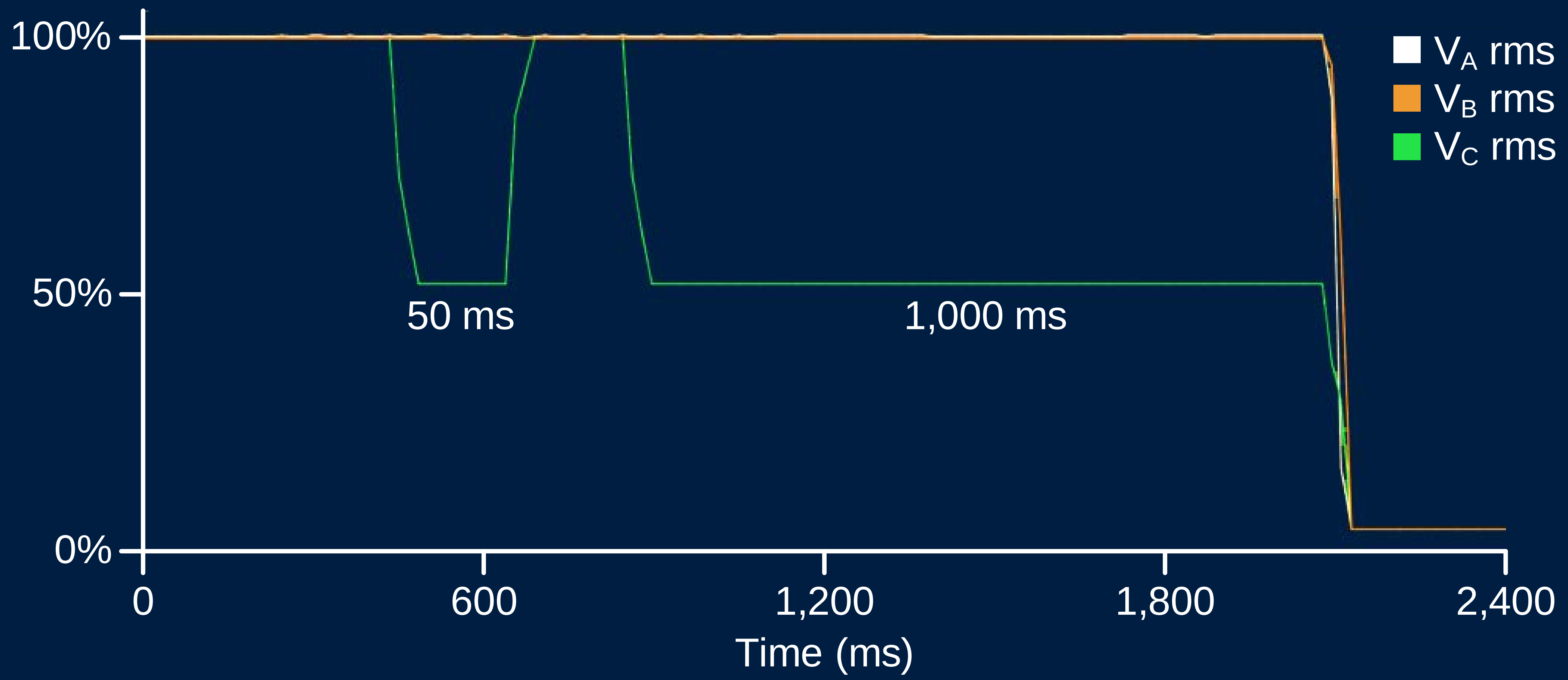
EPRI 2001 Study of Typical PQ Phenomena



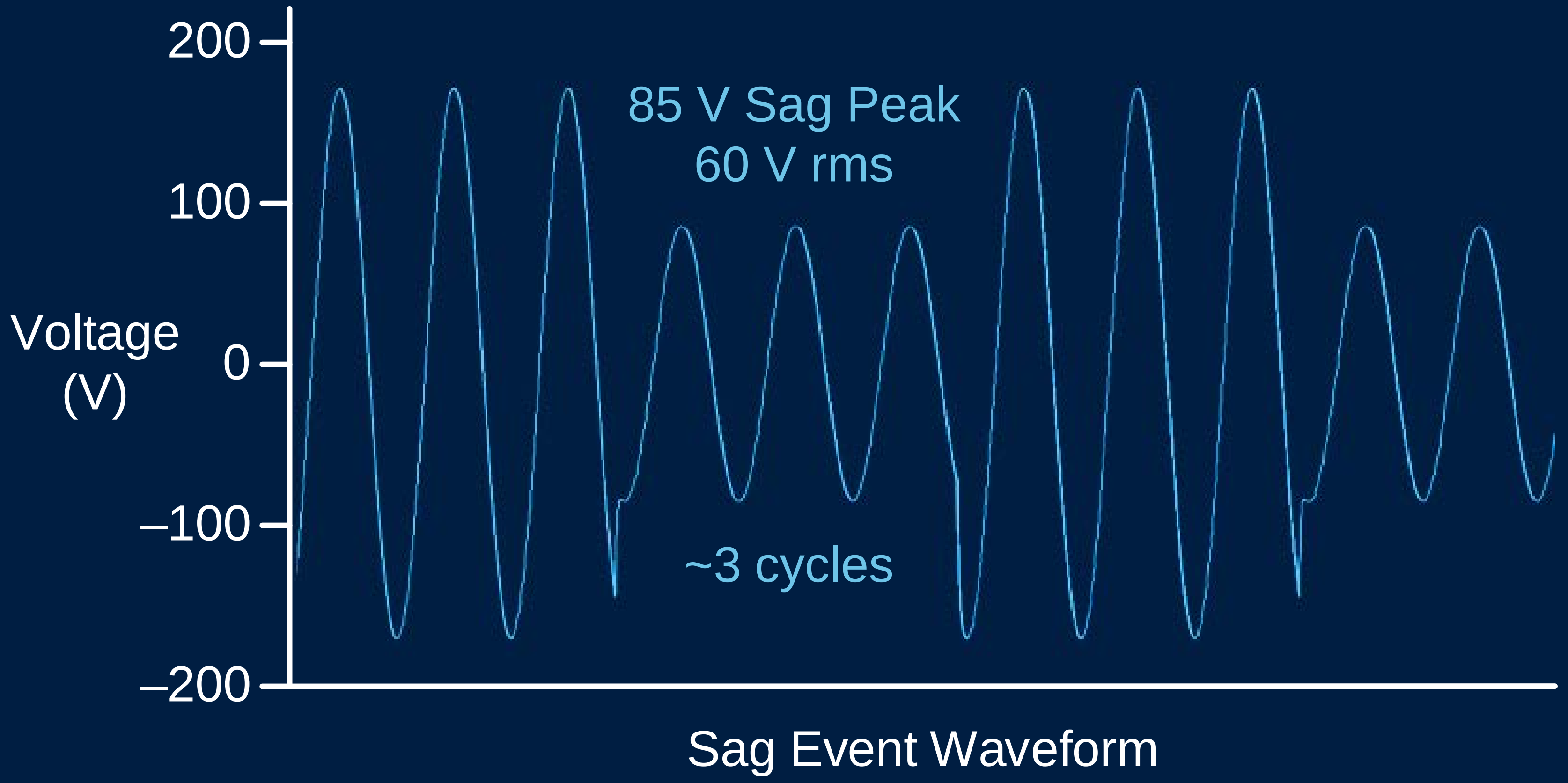
Voltage Sag, Swell, and Interruption (VSSI)



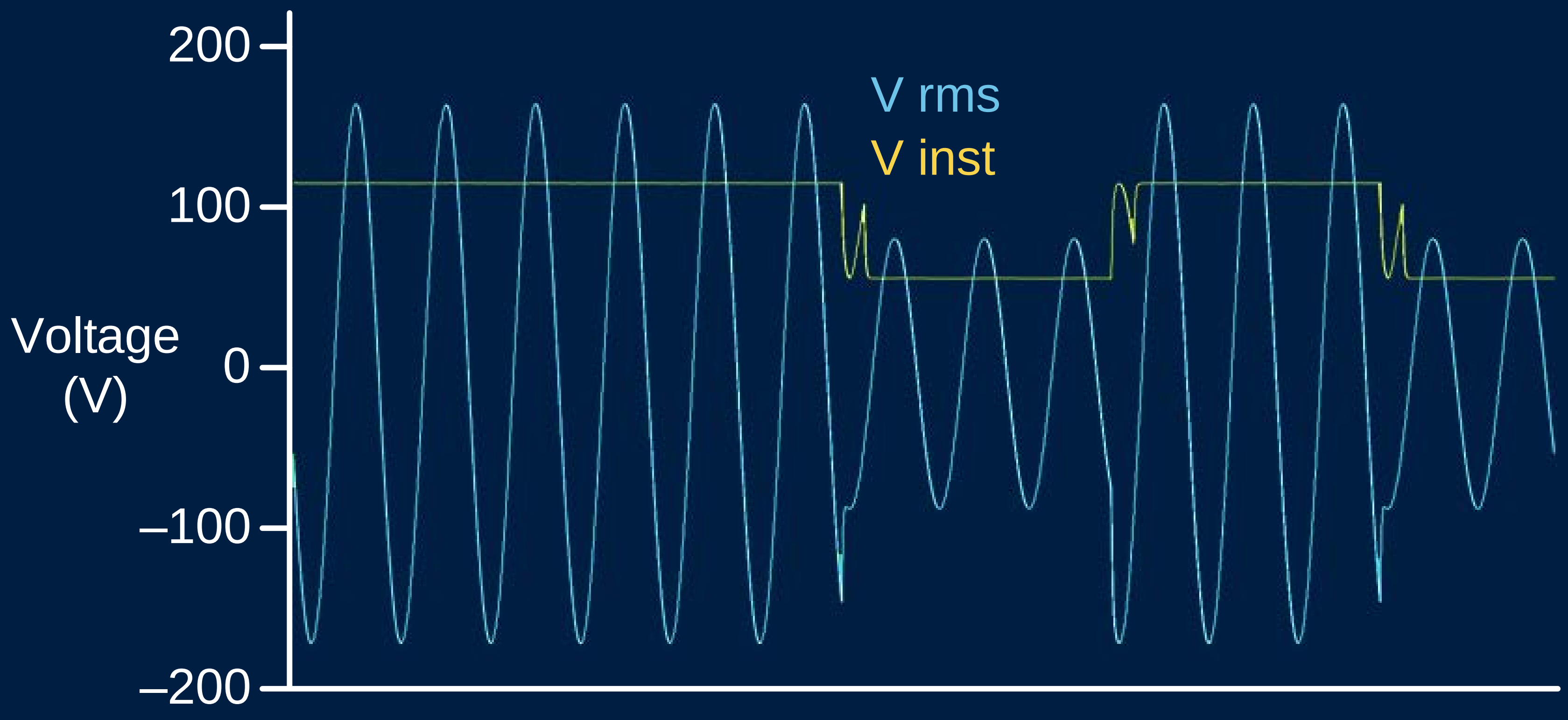
Analyze Sag Event Using Waveform or RMS Plots



VSSI Are Described by Depth and Duration



Combined Waveform and RMS Plot



Overvoltage and Undervoltage Are Long-Term Phenomena

PQ Phenomenon	Amplitude Range	Duration
Sag	10–90%	0.5 cycles to 1 minute
Undervoltage	80–90%	>1 minute
Swell	≥110%	0.5 cycles to 1 minute
Overvoltage	110–120%	>1 minute

Lightning Strikes Cause Voltage Sags

Lightning Strikes Power Pole

▼

Insulators Flash Over and Fault Current Flows

▼

Instantaneous Voltage Drop Occurs

▼

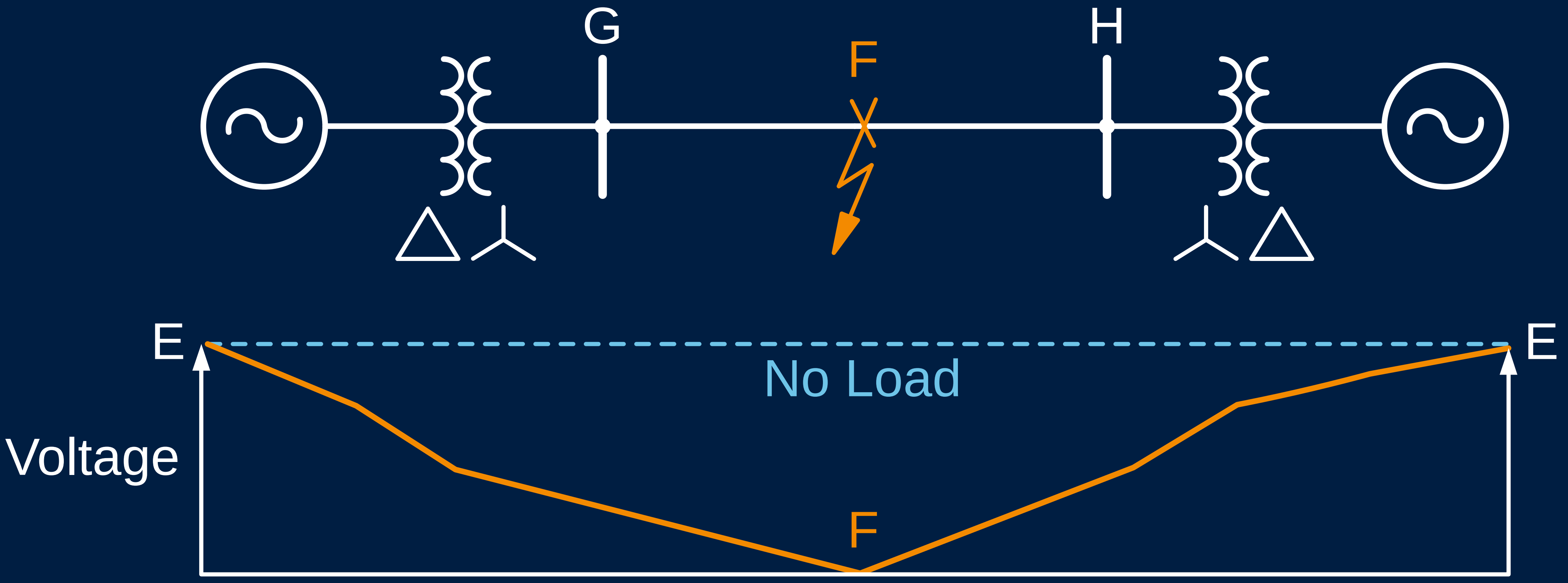
Protective Relays Operate

▼

Circuit Breakers Open

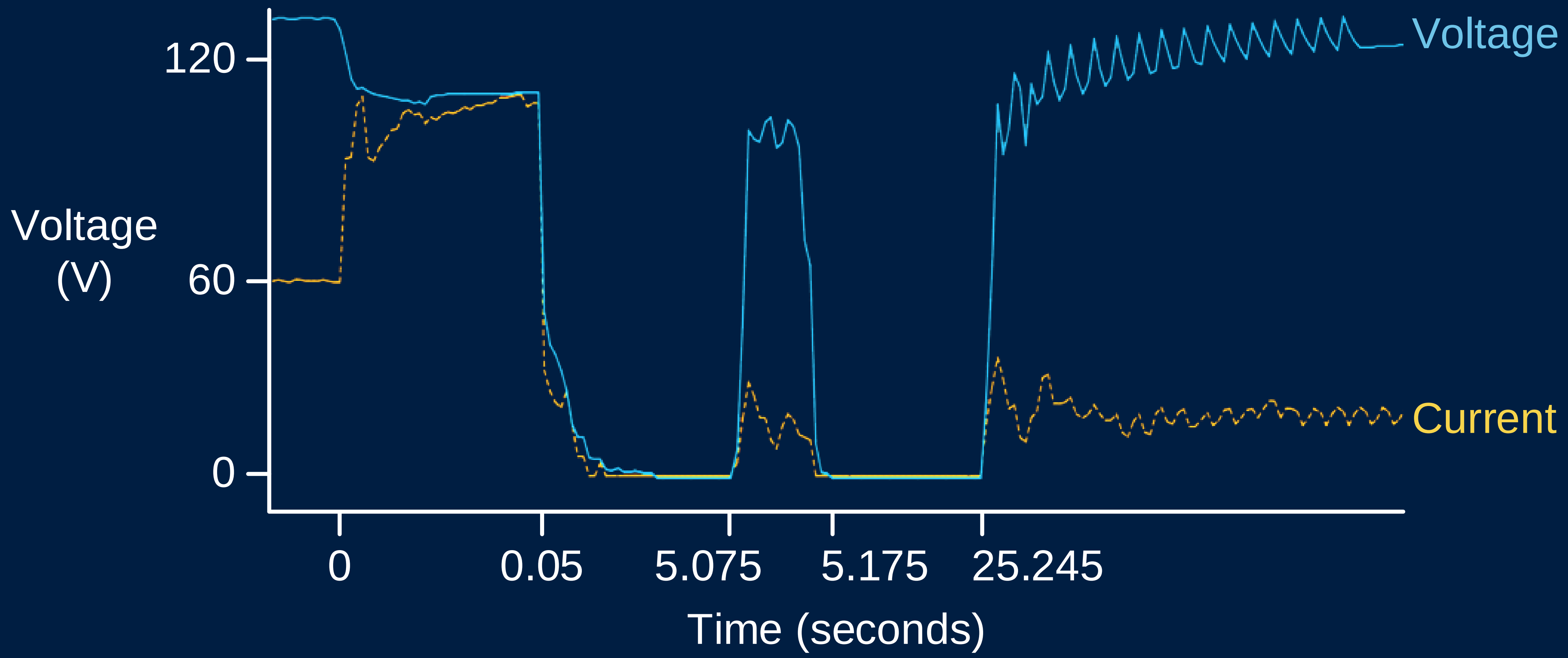
Power System Faults Can Cause Voltage Sags

Voltage Profile of a Three-Phase Fault

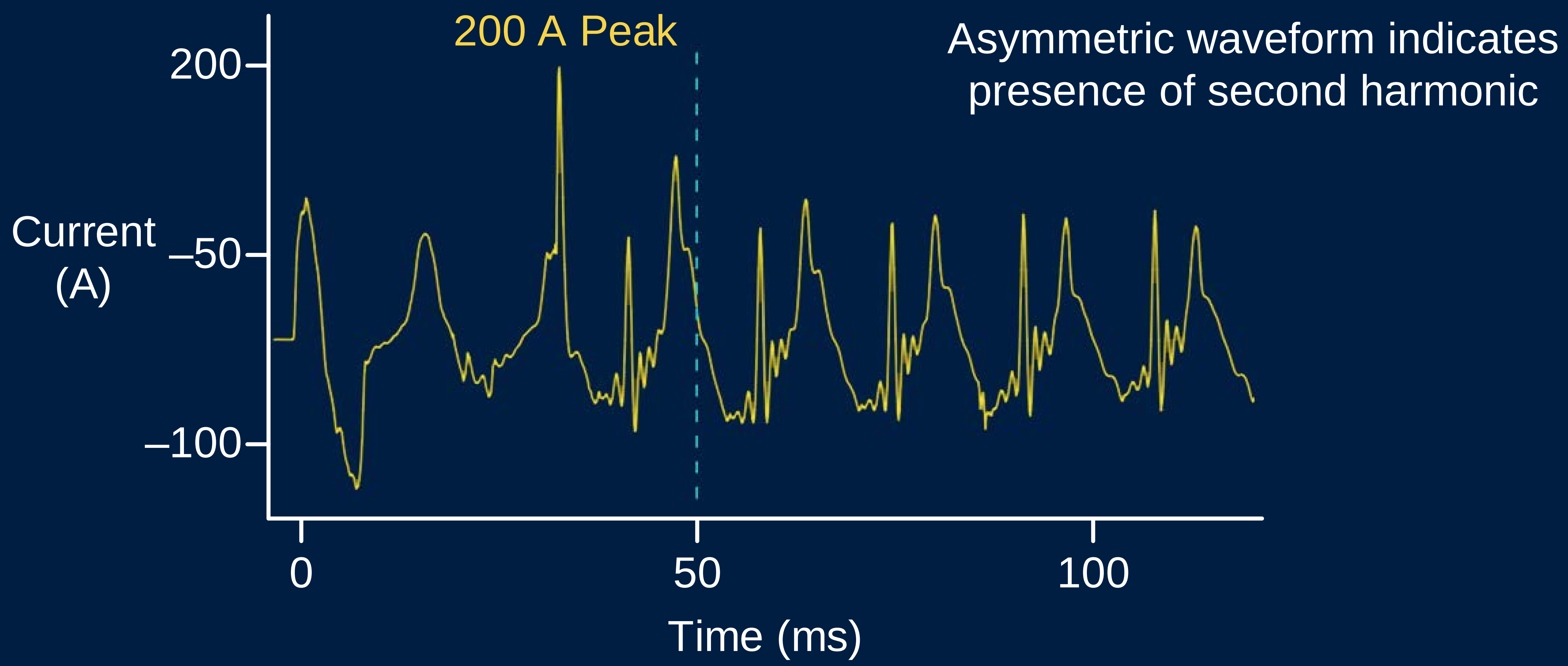


Voltage disturbance effect is more at fault point and less away from it

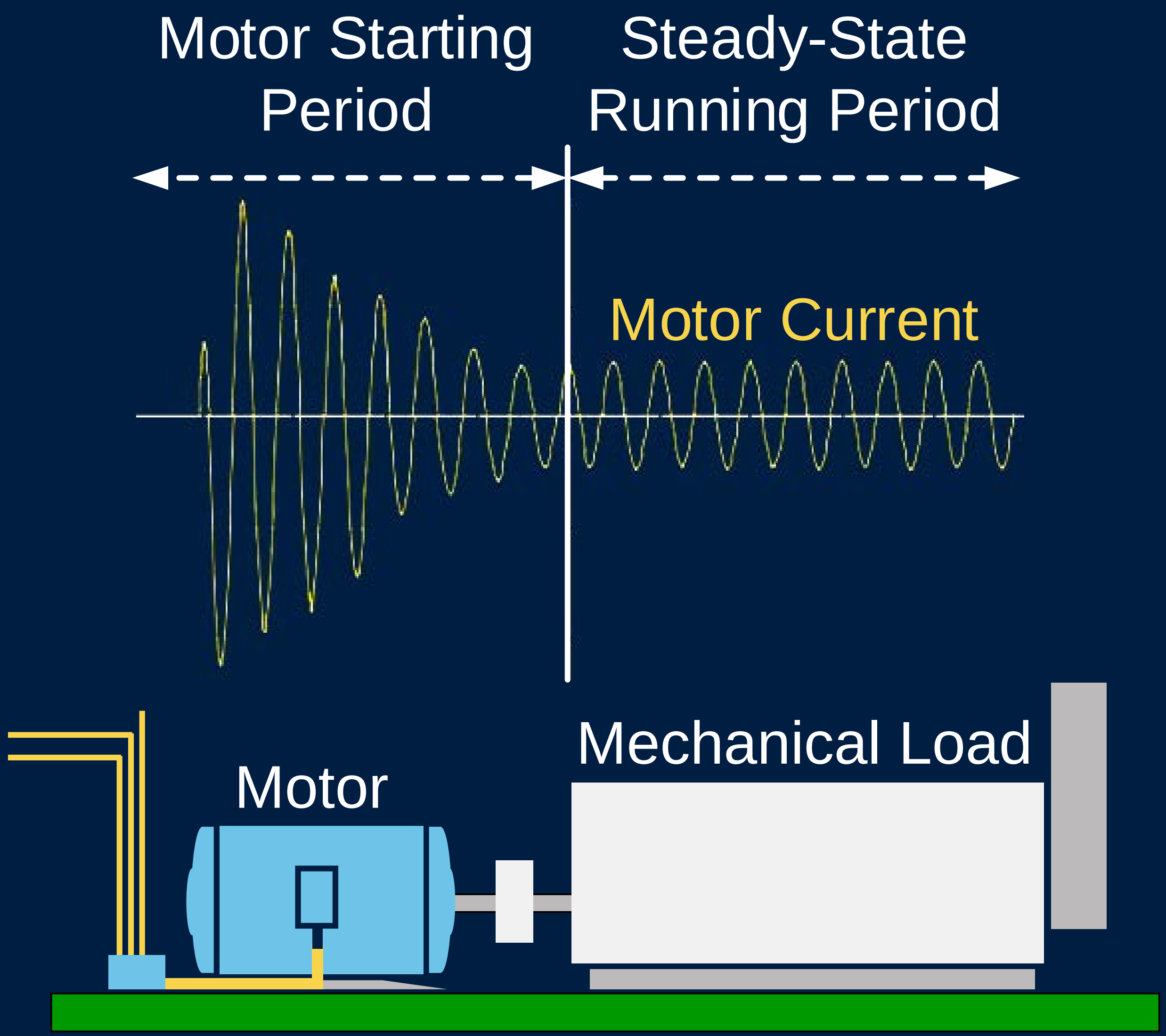
Fault on Transmission Line Causes Sag and Interruption



Restoration Event Causes Damage to 3D Printer

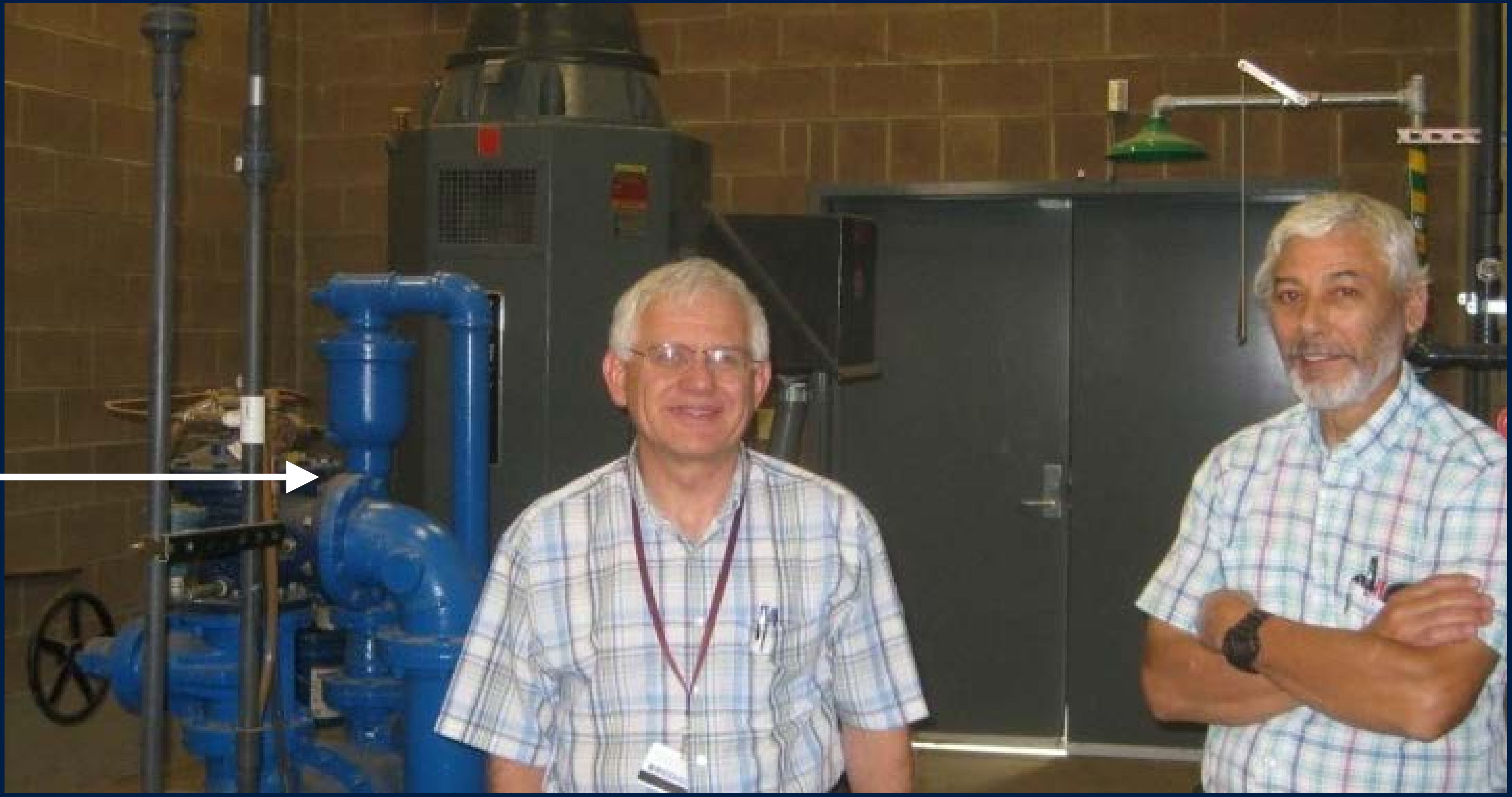


Motor Operation Can Cause Voltage Sags

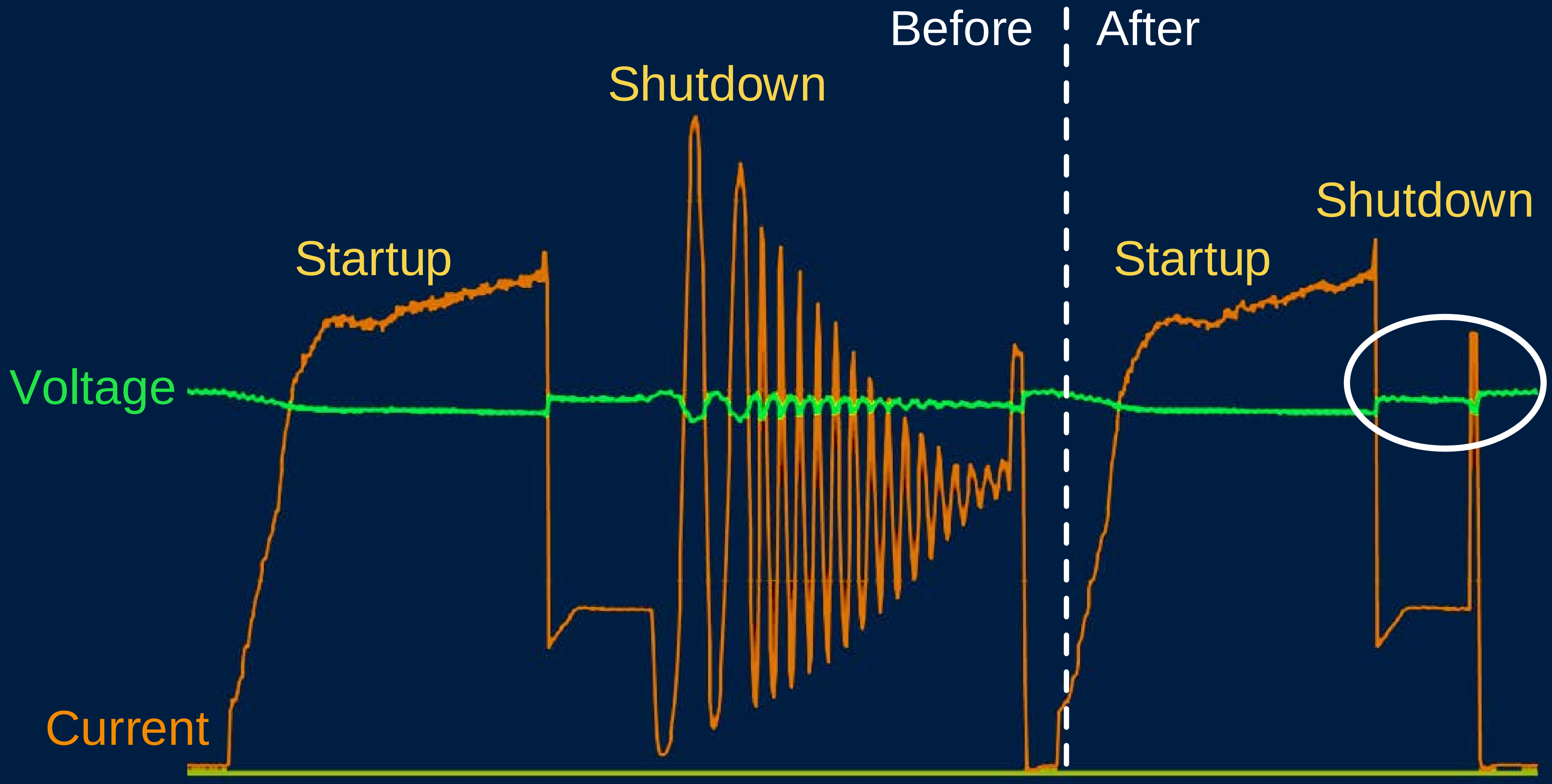


University Uses Voltage Sag Data to Continue Operations and Buy Planning Time

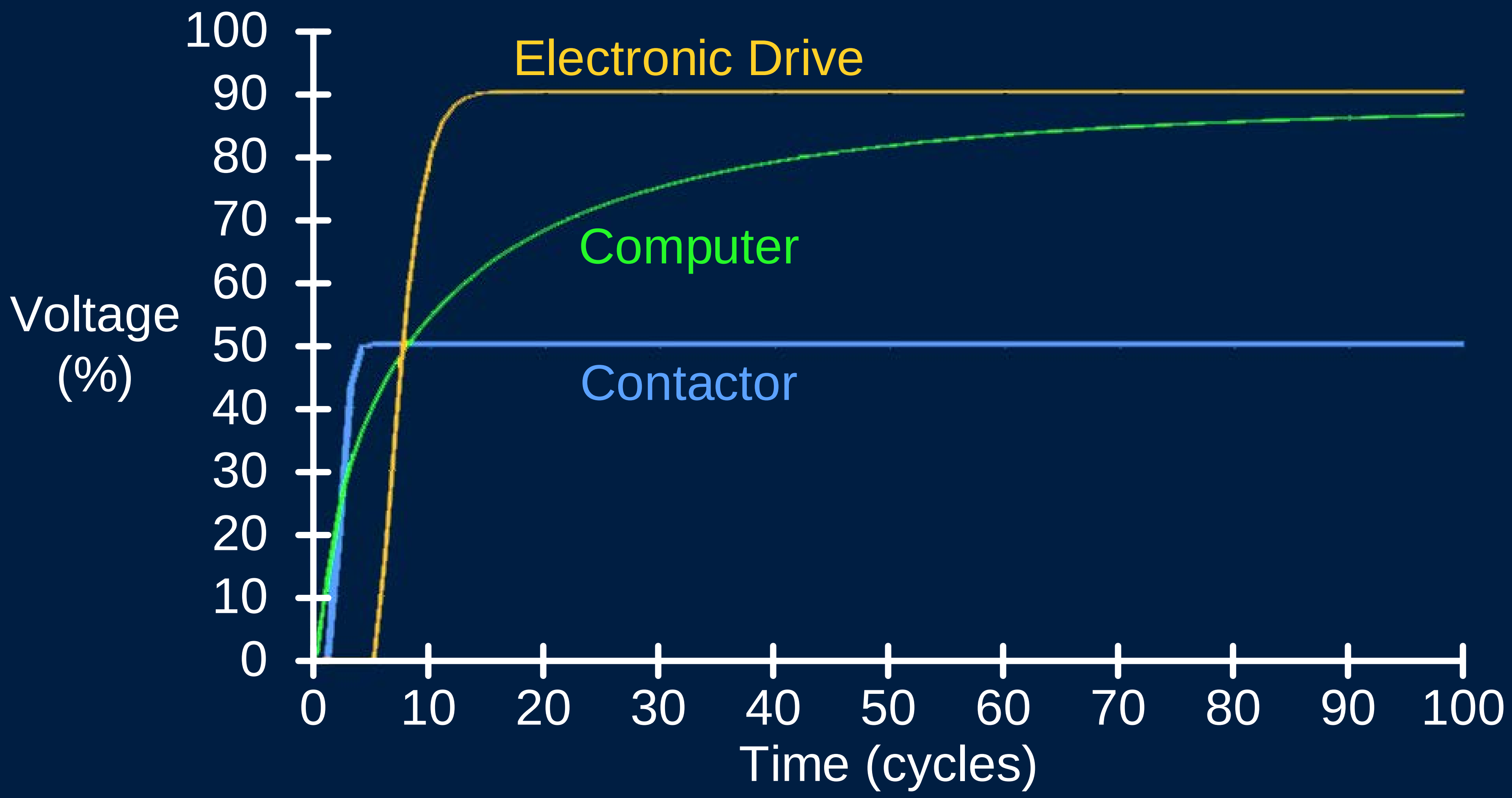
700 hp pump



Optimized Motor Shutdown
Reduces Sag and Eliminates Problems



Voltage Sag Ride-Through Characteristics



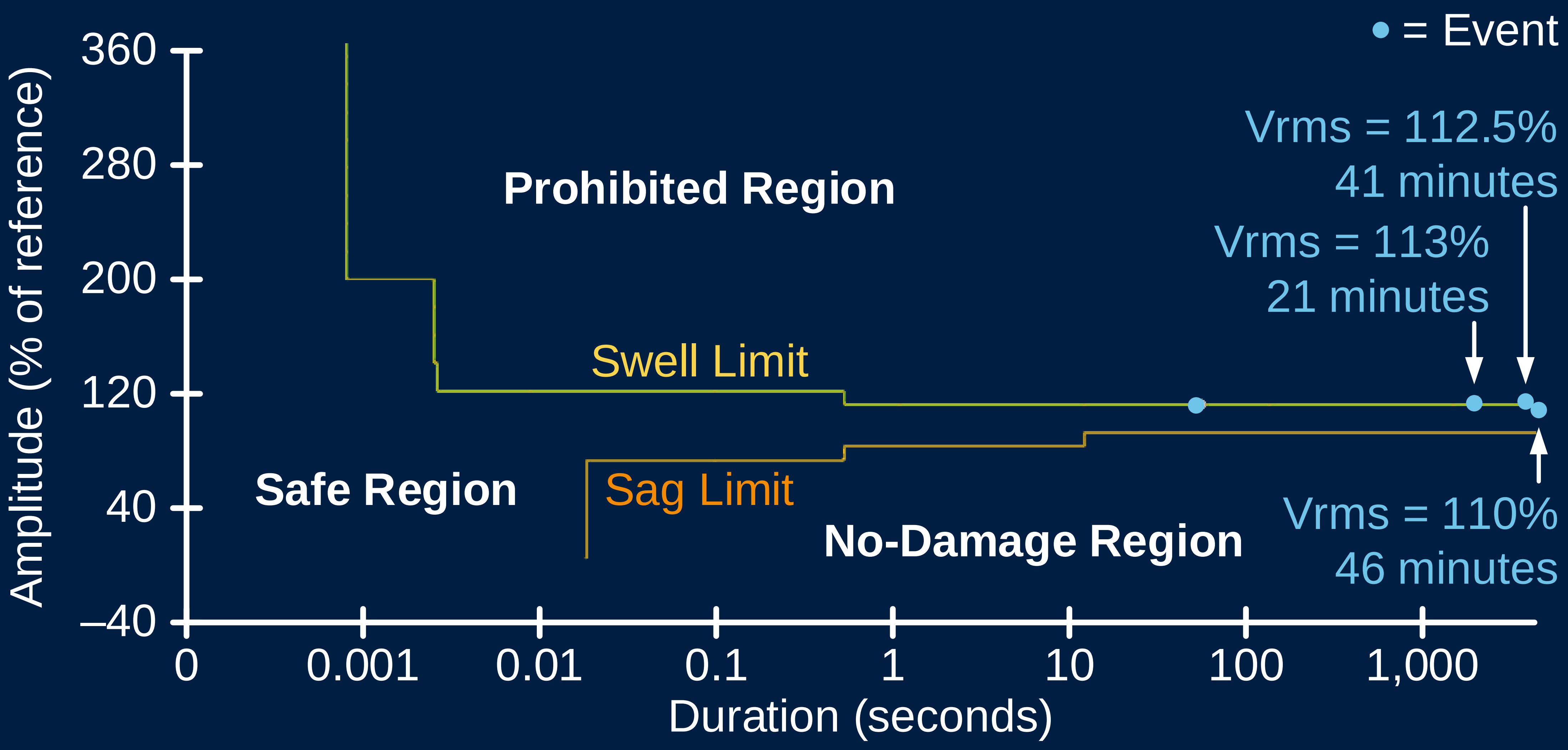
Voltage Events Damage Motors and Sensitive Processing Equipment

$1,300

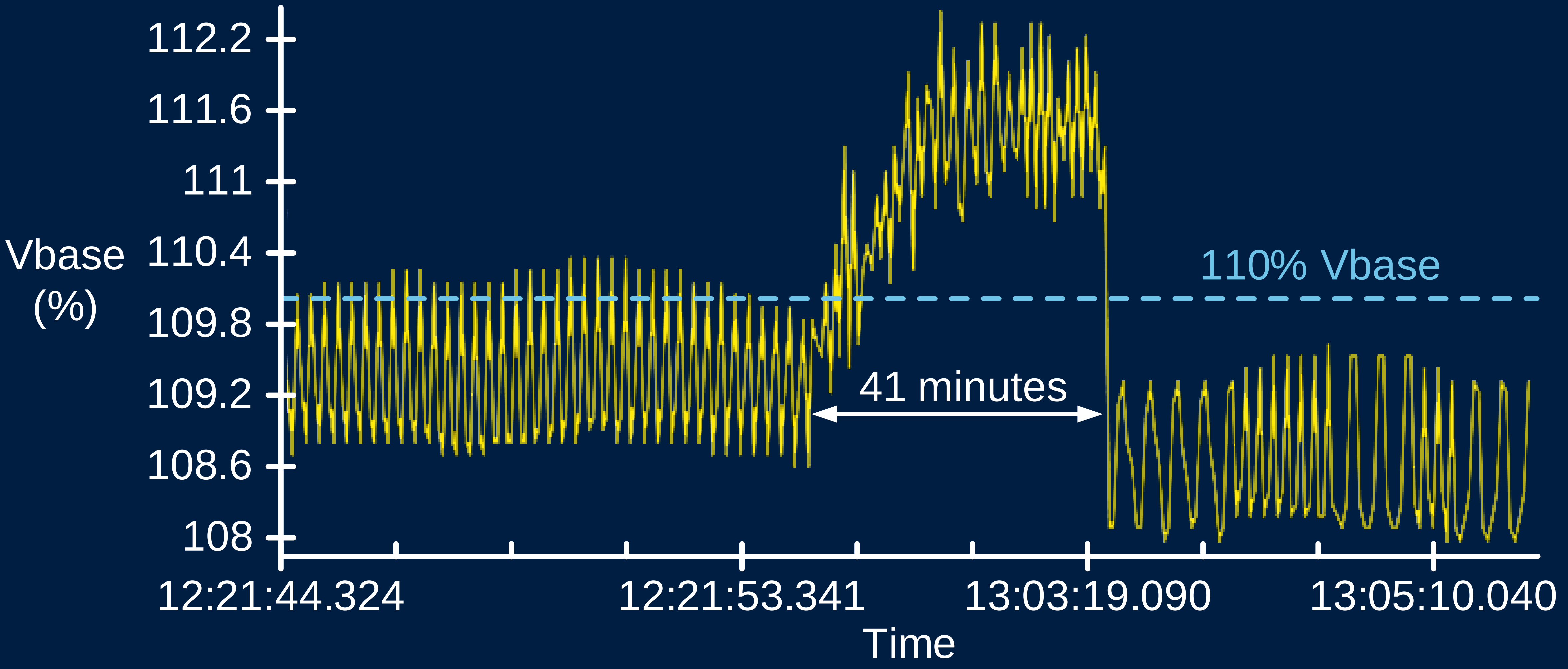
$1,300

$65,000

Voltage Events Damage Motor Fan and Compressor and Degrade Power Supply



VSSI Data Reveal Stuck Load Tap Changer



IEC 61000-4-30 Standardizes PQ Measurements


IEC 61000-4-30

Edition 3.0 2015-02

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

BASIC EMC PUBLICATION
PUBLICATION FONDAMENTALE EN CEM

Electromagnetic compatibility (EMC) –
Part 4-30: Testing and measurement techniques – Power quality measurement methods

Compatibilité électromagnétique (CEM) –
Partie 4-30: Techniques d'essai et de mesure – Méthodes de mesure de la qualité de l'alimentation

Class A: For contractual applications and verifying compliance

Class S: For surveys and assessment

IEC 62586-2 specifies functional test requirements for IEC 61000-4-30

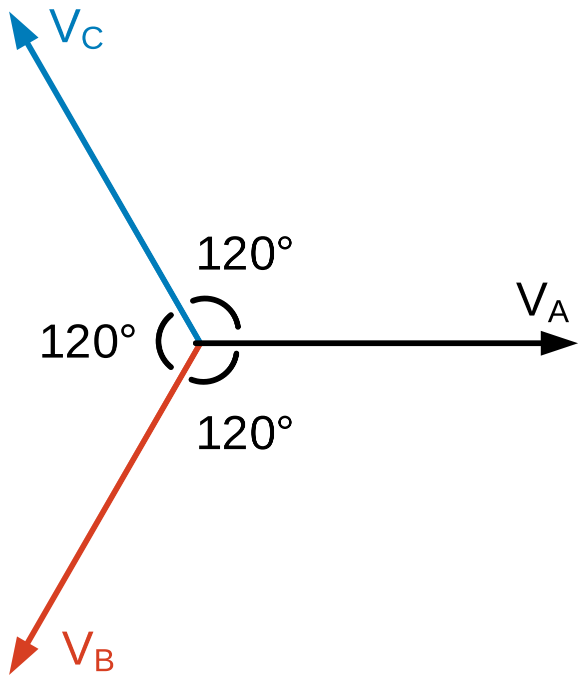
Voltage Unbalance Damages Motors

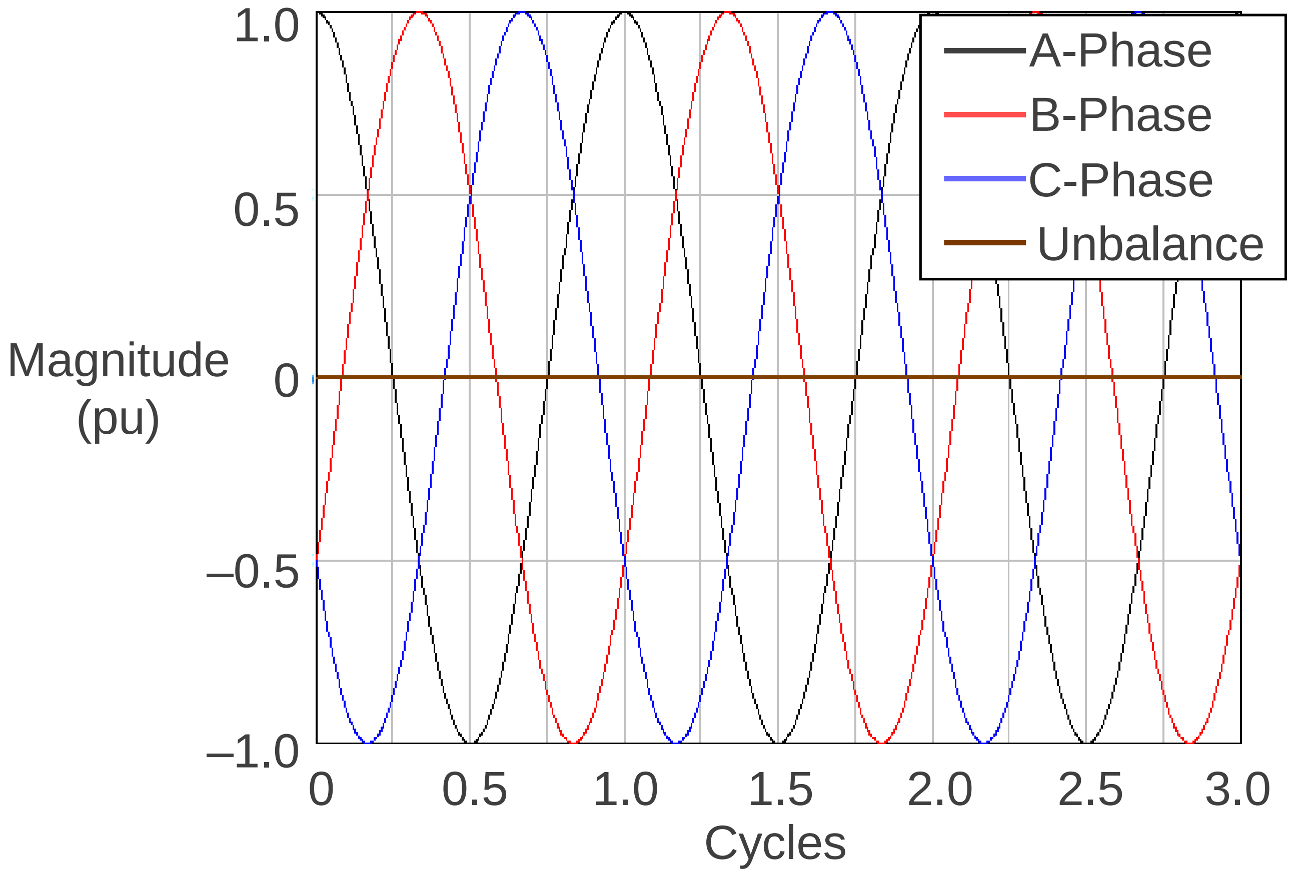
- Causes temperature rise
- Reduces life expectancy

Photo courtesy of Electrical Apparatus Service Association

Unbalance Occurs When $V_A + V_B + V_C \neq 0$ V

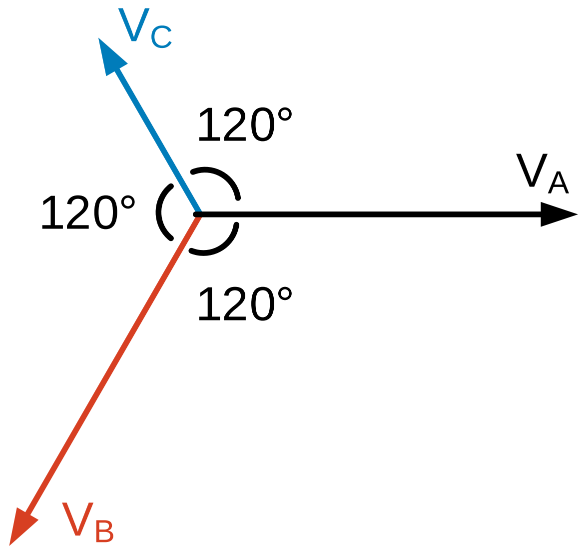
Balanced Three-Phase Waveforms

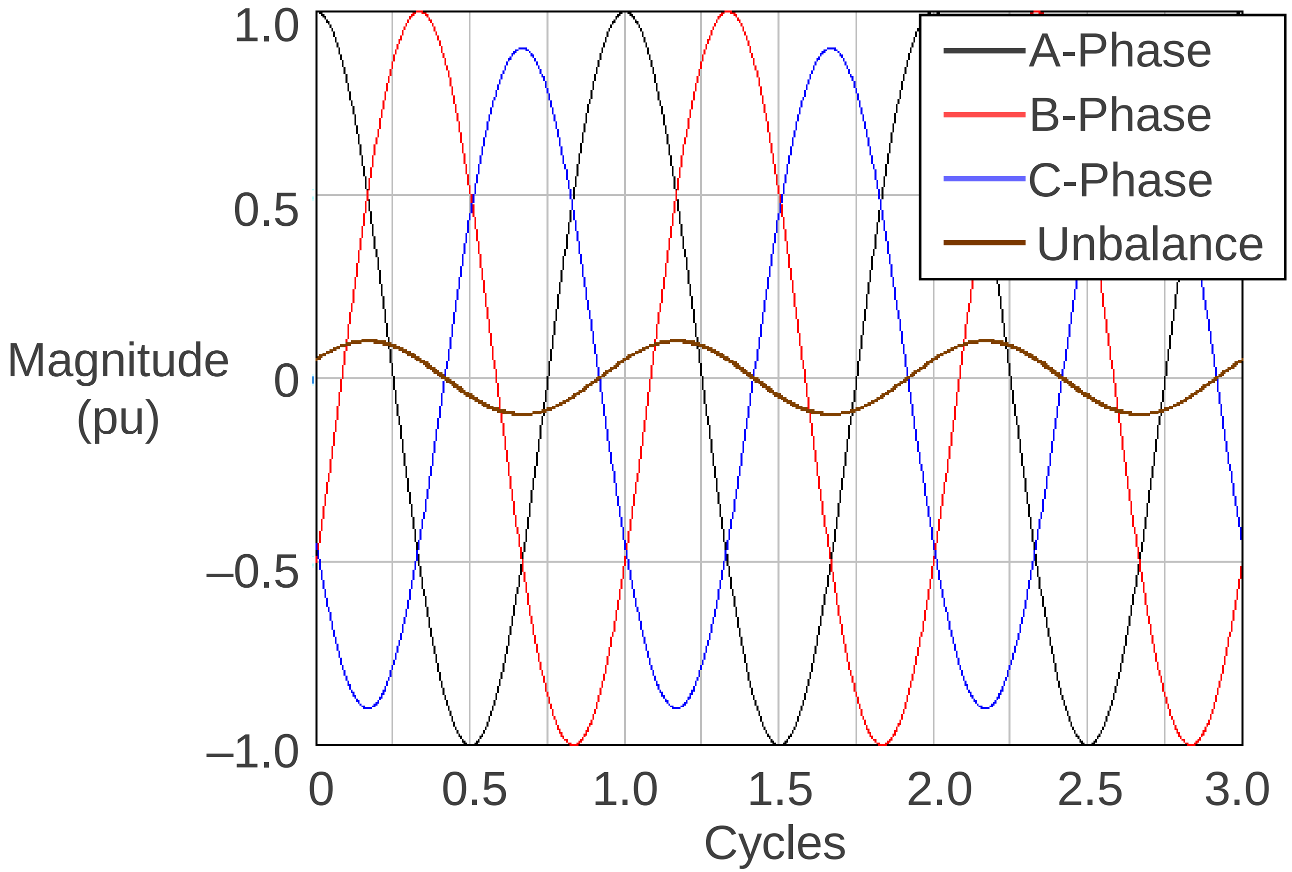




Unbalance Occurs When $V_A + V_B + V_C \neq 0$ V

Unbalanced Three-Phase Waveforms





Typical Voltage Unbalance Levels in U.S.

Three-Phase Power Delivered to Industrial Plants

<1% Unbalance

Operates normally

66%

1–3% Unbalance

Causes overheating and premature aging

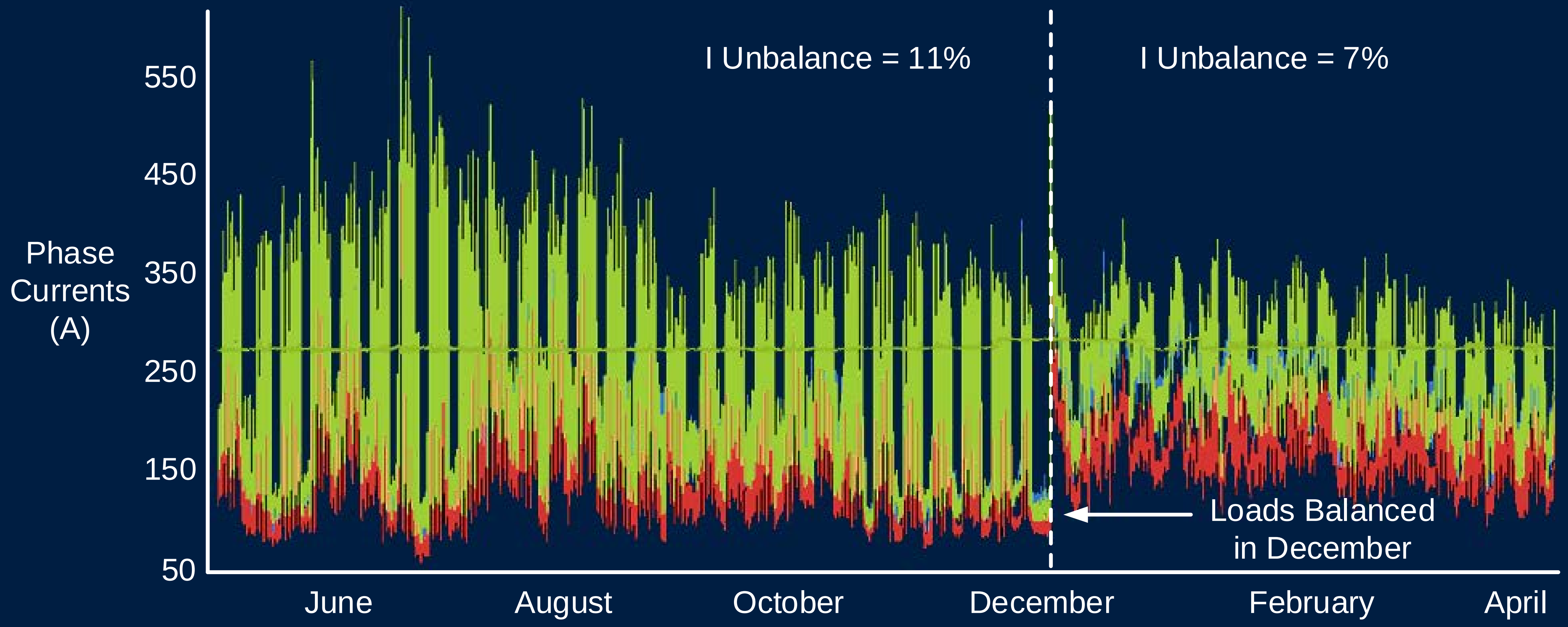
32%

>3% Unbalance

Can cause significant damage

2%

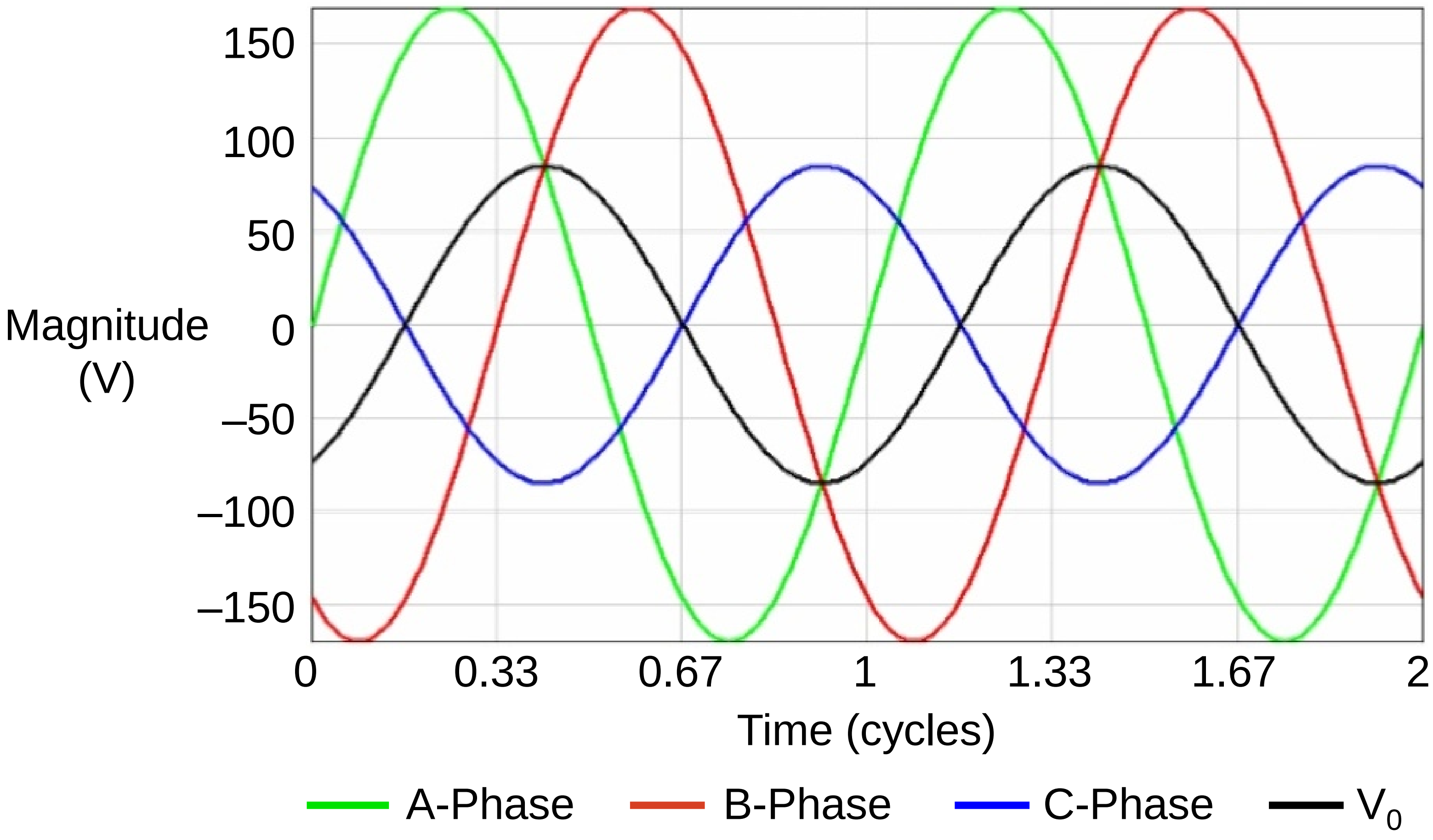
Facilities Operator Uses Data to Balance Loads



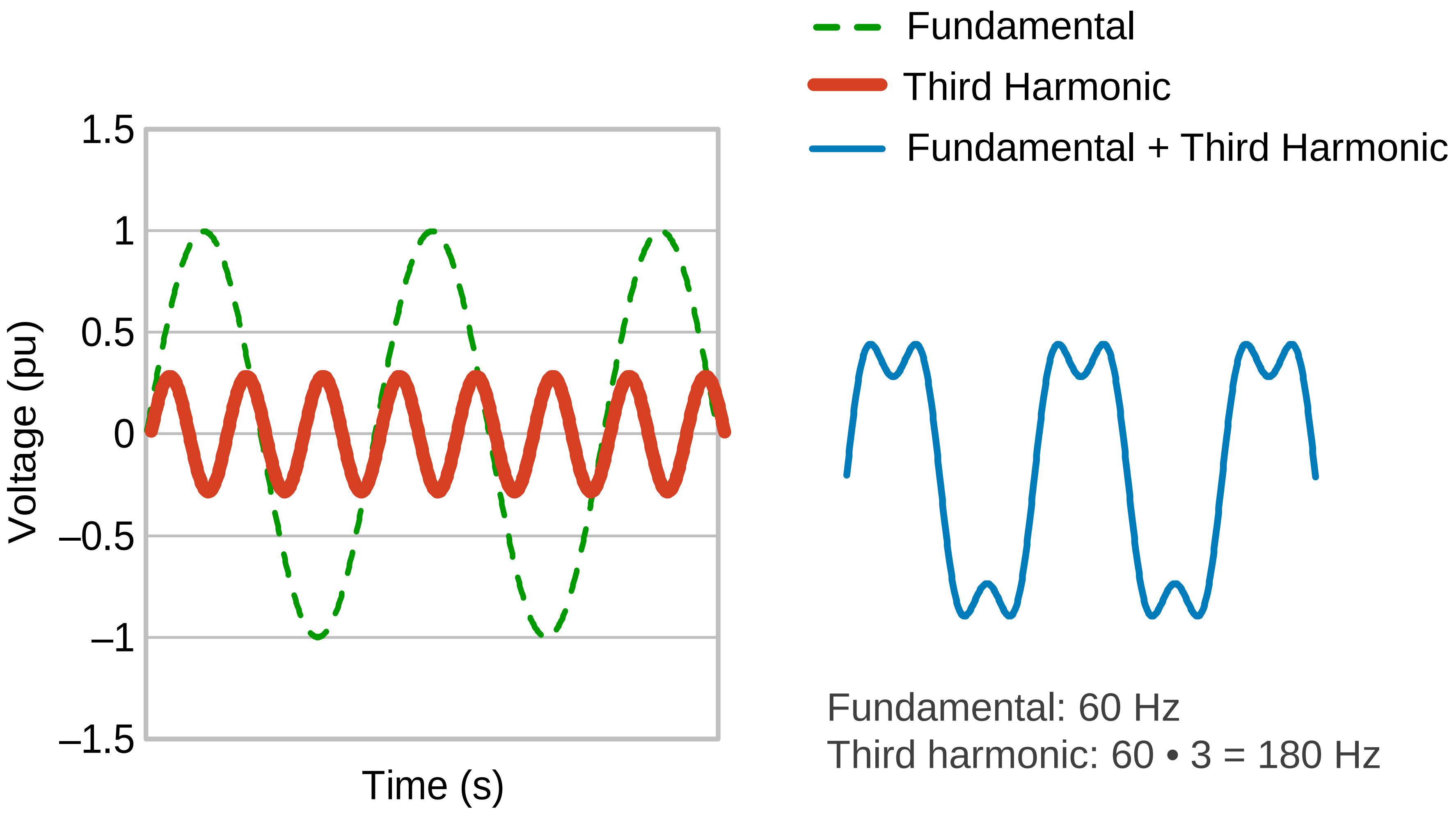
Common Causes of Unbalance

- Faulty distribution equipment
- Random phase loading (arc furnaces)
- Unbalanced distribution feeders

Unbalanced Magnitude Phasor

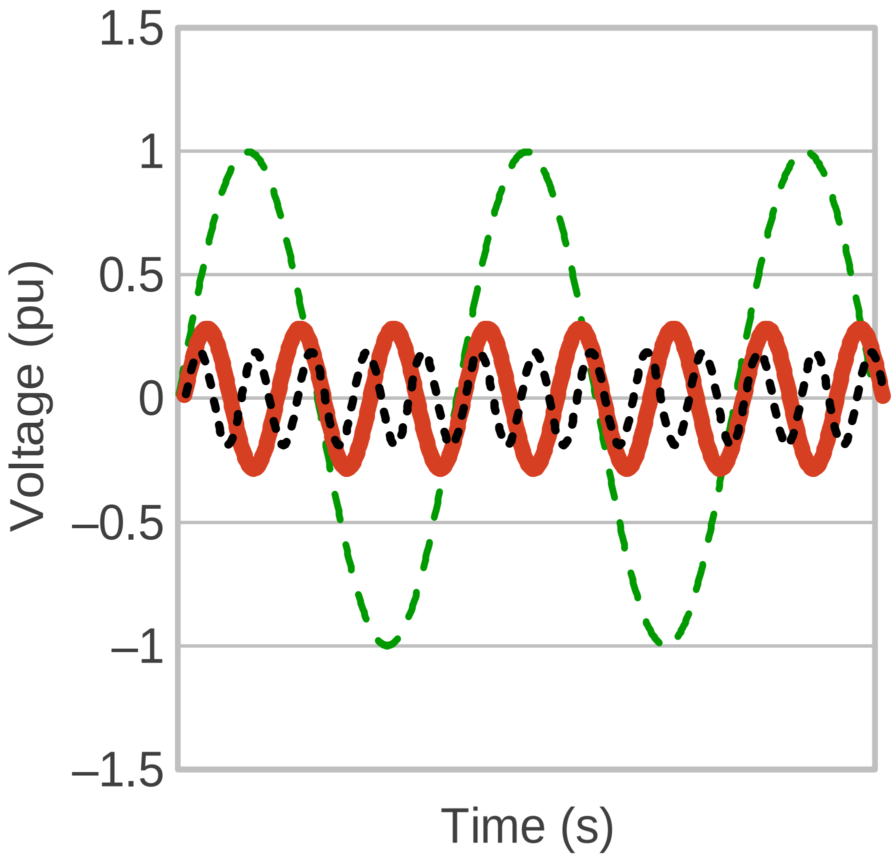


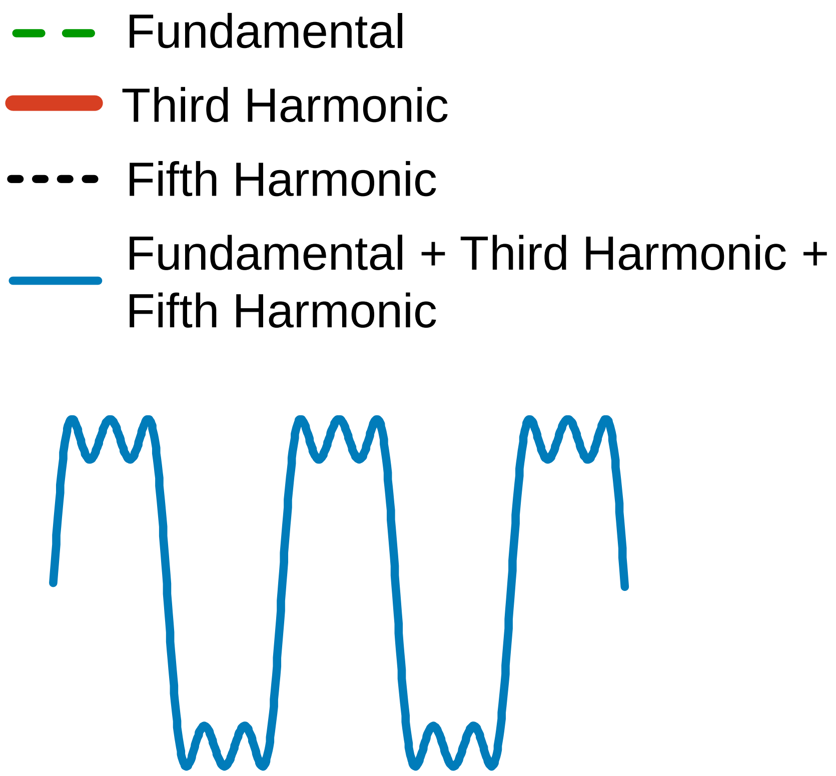
Harmonics Occur as Multiples of 60 Hz



Fundamental: 60 Hz
Third harmonic: 60 • 3 = 180 Hz

Harmonics Occur as Multiples of 60 Hz

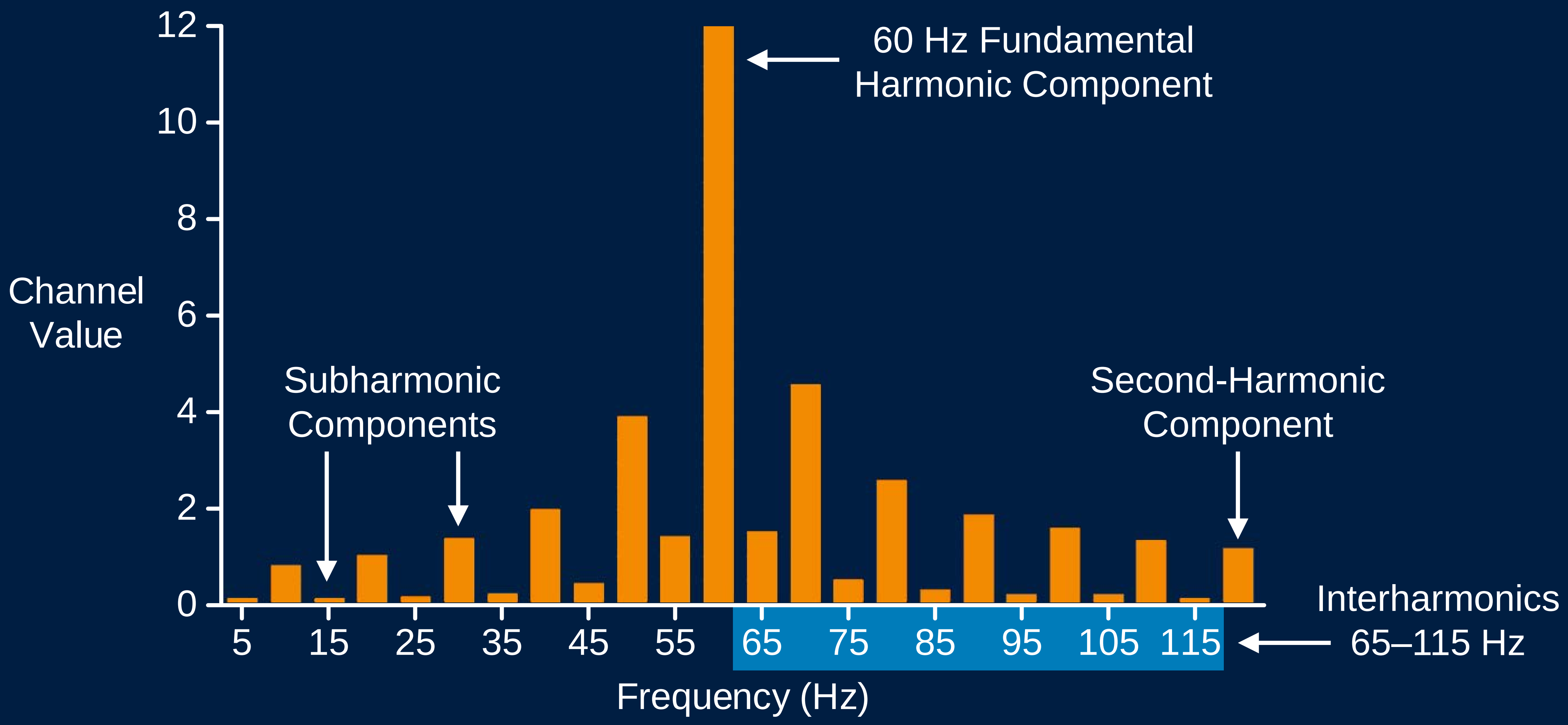




Fundamental: 60 Hz
Fifth harmonic: 60 • 5 = 300 Hz

Harmonics Cause Humming in Transformers

Spectral Analysis Displays Harmonics, Subharmonics, and Interharmonics

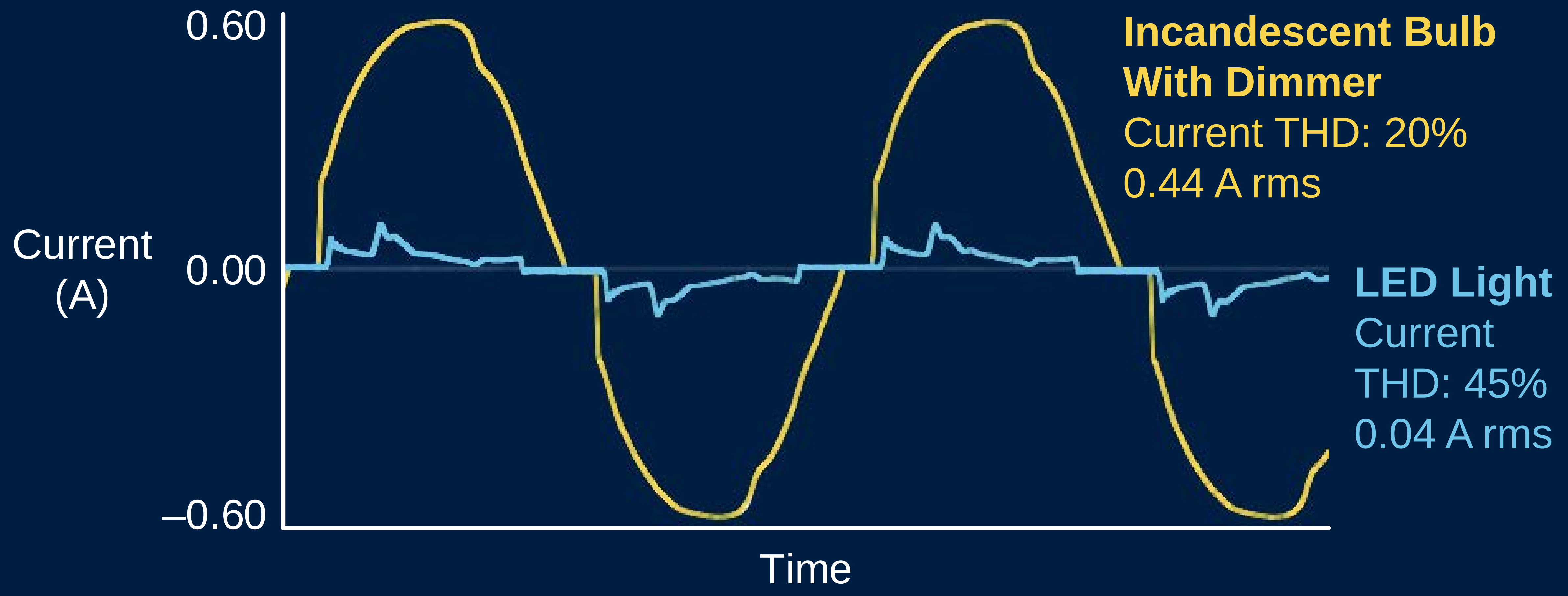


Harmonics Described as Percent of Fundamental Frequency

Harmonic Order	Frequency (Hz)	RMS Value
Fundamental (1)	60	120
3rd	180	6
4th	240	4
5th	300	3

$$THD = \frac{\sqrt{\text{Sum of squares of harmonics}} \cdot 100}{\text{Amplitude of fundamental}} = \frac{\sqrt{6^2 + 4^2 + 3^2} \cdot 100}{120} = 6.5\%$$

Total Harmonic Distortion (THD) Is High Under Low-Load Conditions Although Impact Can Be Low



IEEE 519-2014 Uses Total Demand Distortion (TDD)

Table 2—Current distortion limits for systems rated 120 V through 69 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)[a, b]						
I_{SC}/I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
< 20[c]	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

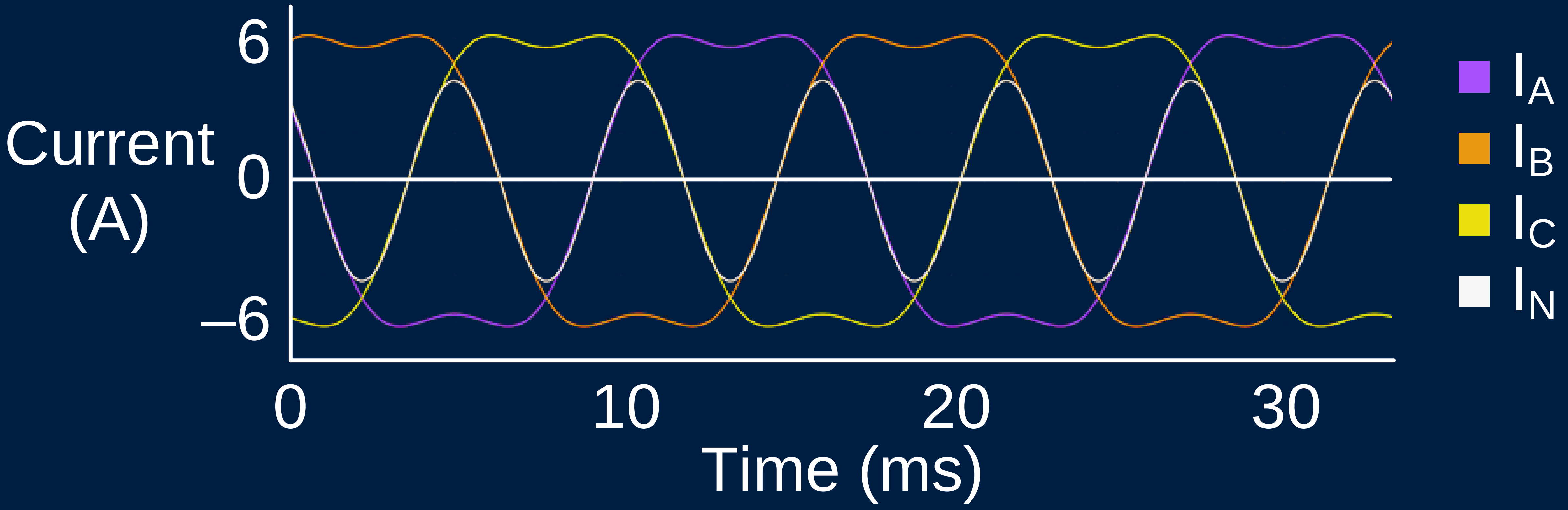
[a]Even harmonics are limited to 25% of the odd harmonic limits above.

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

$$\text{TDD} = \frac{\sqrt{\text{Sum of squares of harmonics}} \cdot 100}{\text{Maximum demand load current}}$$

Third-Order, Odd Harmonics (Triplens) Align With A, B, and C Phases

Peaks align with fundamental peaks of other phases

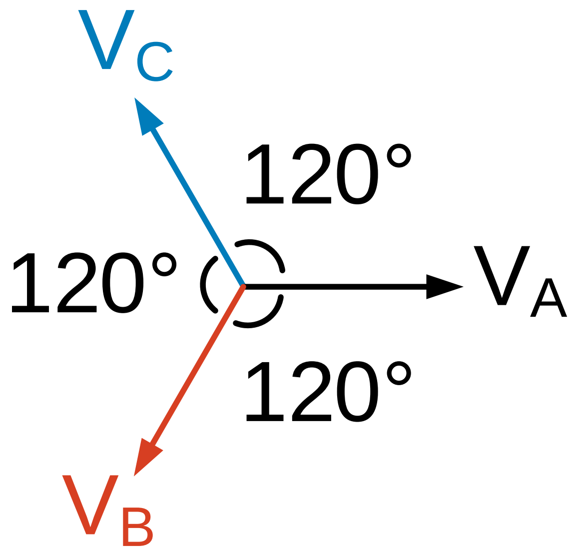


Harmonic Currents Produce Heat and Cause Damage

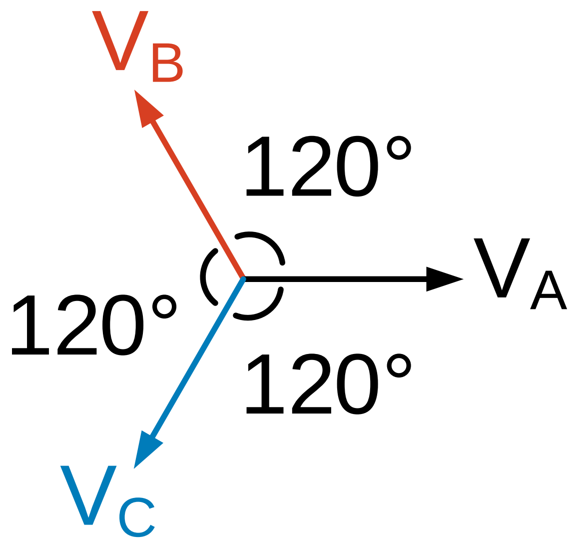
Losses = I^2R

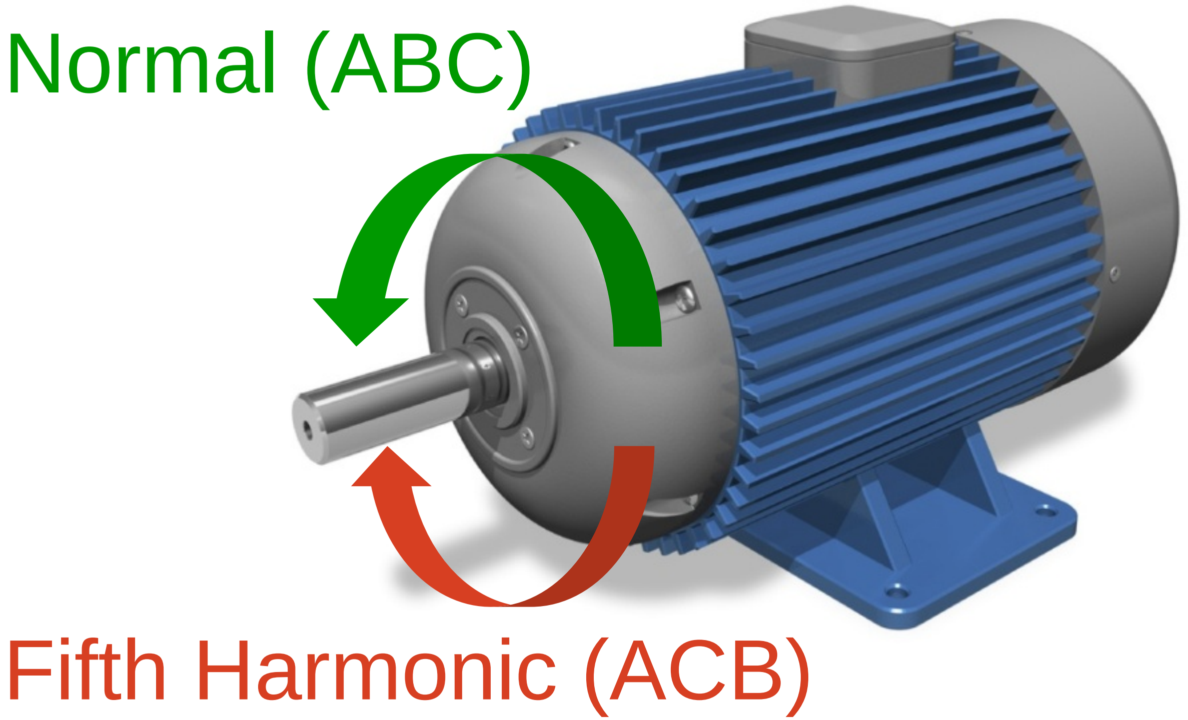
Use K-factor measurements from advanced meters to size transformers to serve distorting loads without overheating

Fifth Harmonic Counters Torque



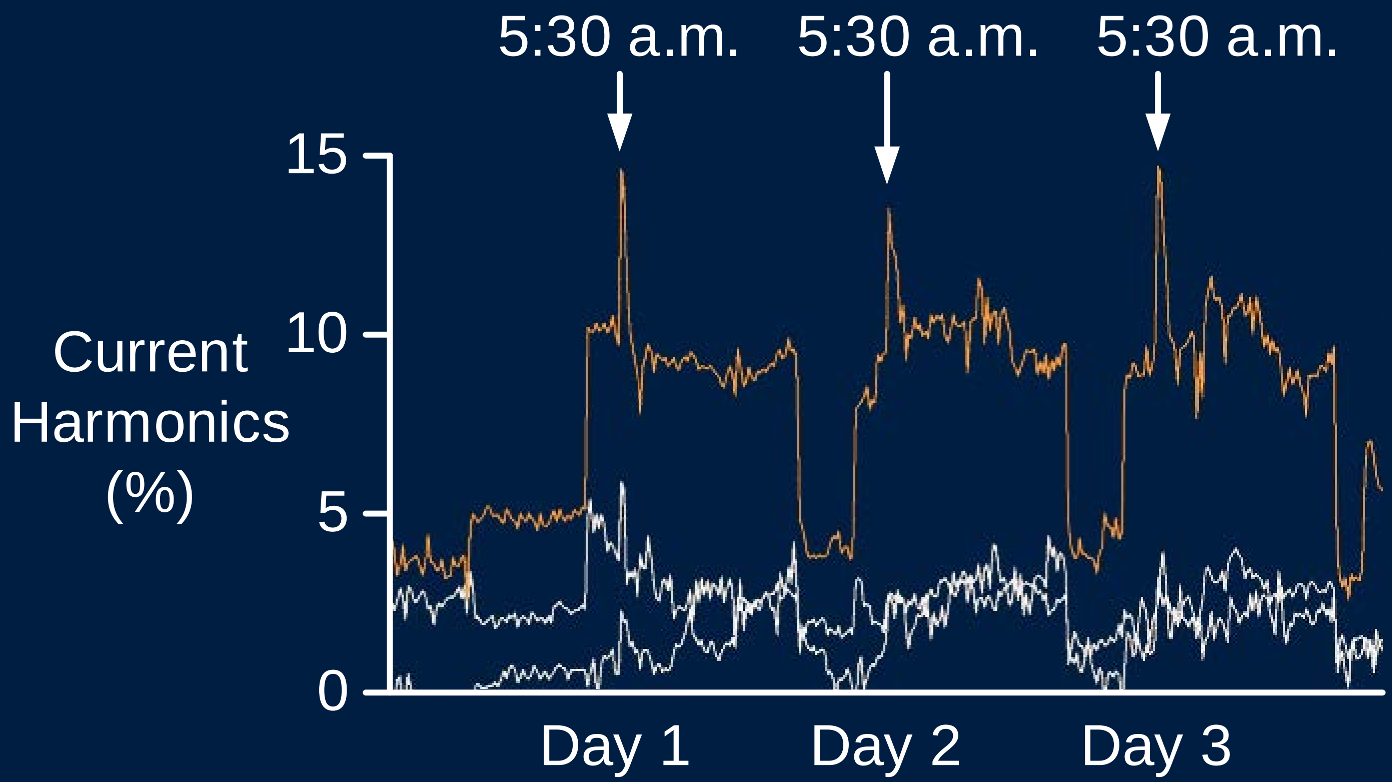
Rotate Angles to 5x Position



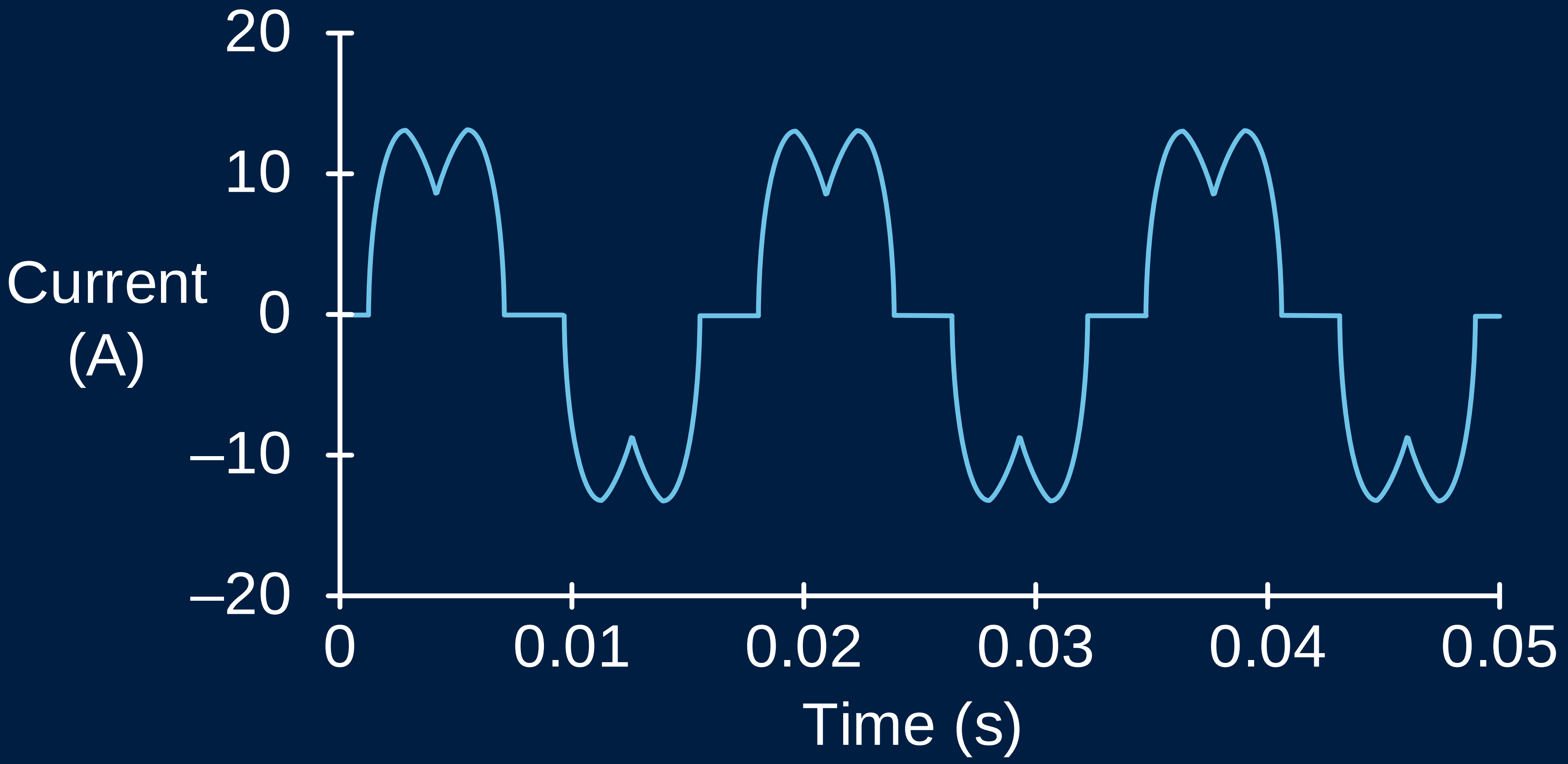


Harmonic Trending Pinpoints Cause of Lighting Ballast Failures

Electronic Ballasts Cause Fifth-Harmonic Disturbance



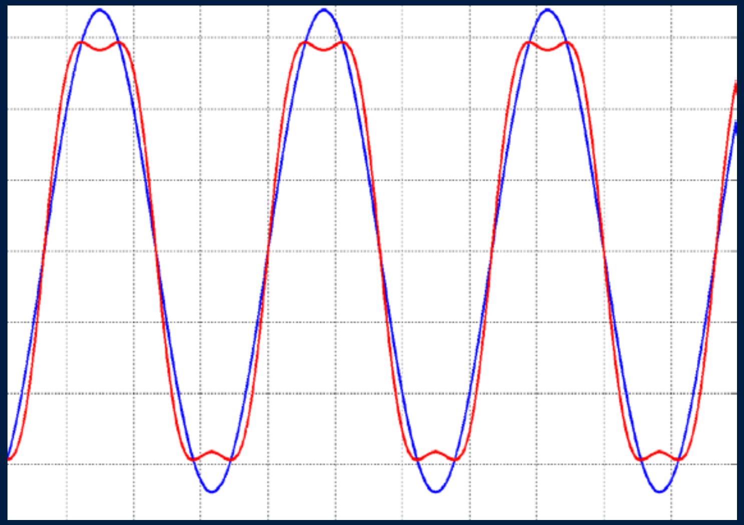
Adjustable Speed Drives Cause Harmonics



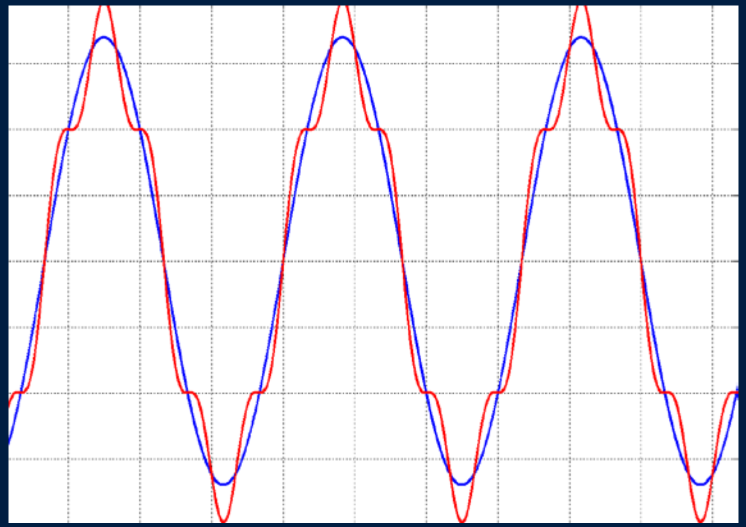
Six-pole adjustable speed drive creates fifth and seventh harmonics

HVdc and Industrial Interties Cause Harmonic Issue for Georgia

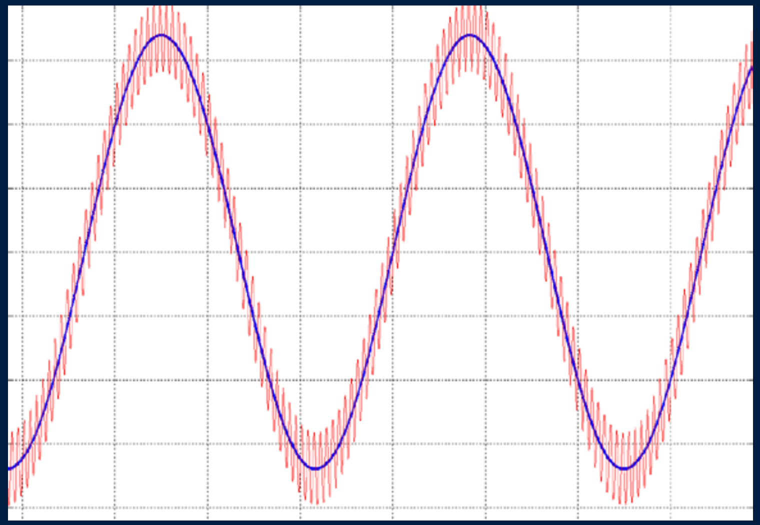
Low Harmonics Are More Common in Power System



Third Order



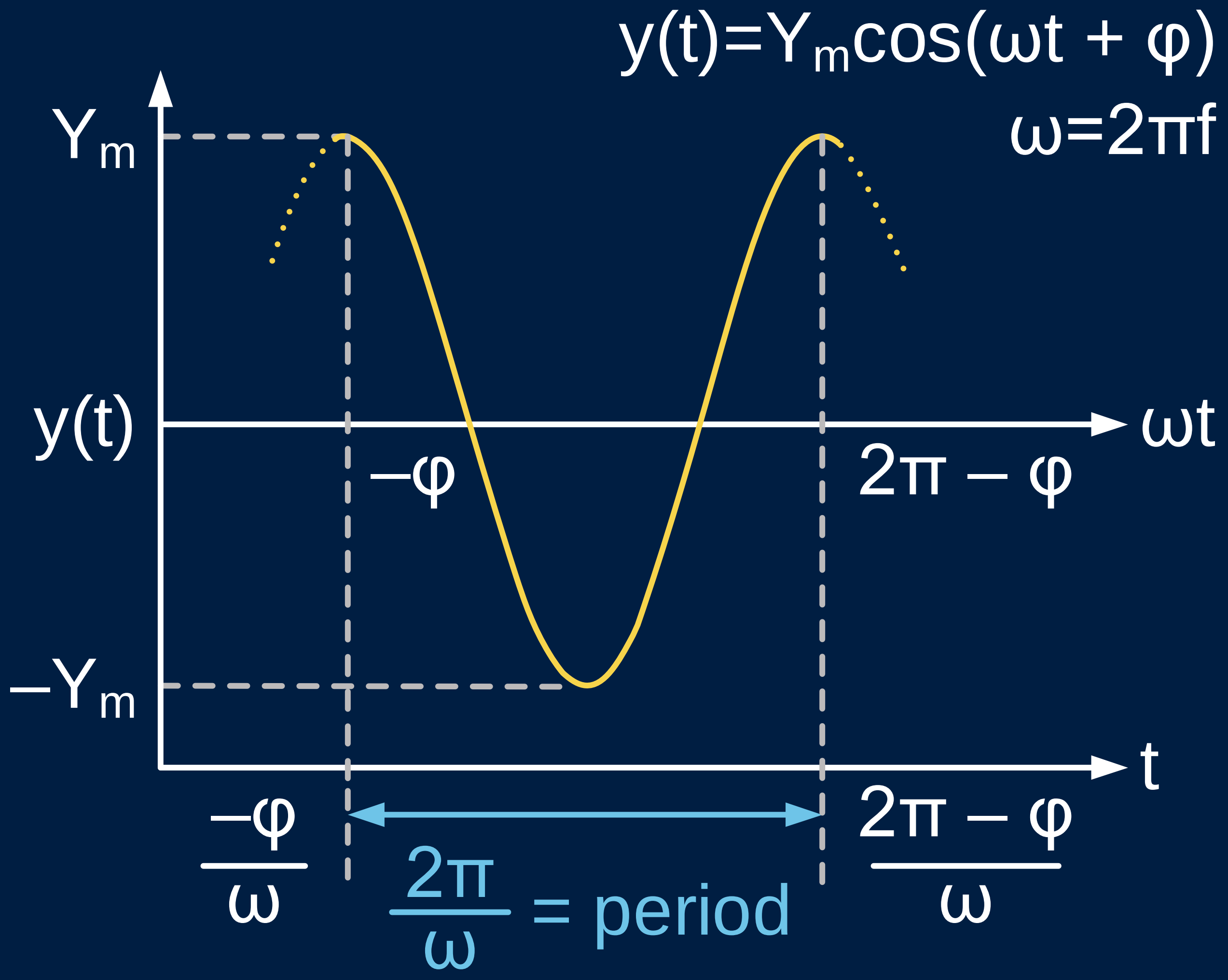
Fifth Order



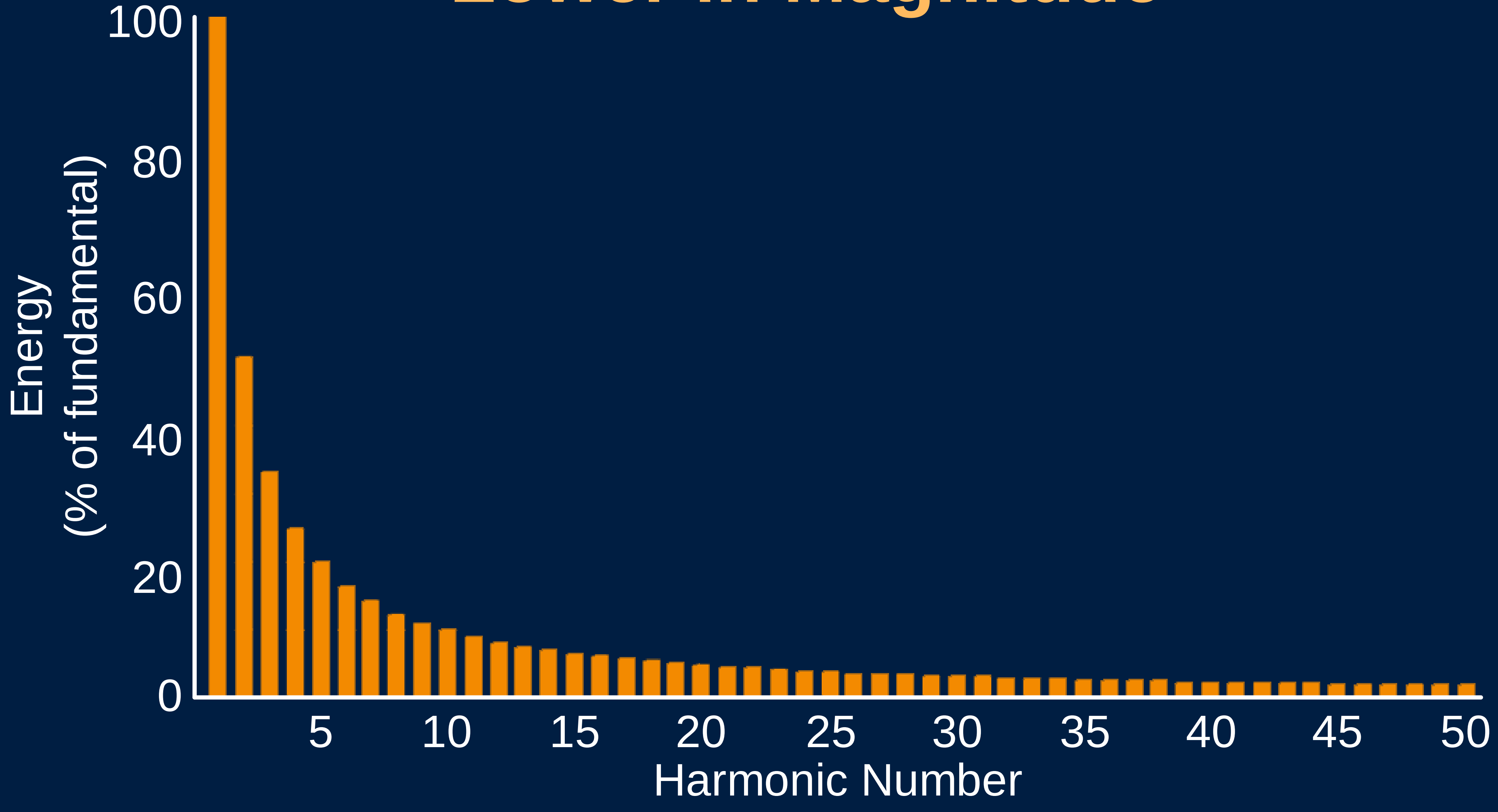
Fiftieth Order

High Crest Factor (CF) Indicates Reduced Lamp Life

- CF = peak / rms
- For ideal sine wave
  - RMS = peak / $\sqrt{2}$
  - CF = peak / rms = 1.414



Higher-Order Harmonics Are Lower in Magnitude



Identify Sources of Harmonics

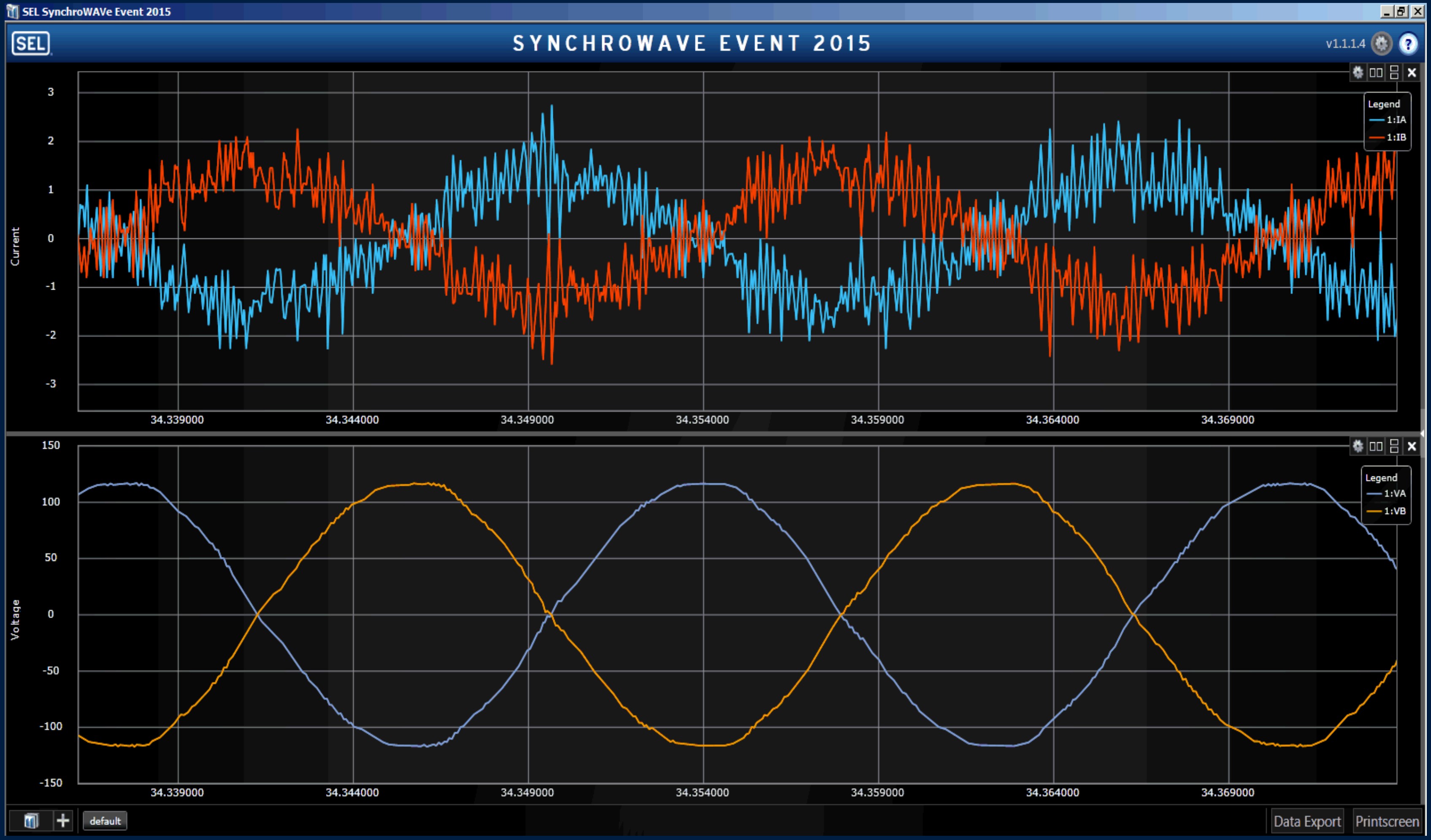
- Nonlinear loads
- HVdc interties
- Saturated transformers
- Arcing devices
- Renewable energy generators
- Electronic-ballast fluorescent lights

Turning on Water Results in Voltage Variation That Affects Lights

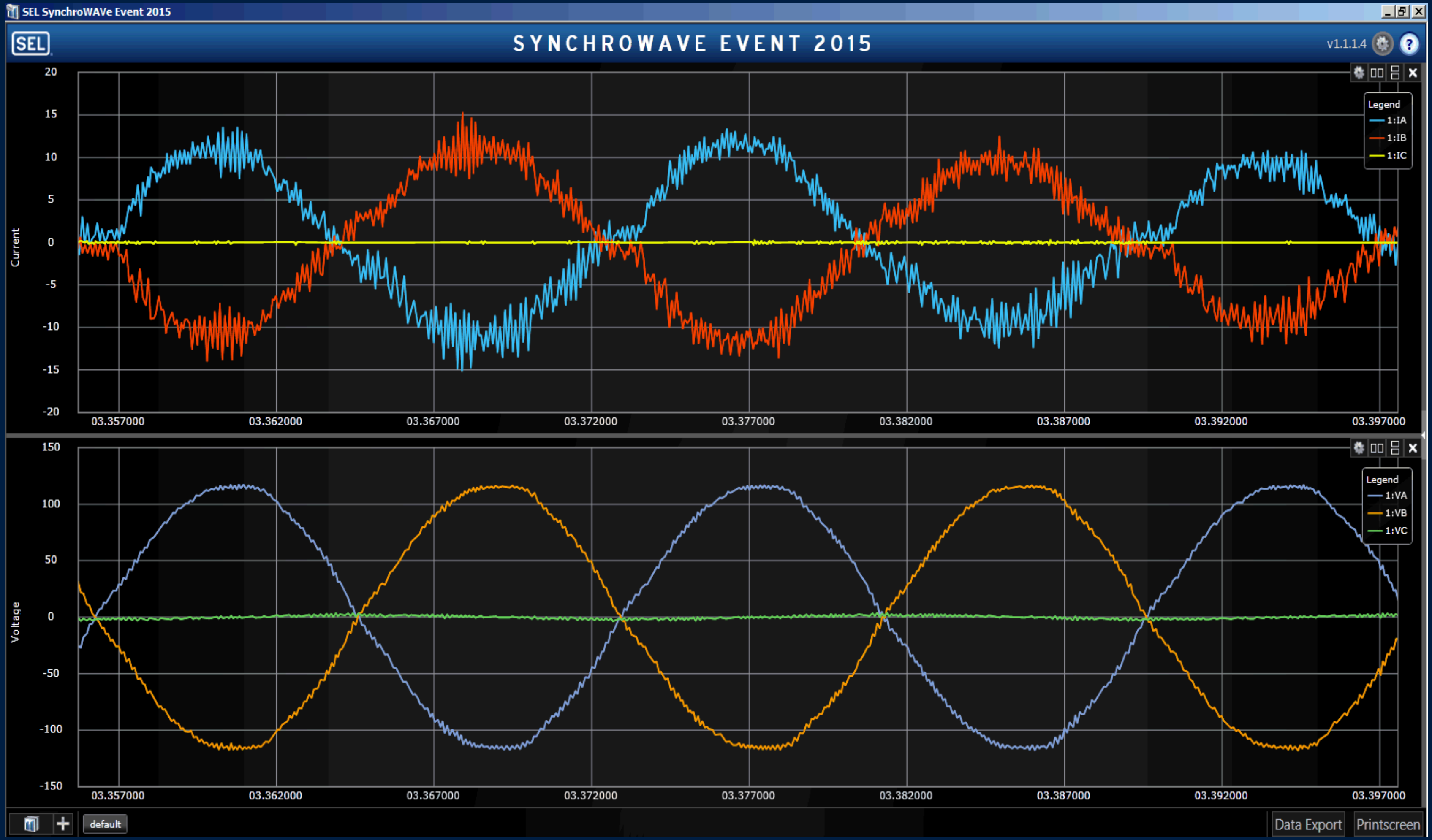
Variable-Frequency Drive (VFD)
for Constant Water Pressure

VFD Not Running

512 Samples Per Cycle



VFD Running
512 Samples Per Cycle

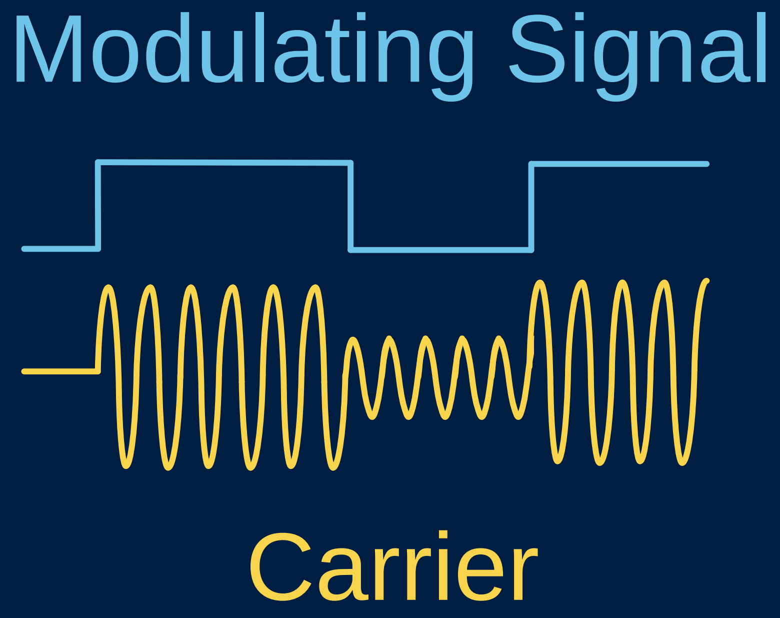


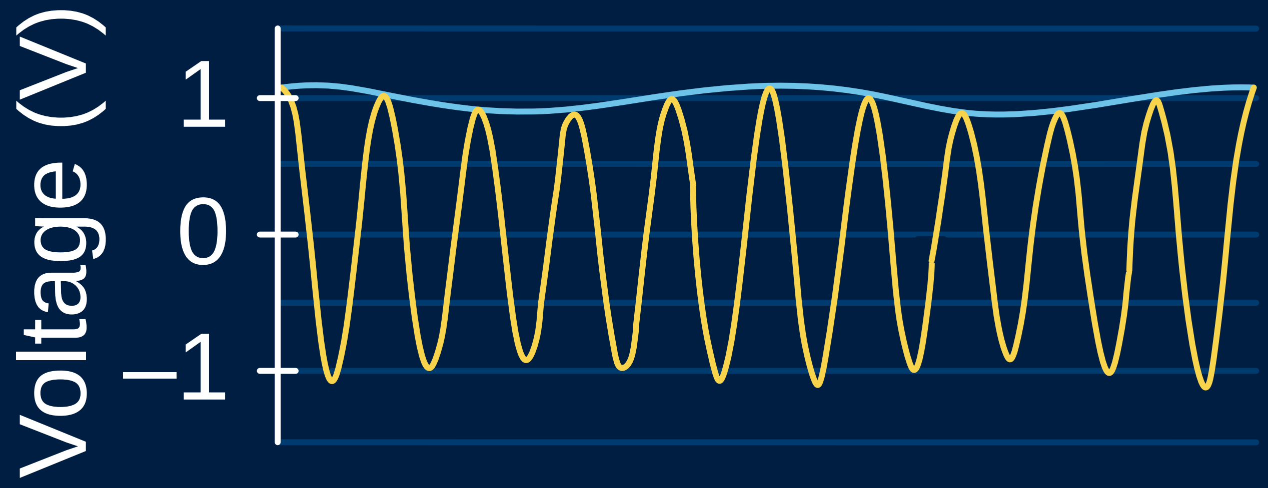
Reduce Harmonic Disturbances

- Isolate voltage sources for sensitive devices from harmonic-generating devices
- Use K-rated transformer or derate transformer
- Install filters between drive and power system

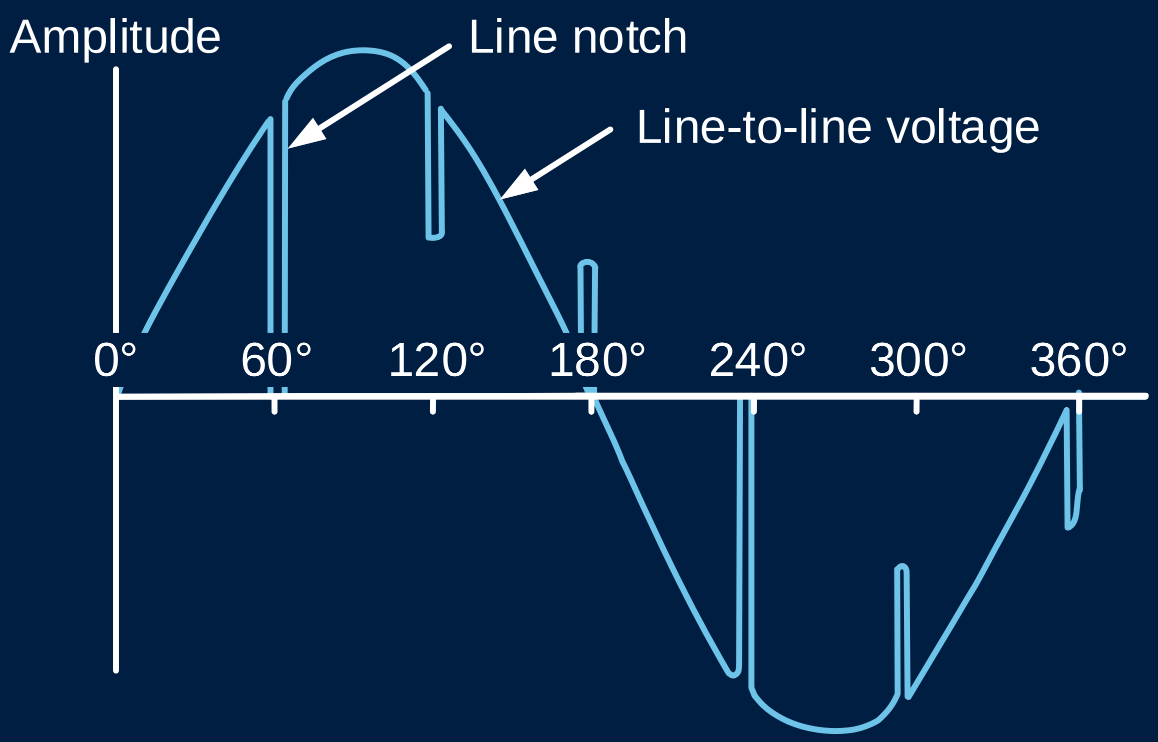
Flicker Affects Human Eye-Brain Response

Amplitude modulation of voltage
when signal carries another signal





Nonlinear Loads Cause Unwanted Zero-Crossings That Affect Digital Clocks



Summary

- PQ issues are changes in electric power supply that can cause equipment to fail, misoperate, or degrade
- Common PQ phenomena are VSSI, harmonics, voltage unbalance, and transients
- PQ characteristics can be described by amplitude, duration, frequency, and wave shape

Troubleshooting Summary

- Look for patterns in disturbances by noting time of day, duration, and how often events occur
- Correlate PQ events with load changes, switching capacitor banks, and so on
- Remember that PQ events are typically worse near the source of the problem
- Note that high neutral current can indicate third harmonics

Questions?