
WELCOME

Music City Power Quality (MCPQ)

IEEE Central Tennessee Section

"Energy Efficiency Improvement in Electrical Distribution Systems and Their Loads"

Tuesday, June 4, 2019

LOCATION:

THE TENNESSEE ENGINEERING CENTER

800 Fort Negley Blvd.,
Nashville, TN 37203
(615) 862-5160

https://events.vtools.ieee.org/m/197400

Today’s Presentation:

“Energy Efficiency Improvement in Electrical Distribution Systems and Their Loads”

Presented By:

Jeffrey R. Turner, P.E.

Vice President - Engineering

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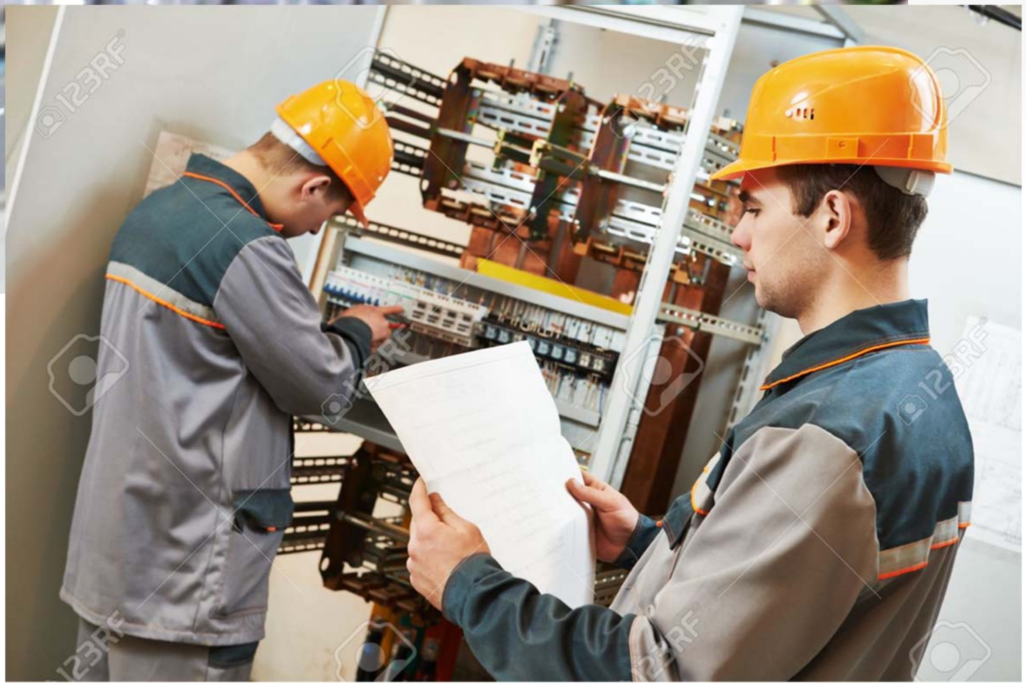
About the Presenter:

- *Prior to joining PQI in 2010, Jeff spent nearly a decade as the Director of Electrical Engineering for a prominent healthcare design A/E firm, The Estopinal Group.*
- *Early in his engineering career, Jeff worked as a process engineer for Ford Motor Company (Kentucky Truck Plant).*
- *In addition, Jeff has worked as an electrical engineer in T&D standards for Louisville Gas & Electric (LG&E) and as a project manager and estimator for Meiners Electric (electrical contractor).*
- *Jeff is an Alumnus of the University of Louisville Speed Scientific School where he received a Bachelor of Science in Engineering Science (BES) degree and a Master of Engineering (MEng) with specialization in the field of Electrical Engineering.*
- *Jeff is a licensed Professional Engineer, has a Master Electrician License and is a member of IEEE, ASHE and NFPA.*

Improving the Efficiency of an Electrical Distribution System and its Loads Reduces Energy Consumption

Are there any unclaimed 'Gold Nuggets'

Energy Services Companies



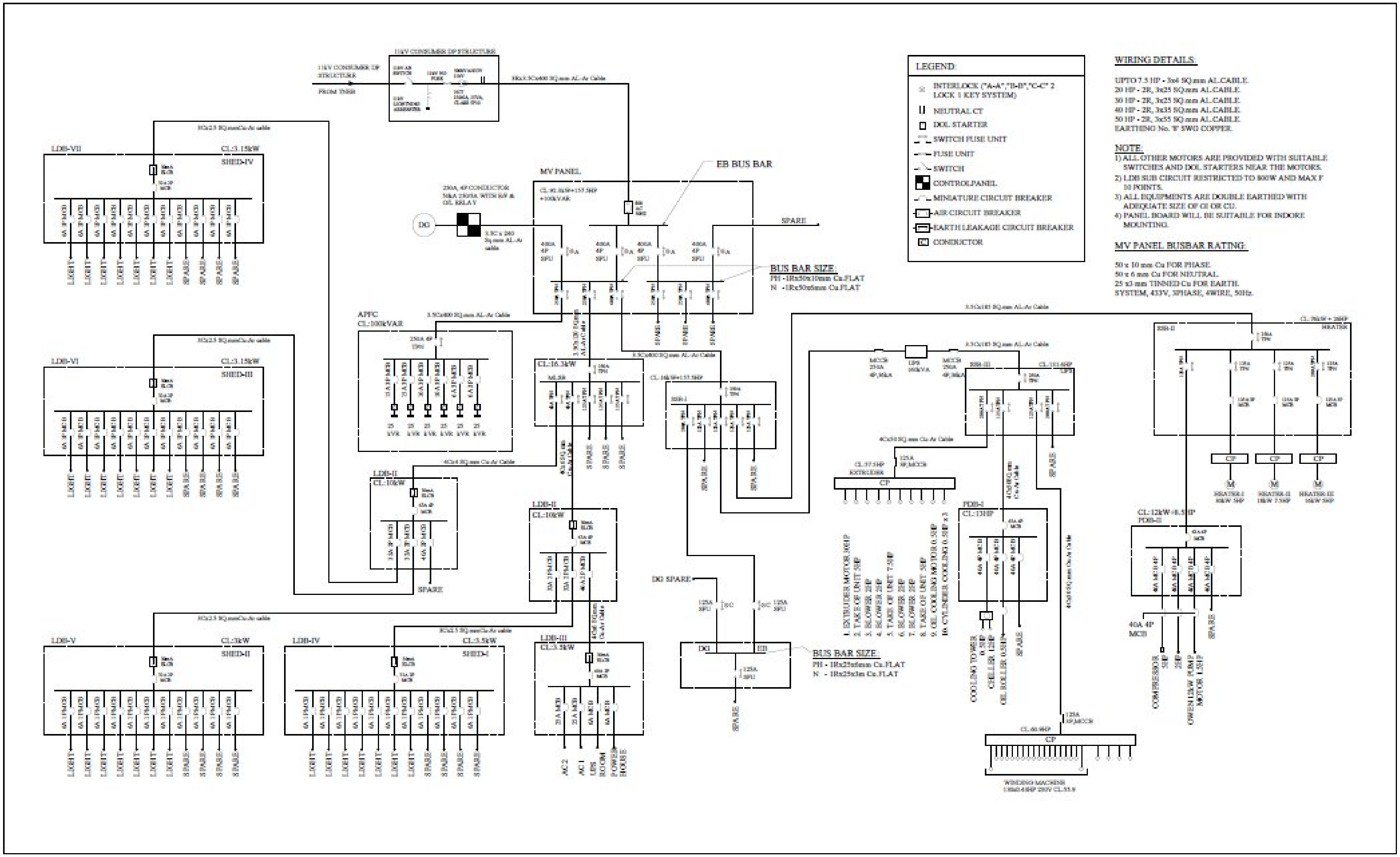
What are Penalty Losses?

‘Penalty Losses’ are defined as consumed power that does not contribute directly to the intended work.

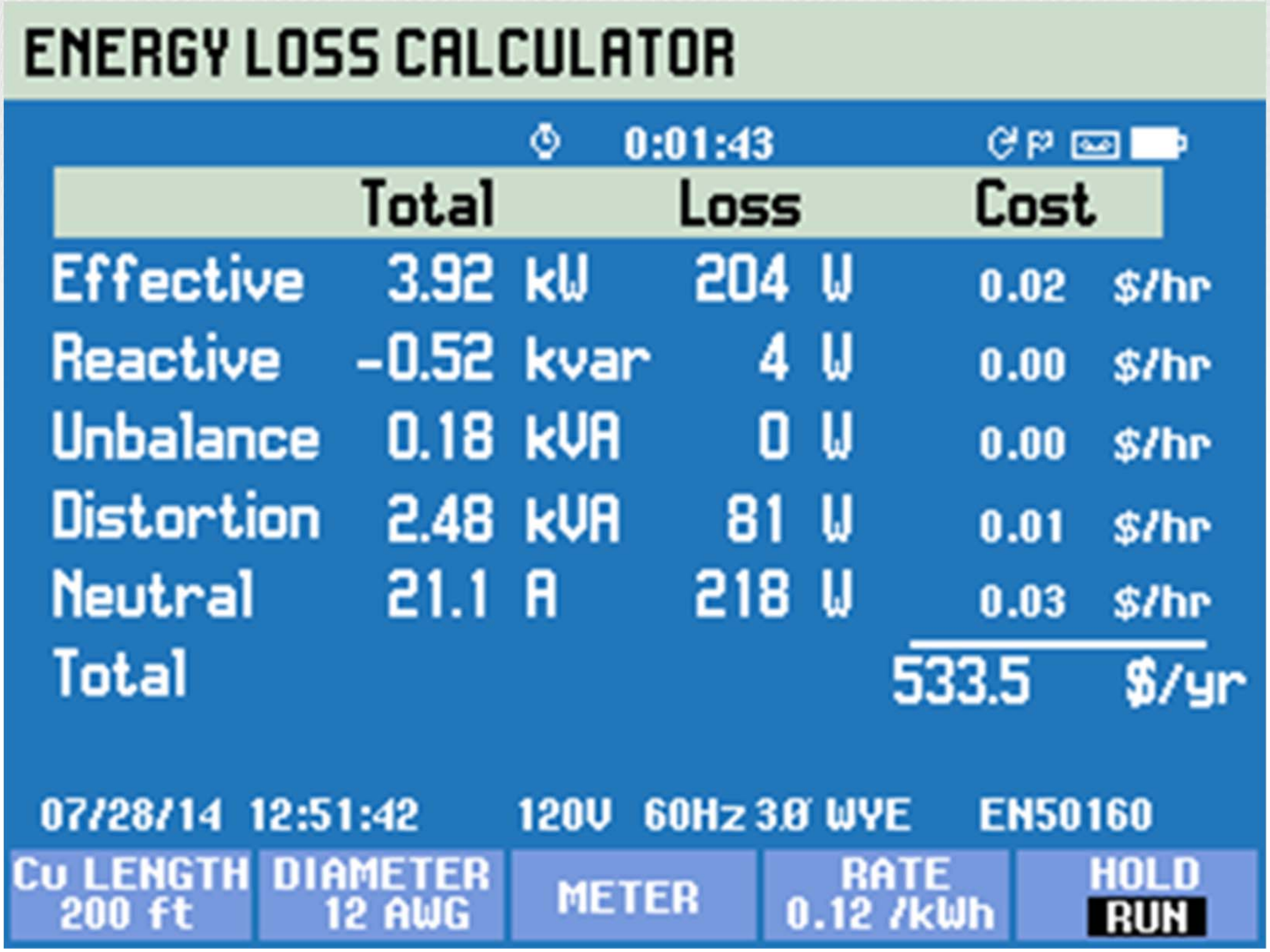
Unavoidable transformer, circuit and load losses at 60Hz are excluded.

What Causes Penalty Losses in Distribution System Circuits?

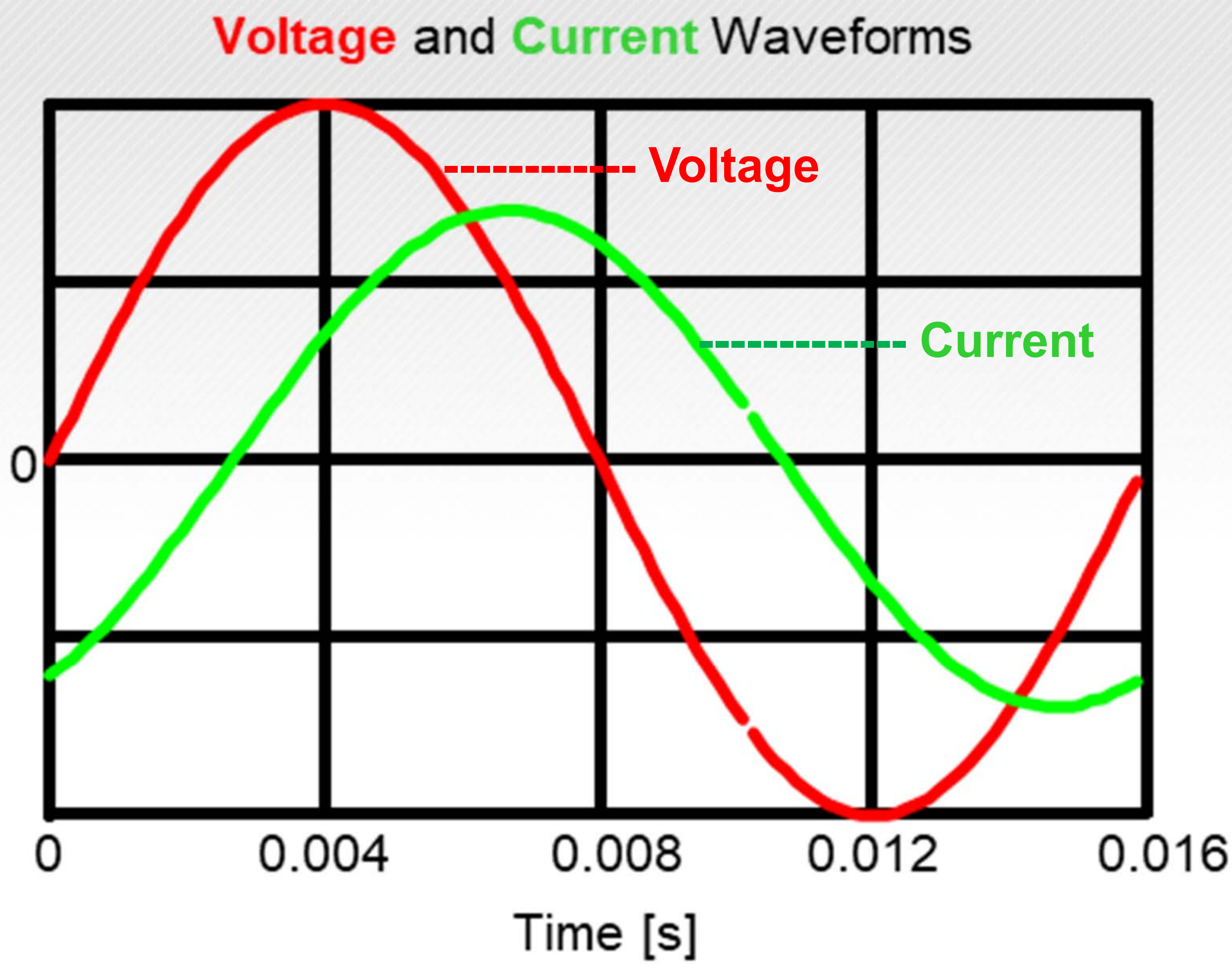
Circuit Penalty Losses



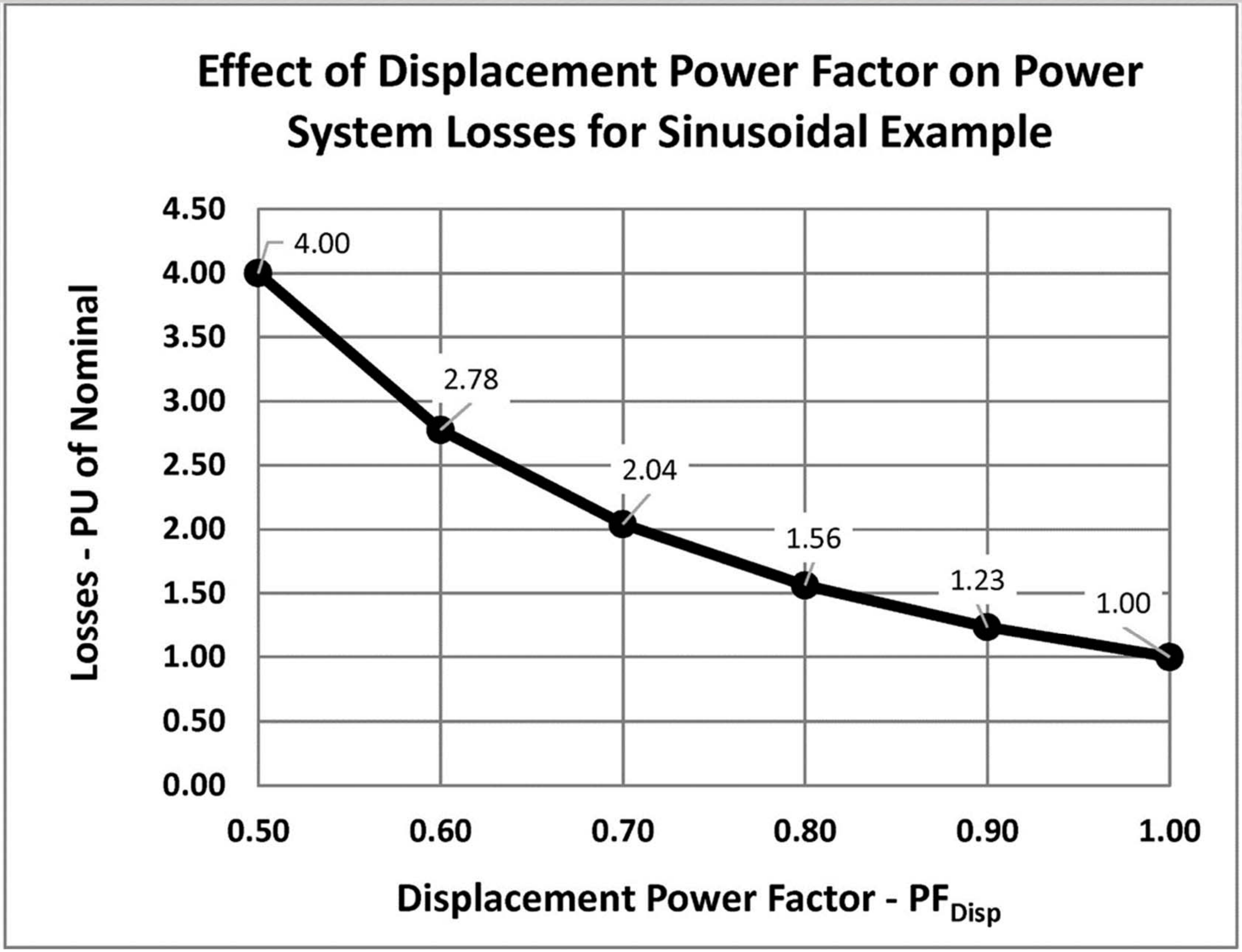
Measuring a Circuit's Penalty Losses



Reactive Load Penalty Losses



Typical Displacement Power Factor (PF_{DISP}) Limits



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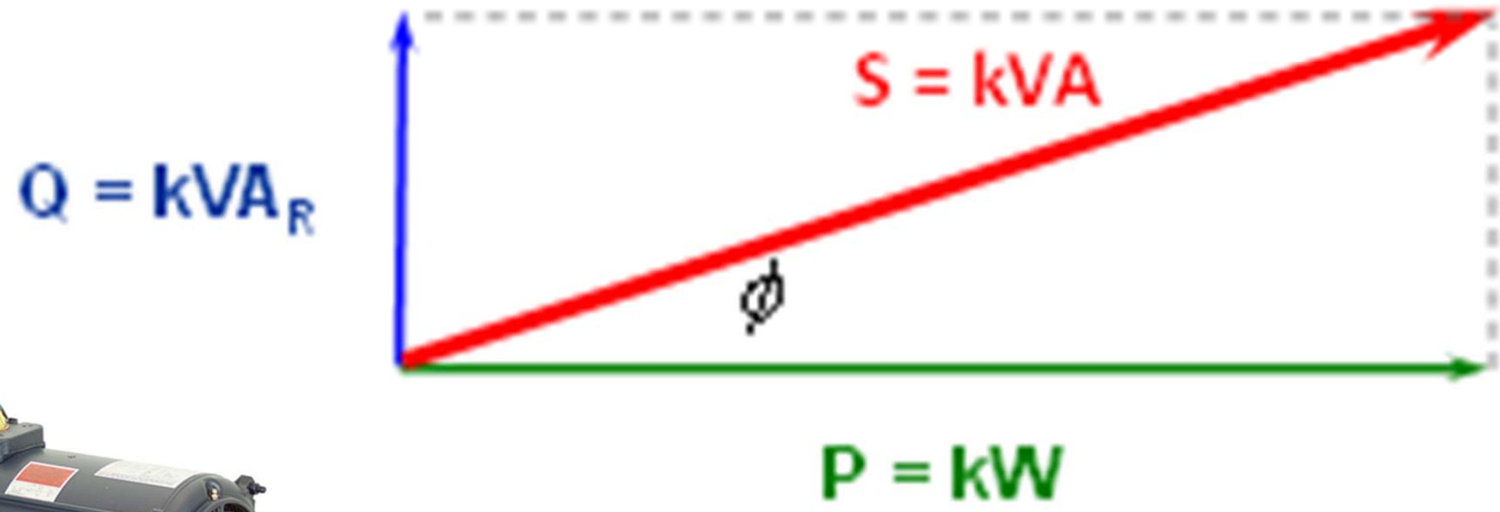
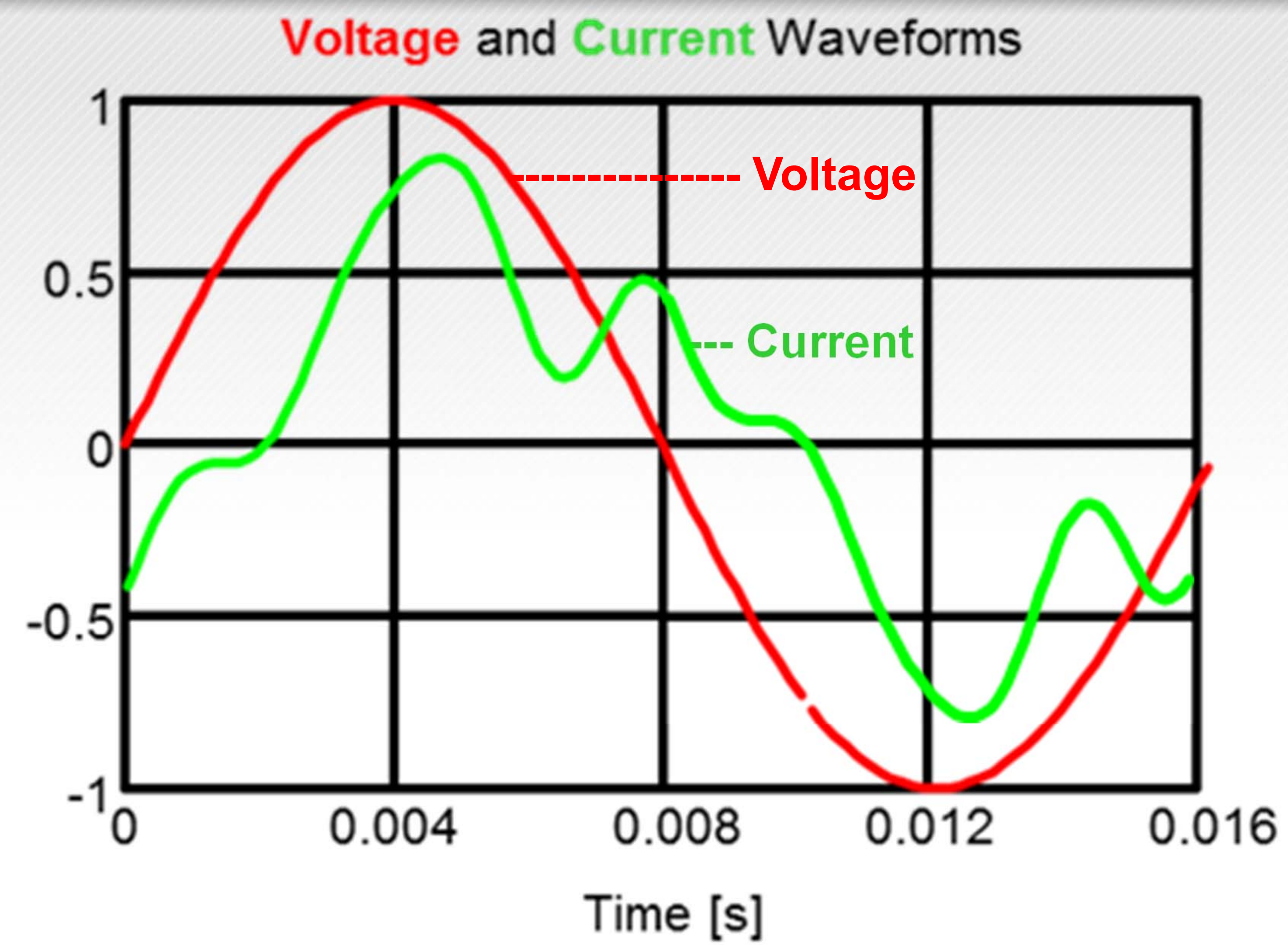
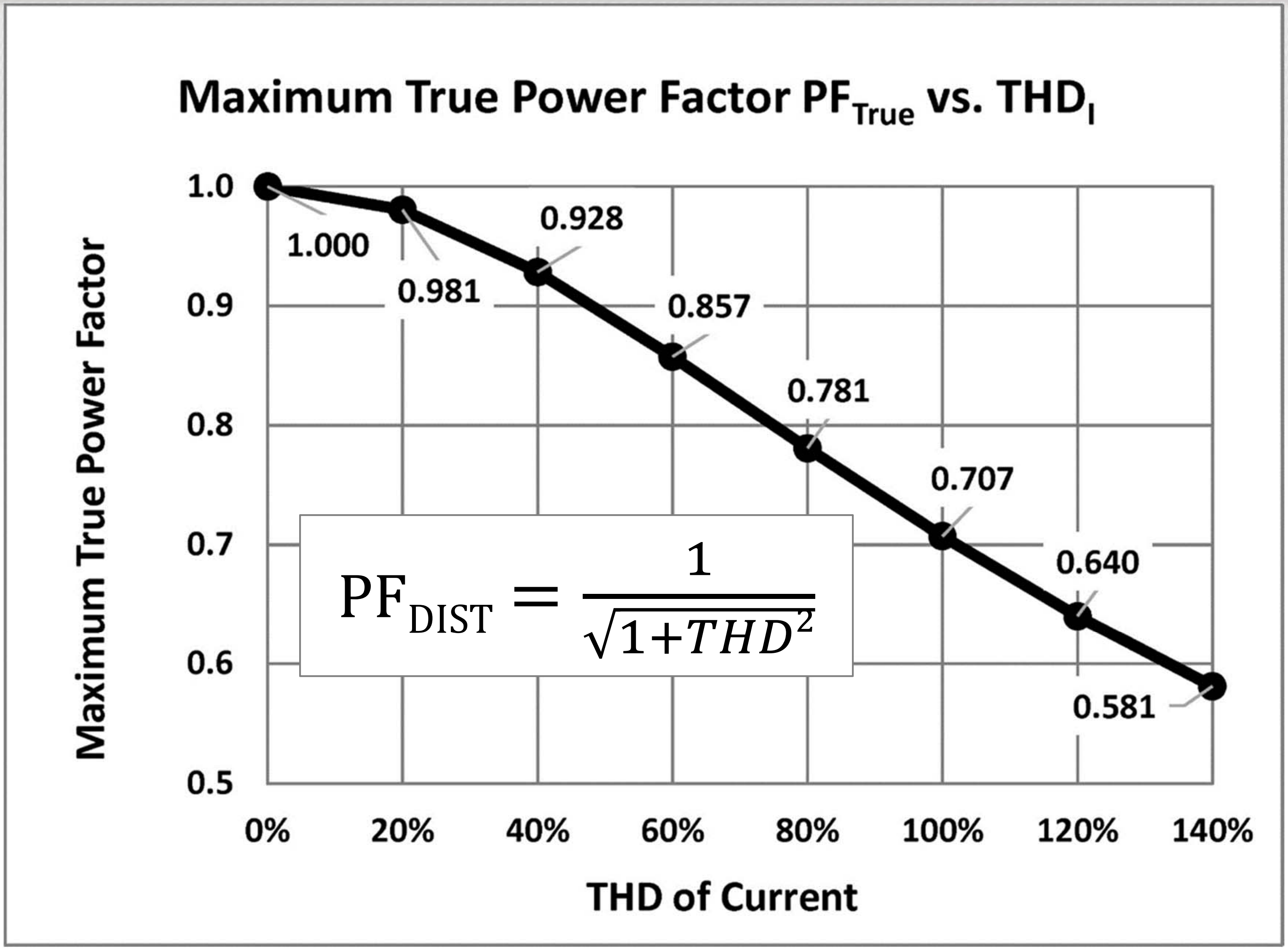
Reactive Load Penalty Loss Solution



Nonlinear Load Penalty Losses



Typical Distortion Power Factor (PF_{DIST}) Limits



$$PF_{DIST} = \frac{1}{\sqrt{1+THD^2}}$$

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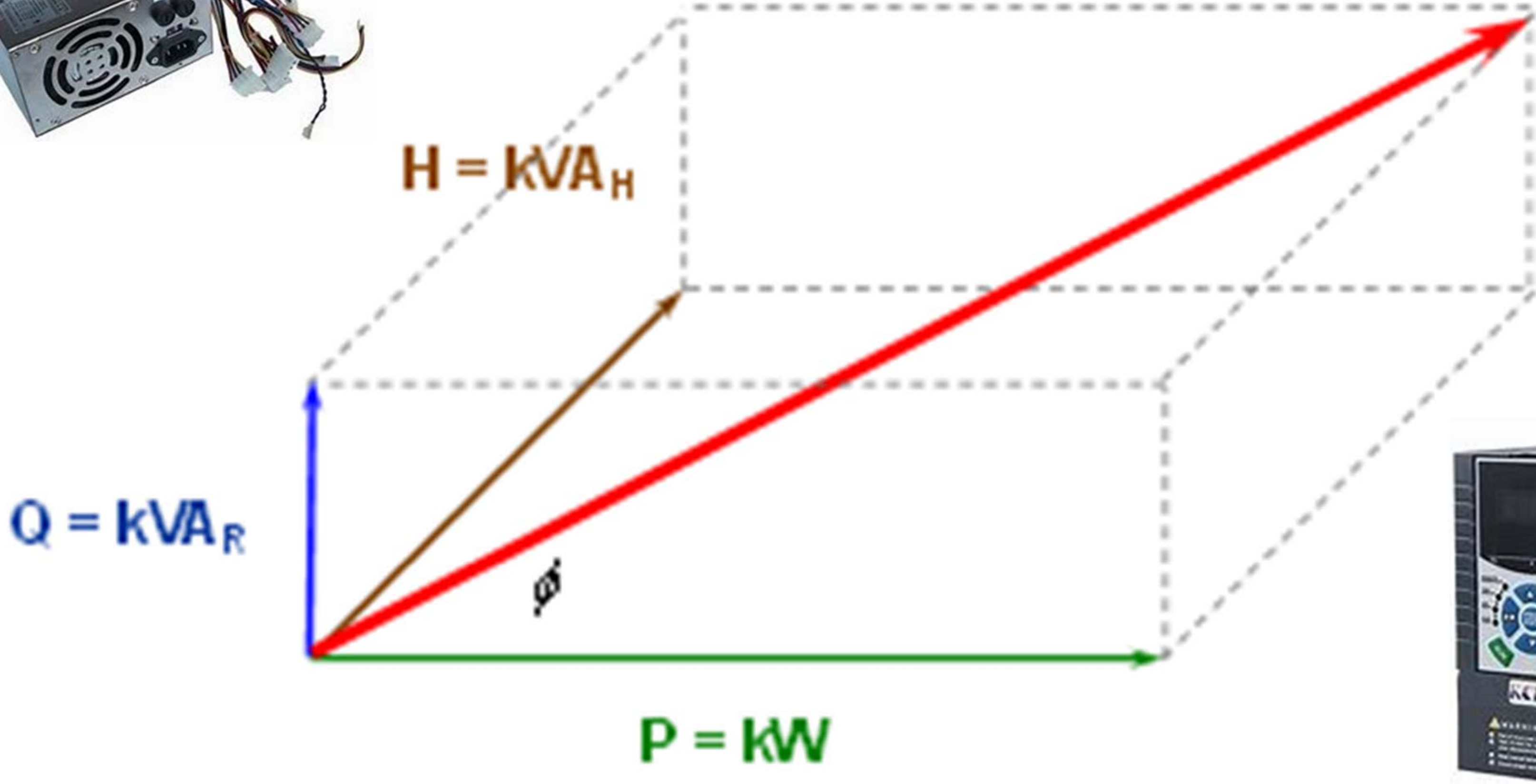
Nonlinear Load Penalty Loss Solution



Nonlinear Load Penalty Loss Solution

In a nonlinear environment, the application of a capacitor bank, without first implementing a harmonic mitigation plan that significantly reduces kVA_H and voltage distortion, will often result in any or all of the following undesirable outcomes:

- **The capacitor bank's protective device may remove the capacitor bank from service.**
- **The capacitor bank may fail before its protective device can remove it from service.**
- **Harmonic current and voltage amplification may occur due to resonance at a particular harmonic frequency or frequencies.**
- **System apparatus and/or load insulation systems may fail due to high harmonic voltages and dV/dT stresses.**

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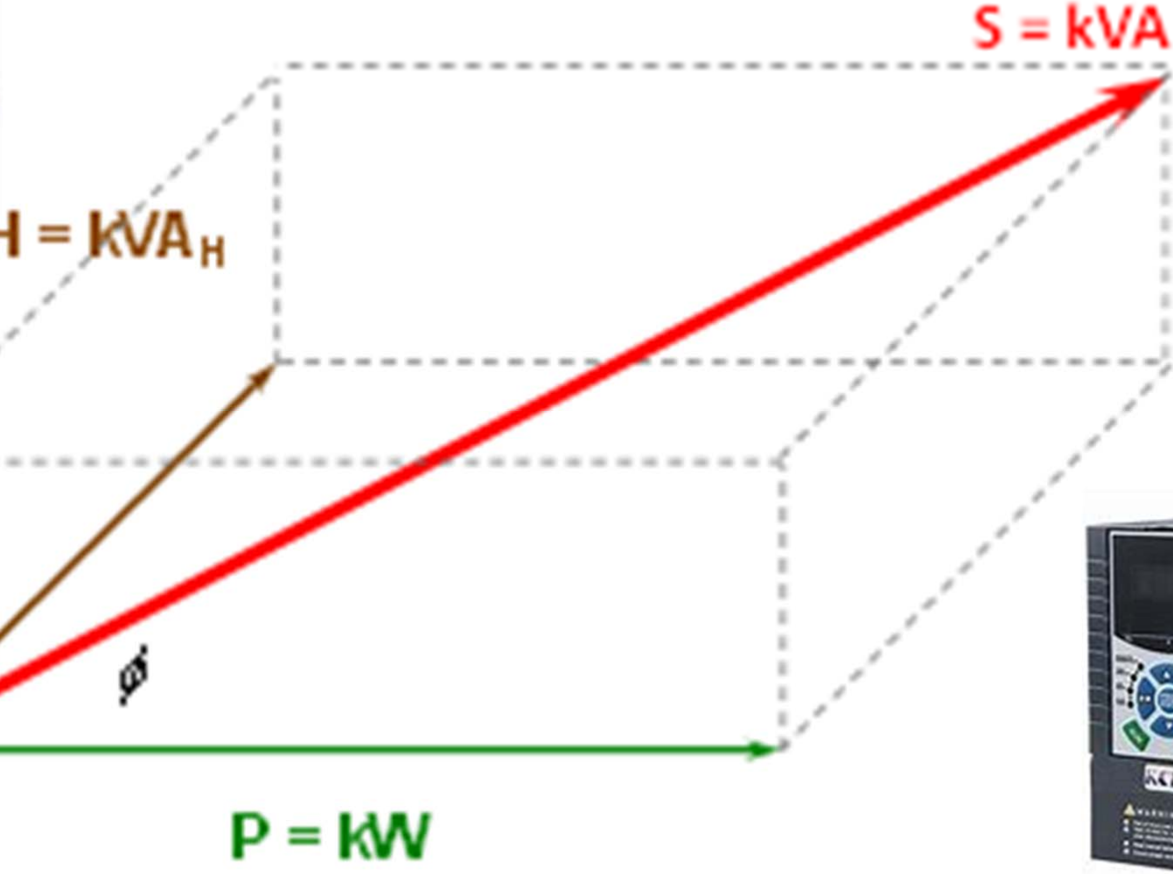
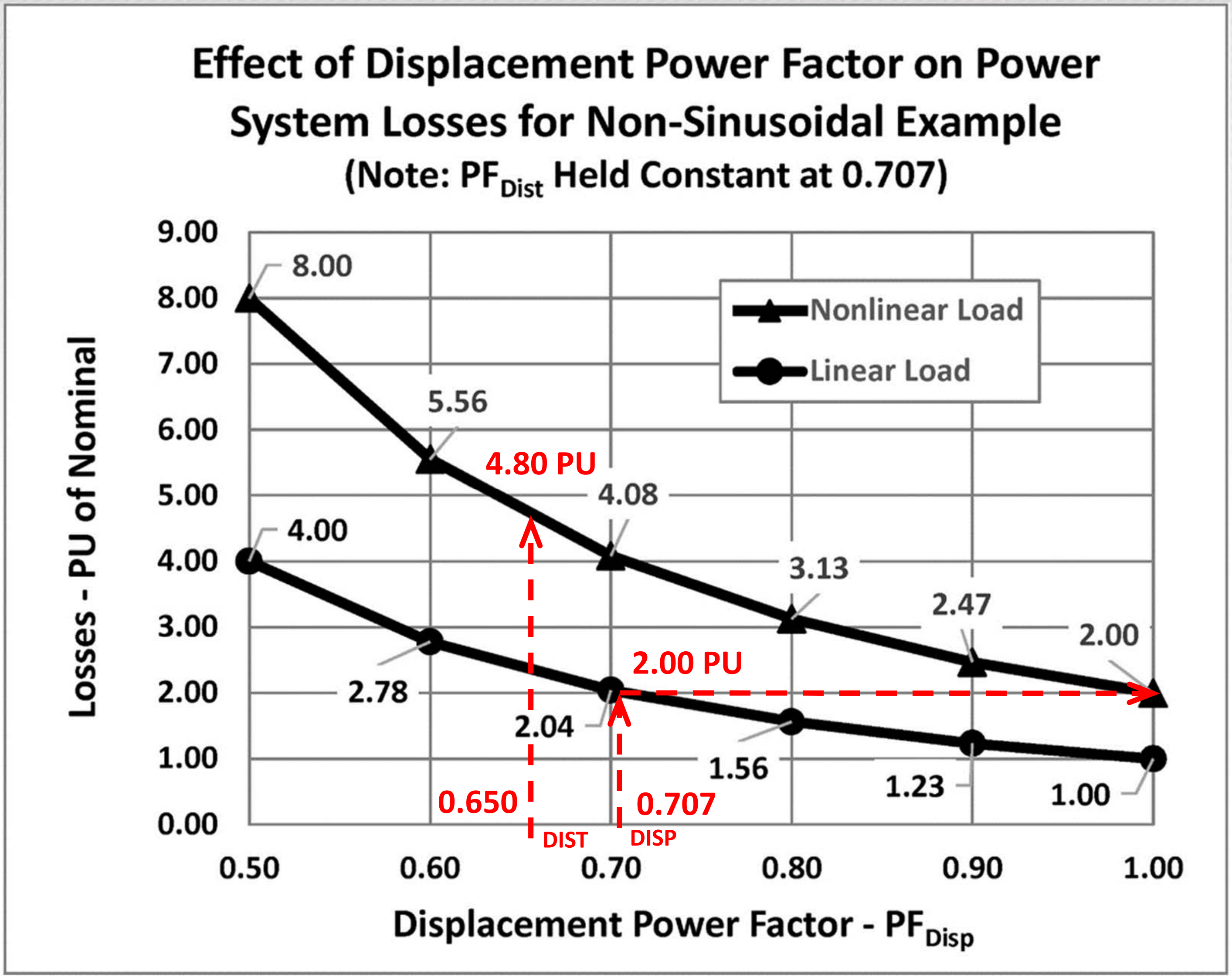
A Procedure for Estimating Circuit & Load Penalty Losses

Estimating Circuit & Load Penalty Losses



Estimating Circuit & Load Penalty Losses



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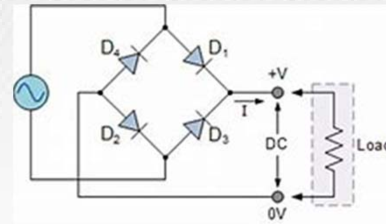
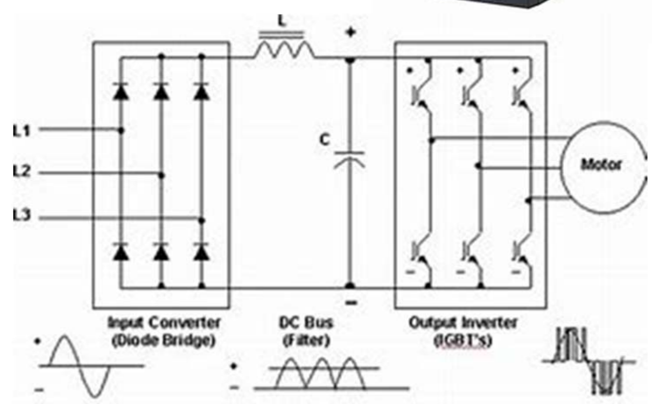
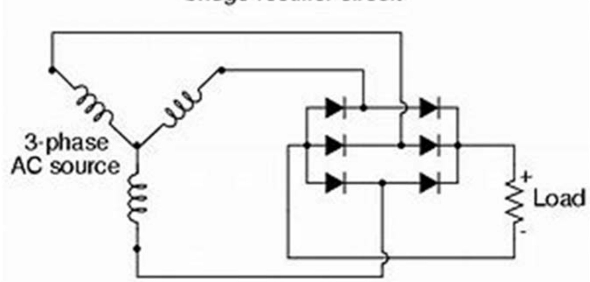
Estimating Load Penalty Losses

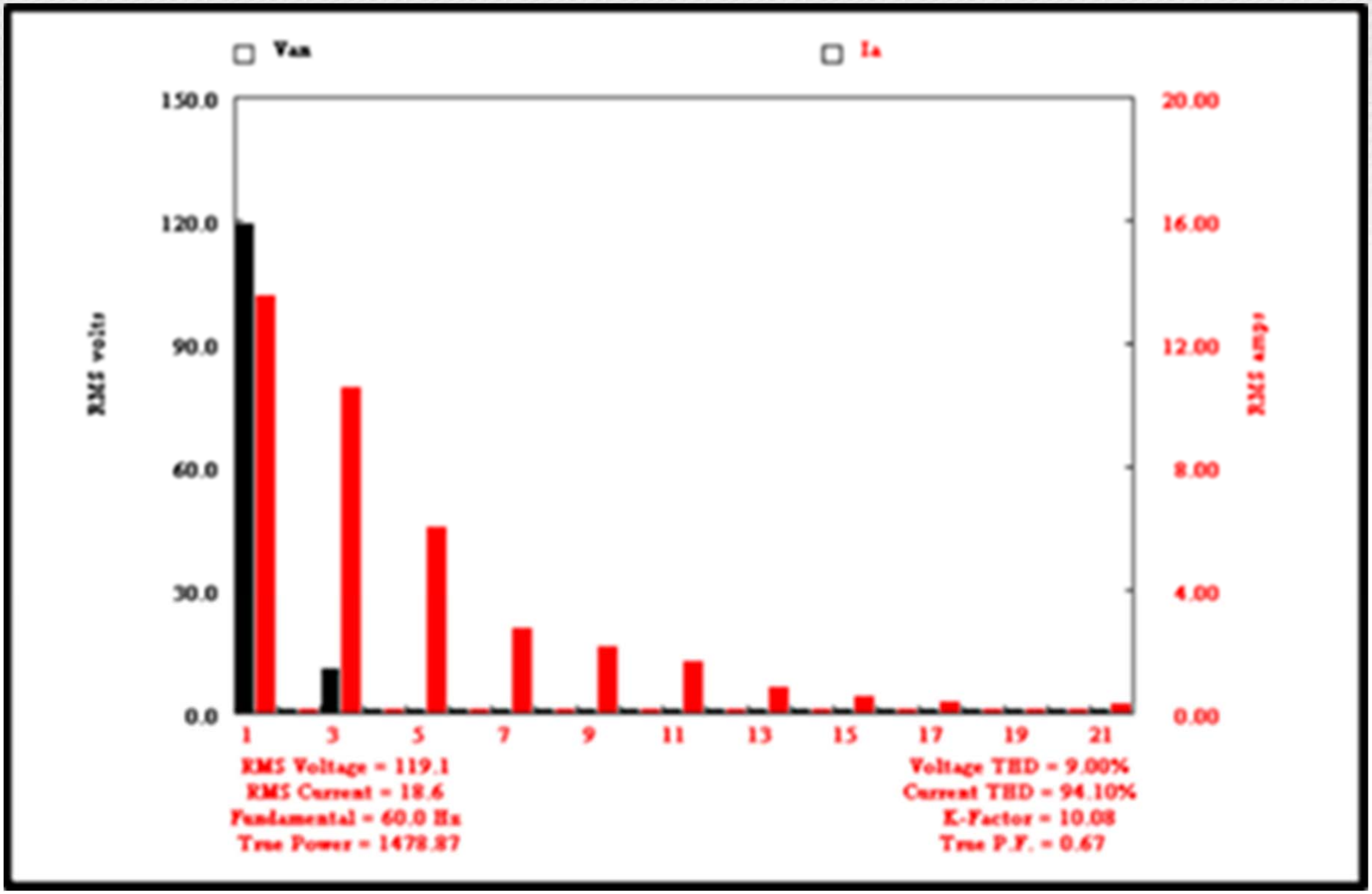




Three-phase, full-wave bridge rectifier circuit



Estimating Load Penalty Losses



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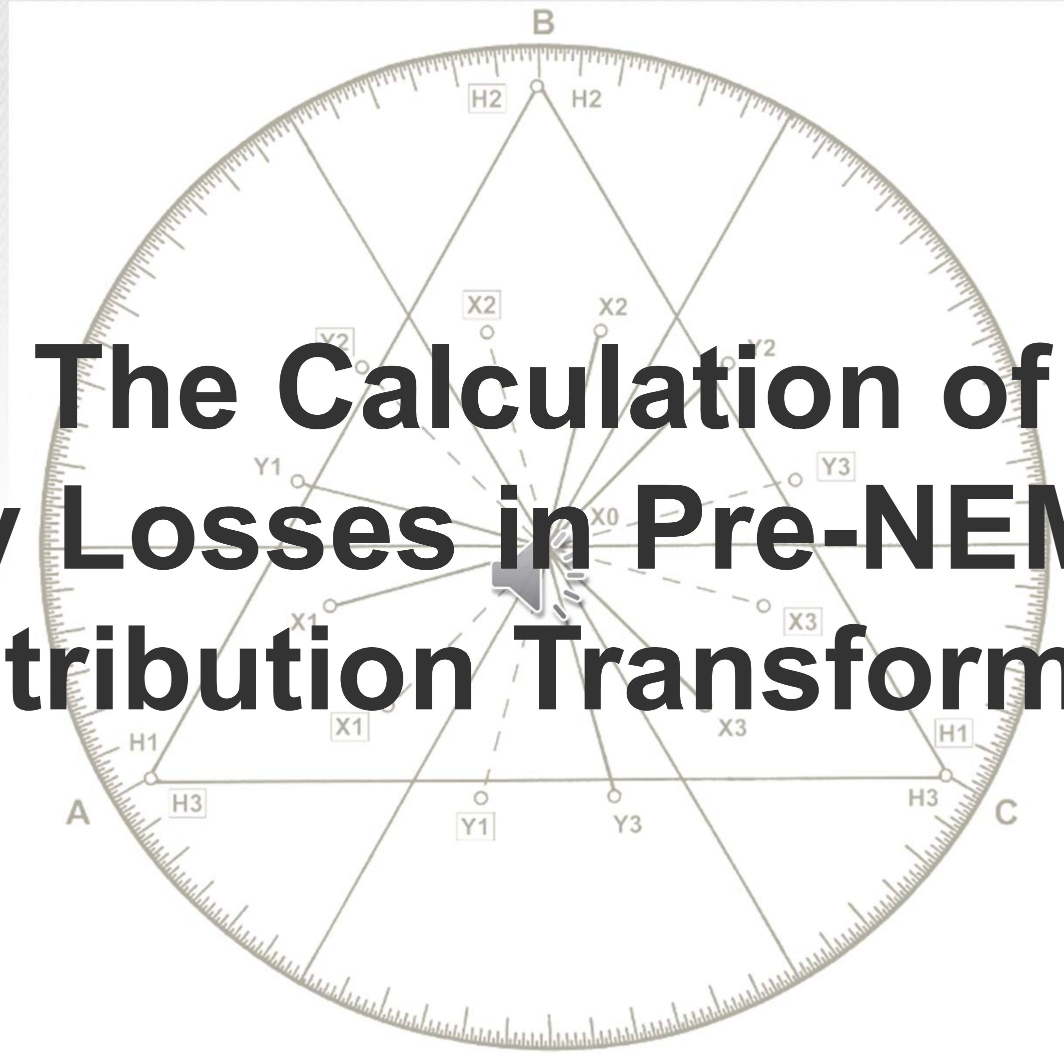
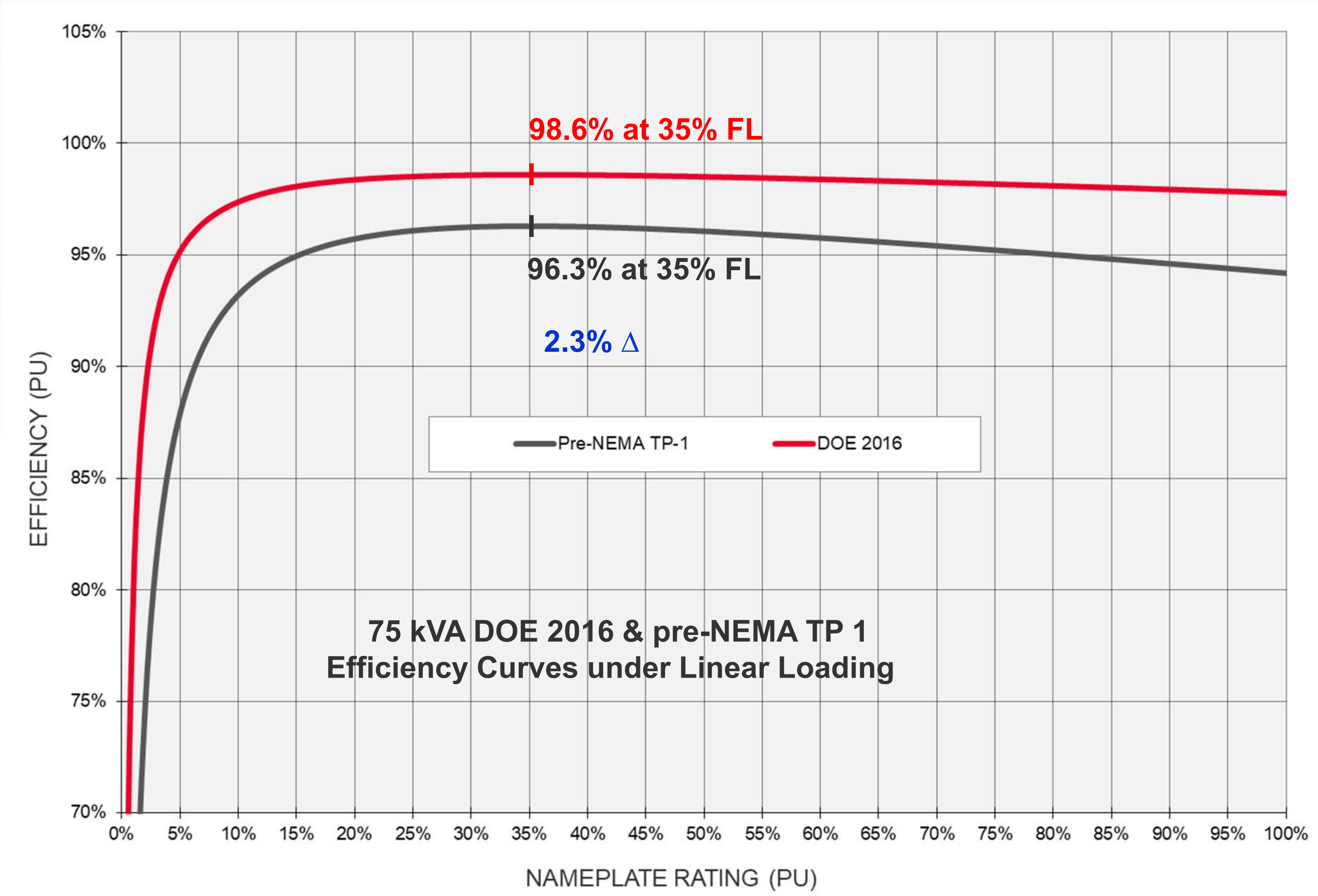


The Calculation of Penalty Losses in Pre-NEMA TP 1 Distribution Transformers

Pre-NEMA TP 1 Efficiency Problem



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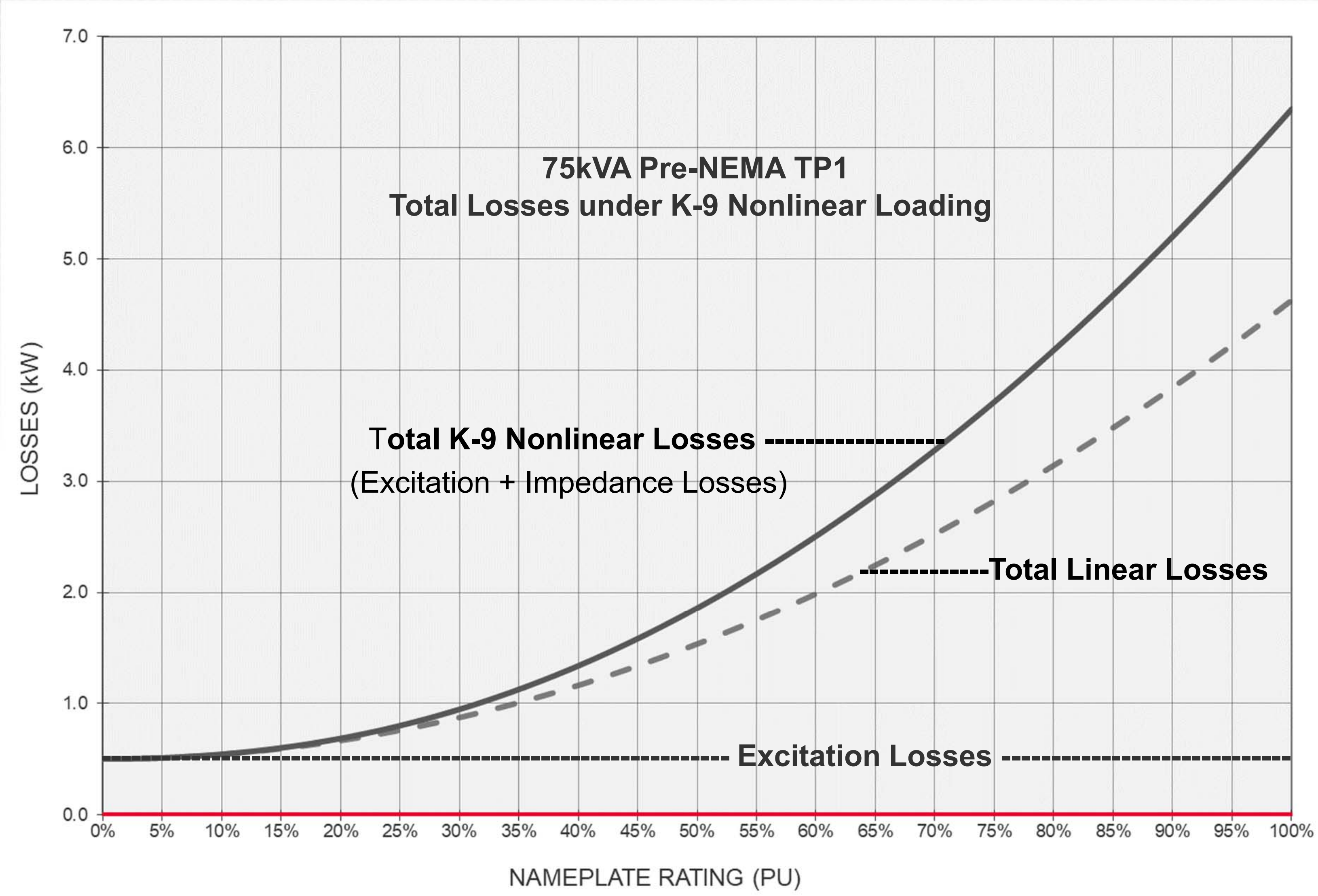
Pre-NEMA TP 1 Harmonic Problem



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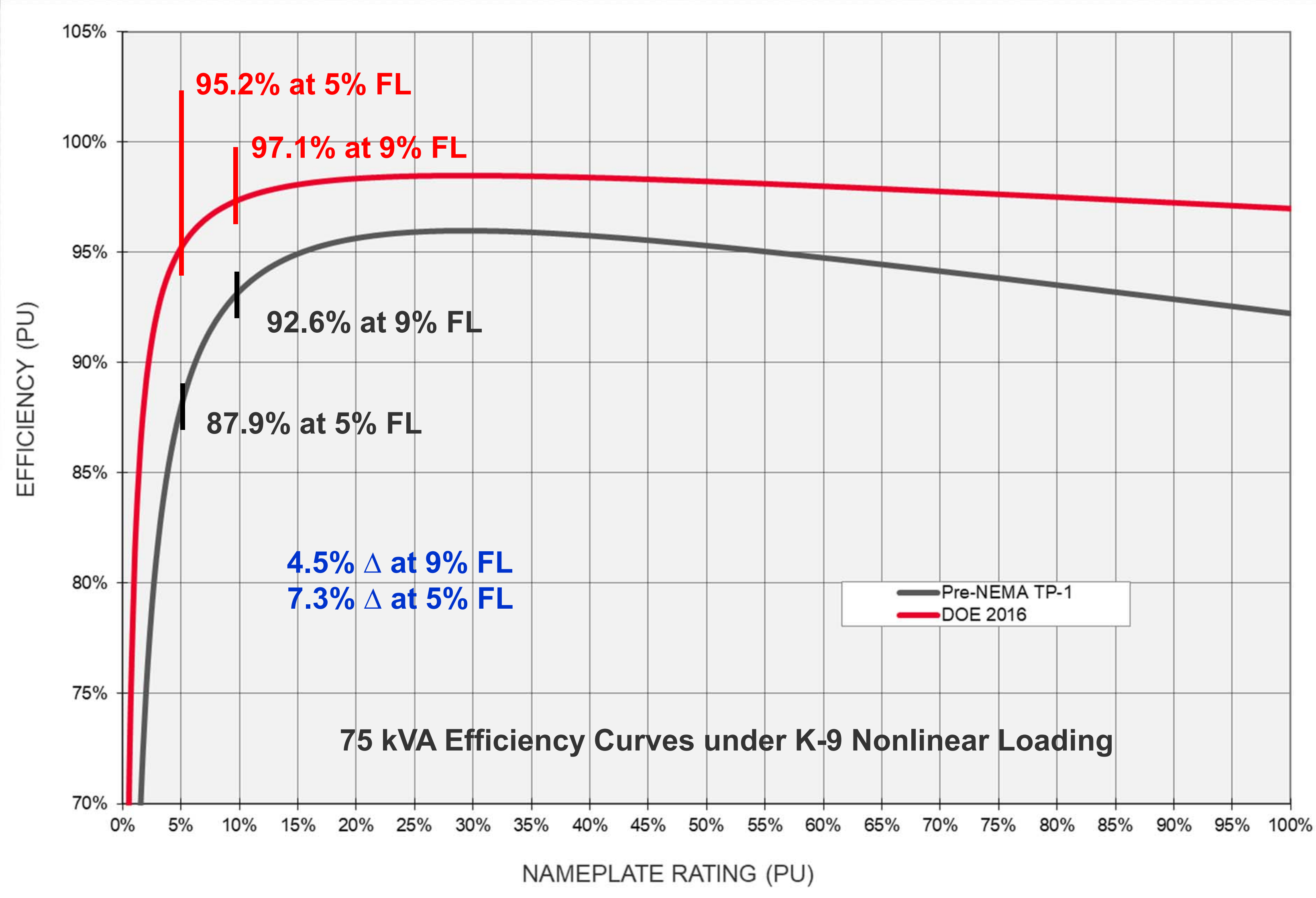
The ‘Same Size’ Replacement Solution



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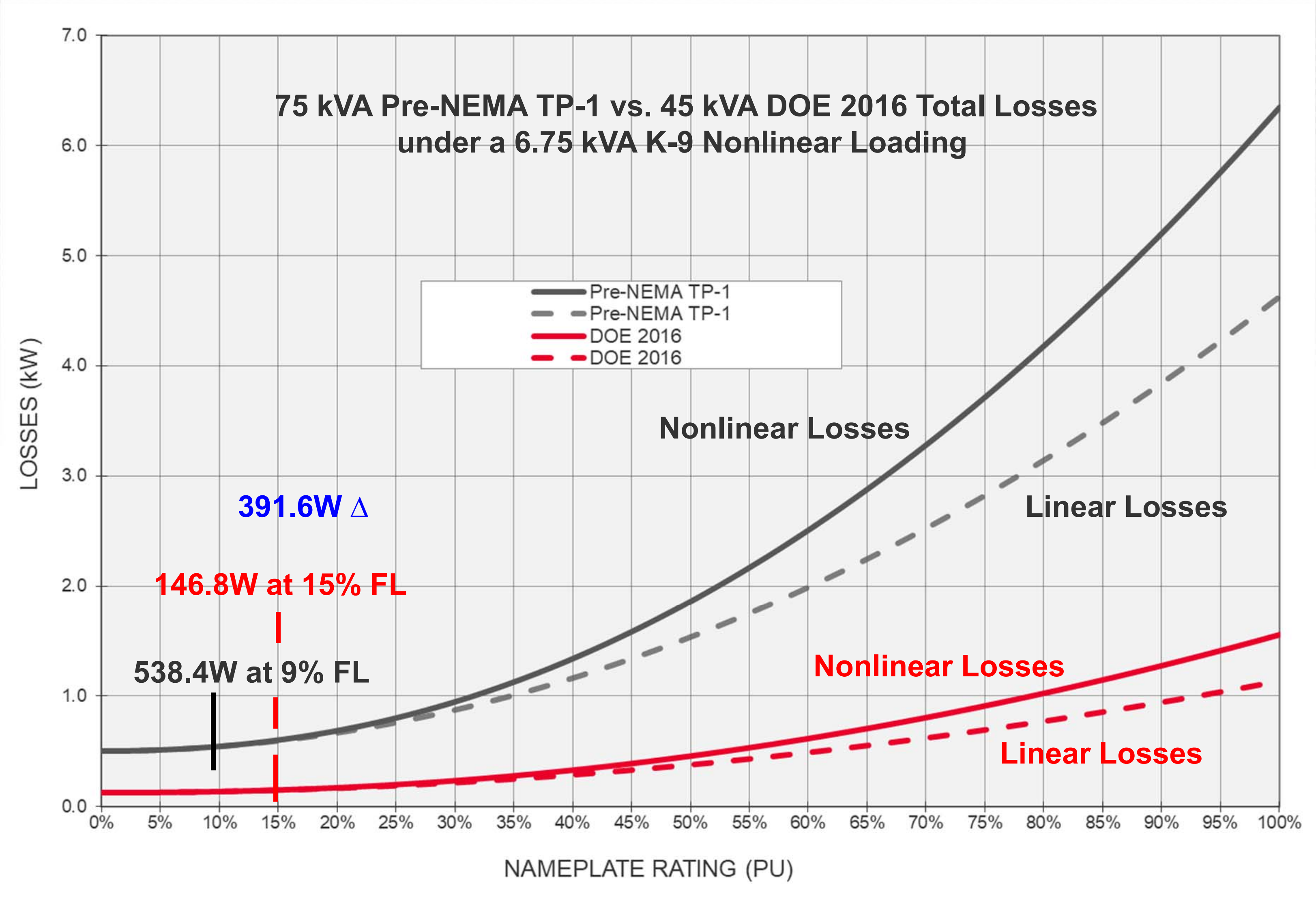
The ‘Right Sizing’ Replacement Solution



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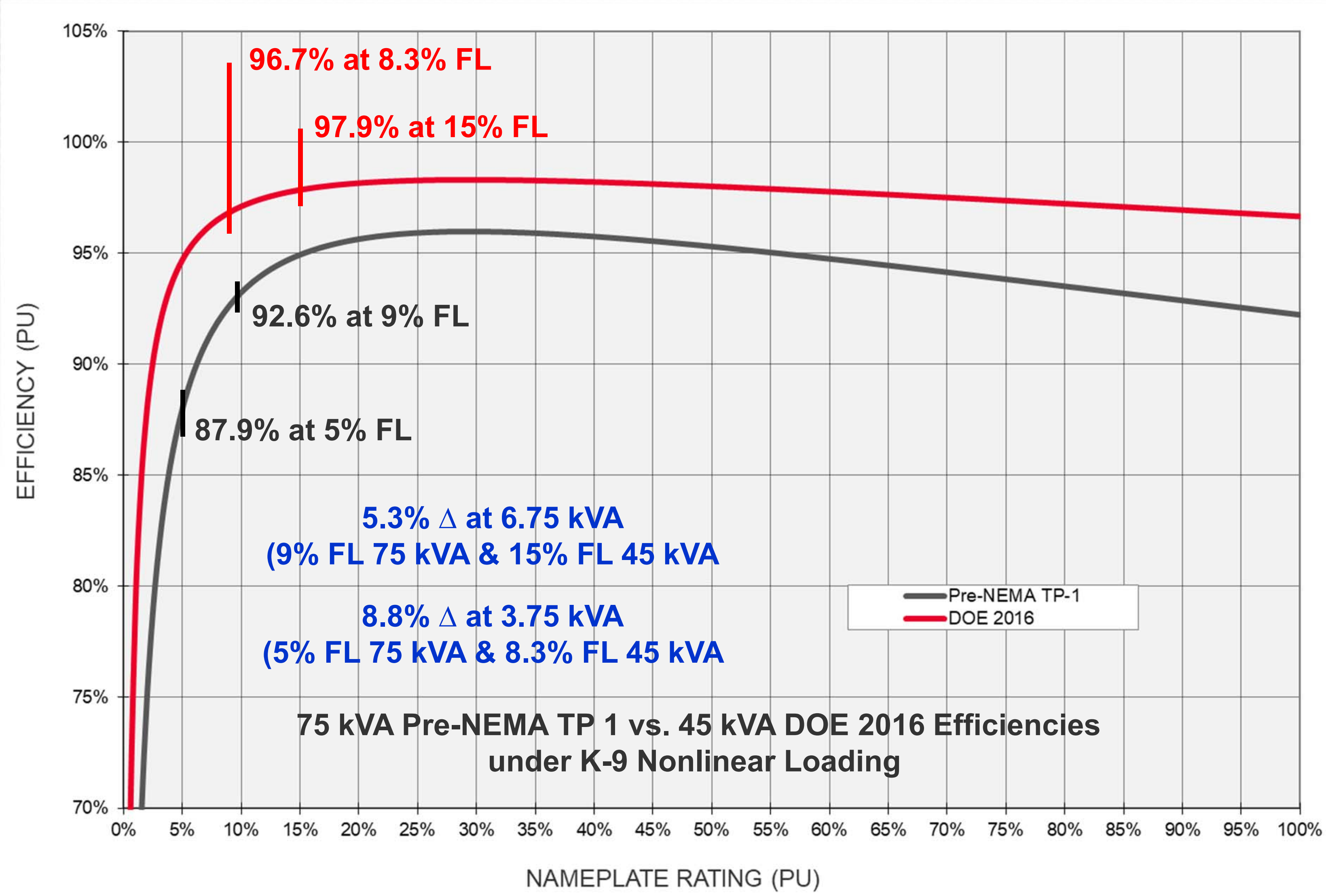
The 'Right Sizing' Replacement Solution



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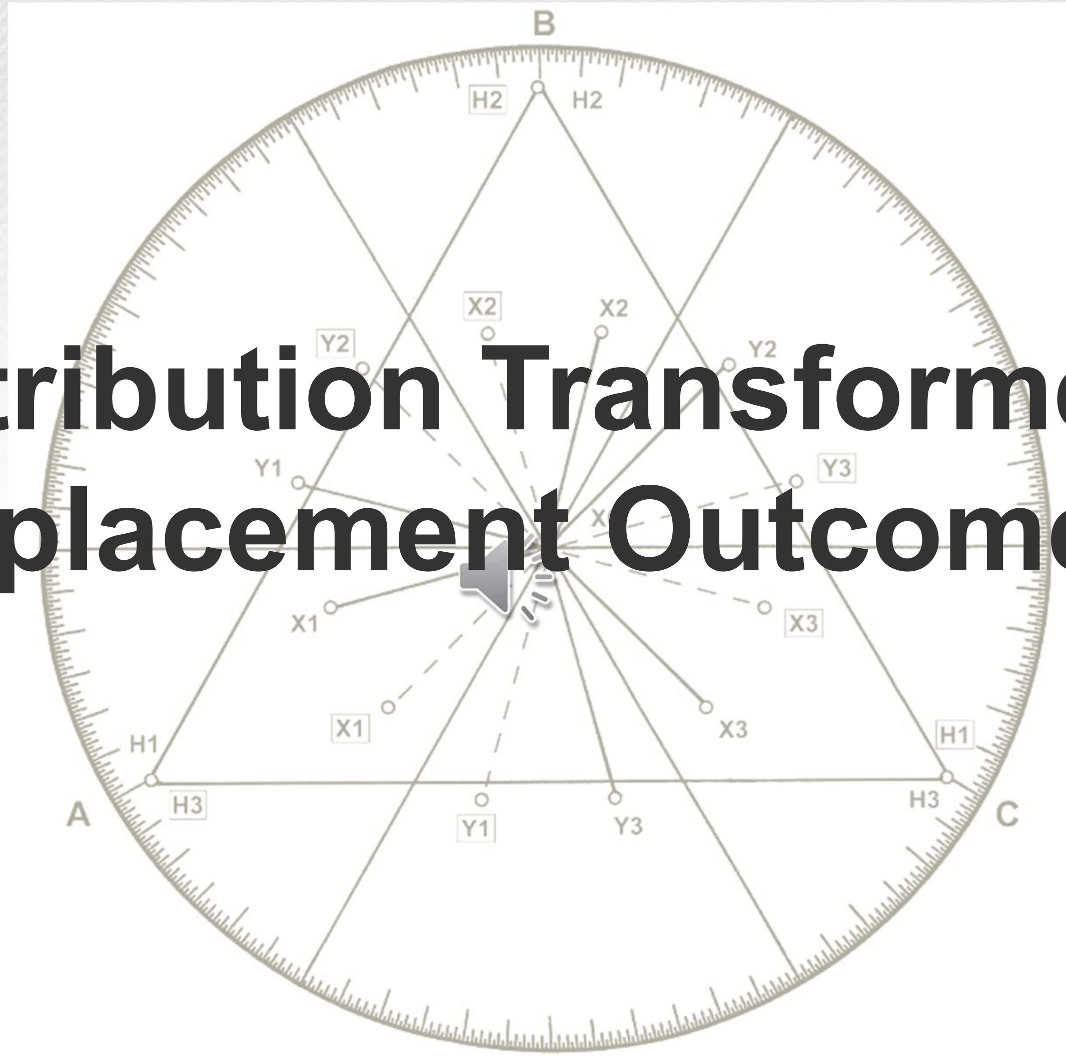

Distribution Transformers Replacement Outcomes

An Energy Efficiency Case Study

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CASE STUDY

Johns Hopkins University
School of Medicine
The Koch Cancer Research Building
Baltimore, MD

Facility Description

Johns Hopkins Medicine, headquartered in Baltimore, Maryland, is an $8 billion integrated global health enterprise and one of the leading health care systems in the United States. Johns Hopkins Medicine unites physicians and scientists of the Johns Hopkins University School of Medicine with the organization's health professionals and the facilities of The Johns Hopkins Hospital and Health System.

- 267,000 square foot building
- Five floors of laboratories
- 10 stories of office space
- 250-seat, high tech auditorium connects this research tower to its twin, the Bunting Blaustein Cancer Research Building
- Mission-Critical Facility
- Completed in 2006

Existing Electrical Distribution System Conditions

- 24 low voltage, dry-type distribution transformers
- 7 year old transformers had pre-NEMA TP-1 efficiencies
- Extremely light electrical loading
- Average load factor was 11.7% of system capacity
- Load-generated harmonic profiles were in a range between K-4 & K-9

Challenge

Significant 'penalty losses'[1] were present in the low voltage distribution system due to oversized distribution transformers. Transformer oversizing is the usual outcome when meeting the requirements of the National Electrical Code. In addition to the higher capital cost of oversizing, the higher operating costs of lightly loaded transformers are significant. 'Penalty losses' were also present in the circuitry because of load-generated harmonic currents. The system's harmonic impedances created significant voltage distortion at the loads.

Over a seven-year period, electronic loads were added to a distribution system that was never designed to supply nonlinear electronic loads.

Solution

PQI was contracted by the Johns Hopkins' Energy Engineer to develop a distribution system solution that would reduce 'penalty losses', increase overall power quality and efficiency, and ensure system-load compatibility.

After confirming each transformer's maximum and average load factors, and harmonic current load profile, PQI's engineers optimized the system by replacing the twenty-four oversized, inefficient transformers with rightsized, ultra-efficient harmonic mitigating transformers. The transformer downsizing was made in accordance with CSA C802.4 and nationalgrid® guidelines.

To maximize payback and return-on-investment we were limited in downsizing to one standard kVA rating. This limitation, which was far less than recommended by CSA or nationalgrid® guidelines, was necessary to avoid the need to change the protective circuit breakers and cabling.

894,977 kWh total energy savings

$89,498 total financial savings

$43,382 energy savings due to transformer replacements

$46,116 energy savings due to harmonic current reduction in the circuitry and voltage distortion improvement at the loads

9.4% energy cost reduction

2.1 years project payback

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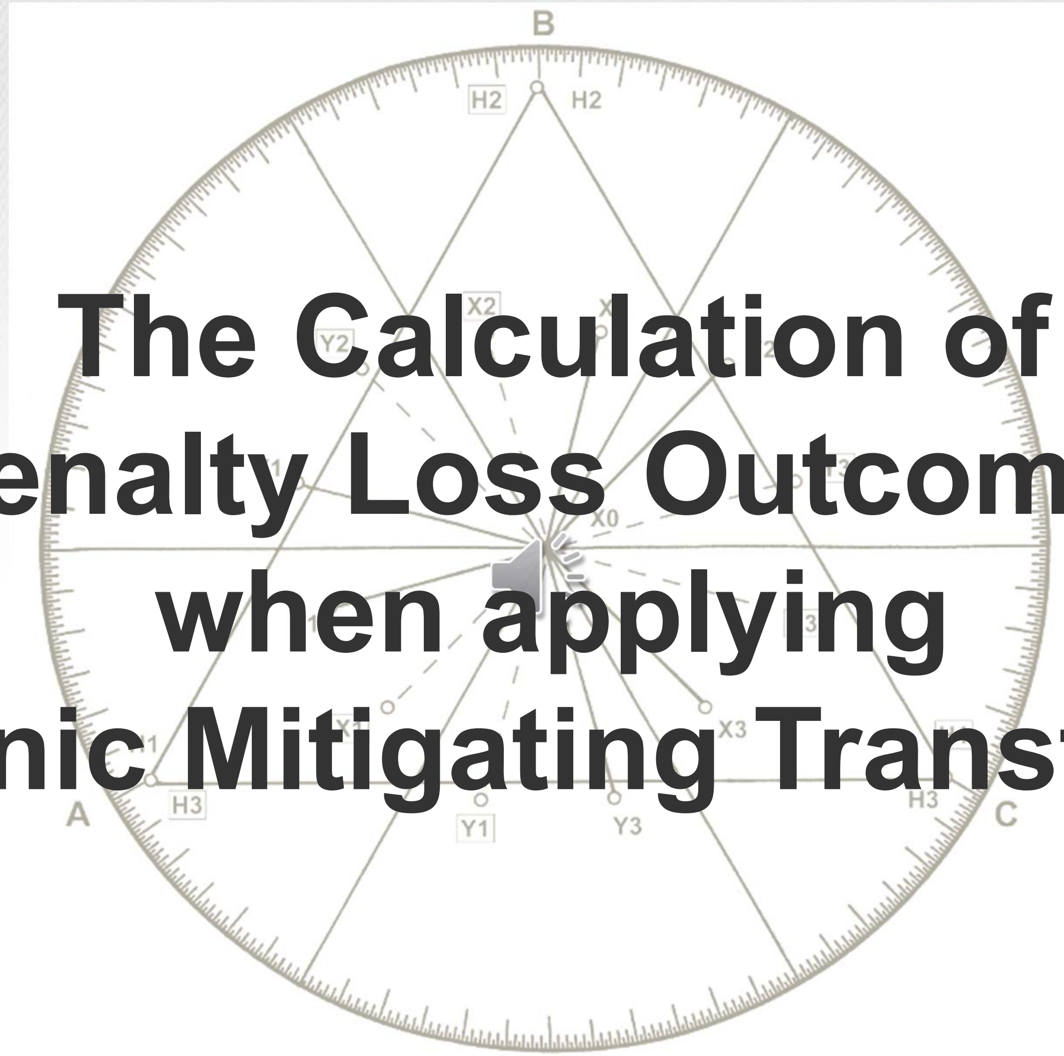


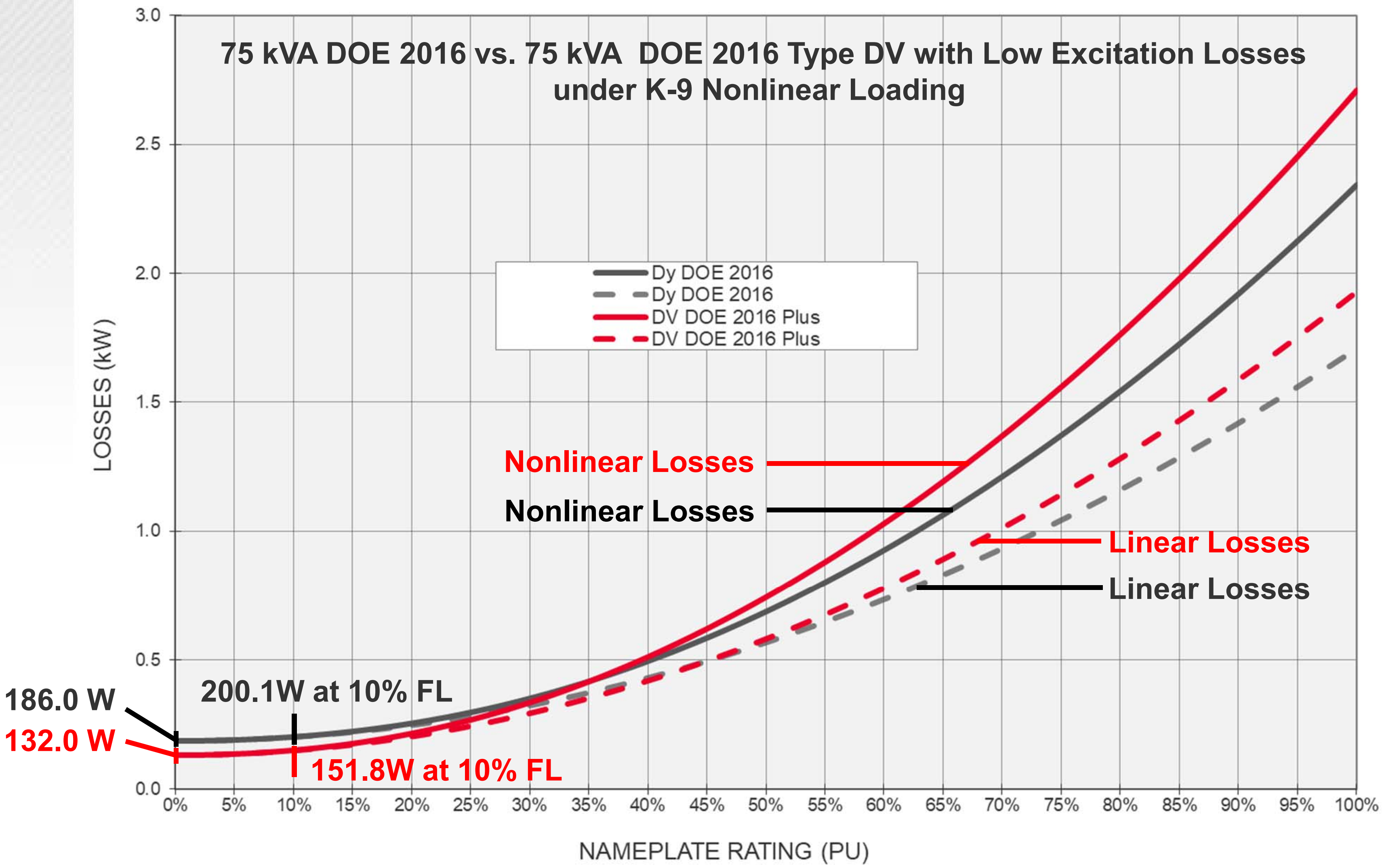
The Calculation of Penalty Loss Outcomes when applying Harmonic Mitigating Transformers

U.S. DOE and Transformer Efficiency

kVA Rating	NEMA TP 1-2002 %	DOE 2016 %	2002 - 2016 % Improvement
15	97.00	97.89	0.92
30	97.50	98.23	0.75
45	97.70	98.40	0.72
75	98.00	98.60	0.61
112.5	98.20	98.74	0.55
150	98.30	98.83	0.54
225	98.50	98.94	0.49
300	98.60	99.02	0.43
500	98.70	99.14	0.45
750	98.80	99.23	0.54
1000	98.90	99.28	0.38
			0.58 Average

PQI Type DV Distribution TransFilter™

PQI Type DV Distribution TransFilter™



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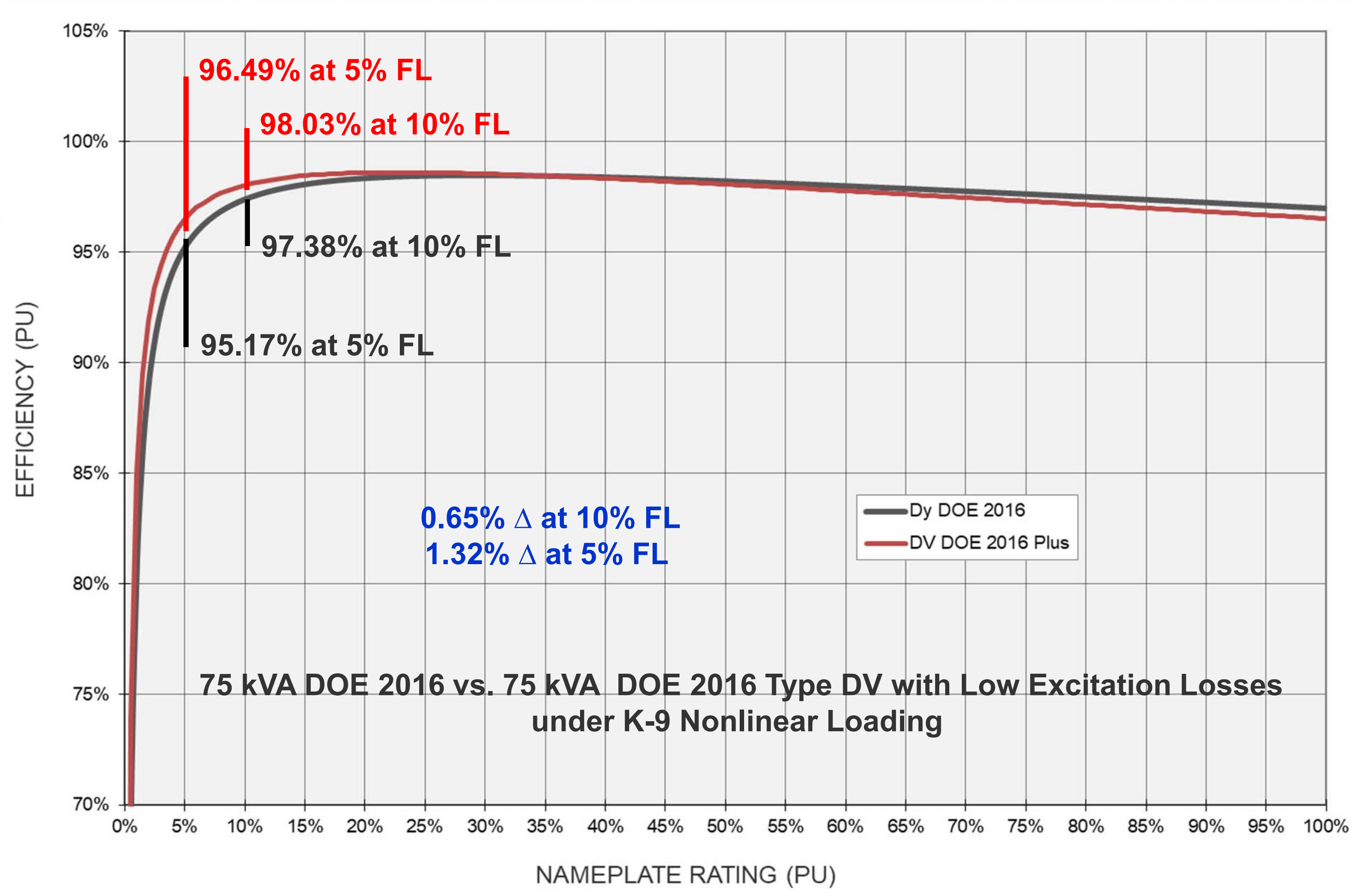
PQI Type DV Distribution TransFilter™



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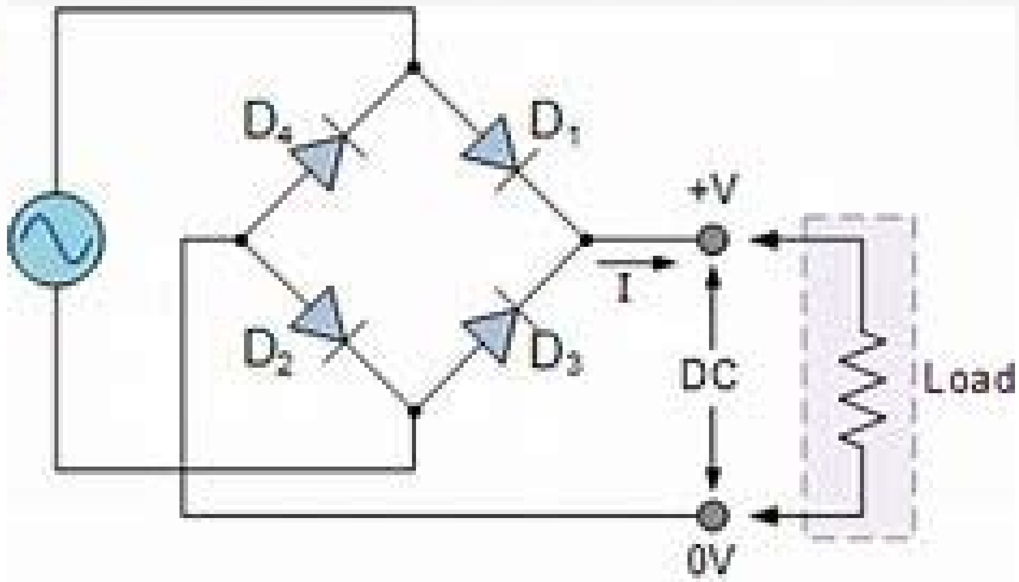
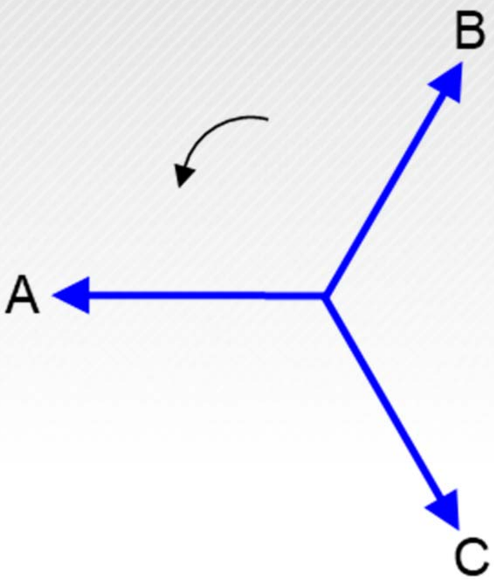
Single-Phase Nonlinear Loads connected Phase-to-Neutral in Three-Phase, Four-Wire Systems

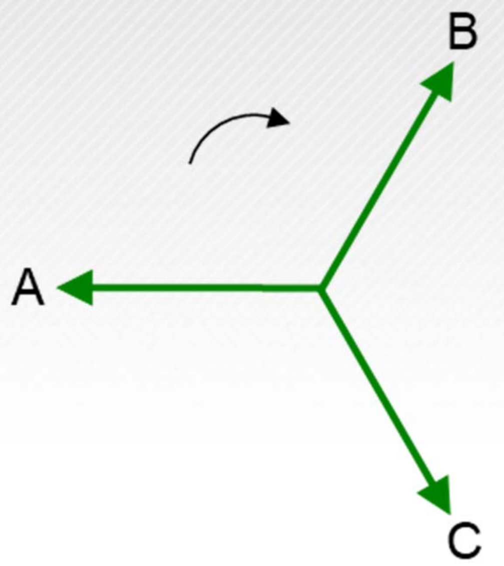
Switch-Mode Power Supplies



Harmonic Currents



Positive Sequence
Harmonic Currents
(i.e. 1^{st} , 7^{th} , 13^{th} , 19^{th} , 25^{th} , --)

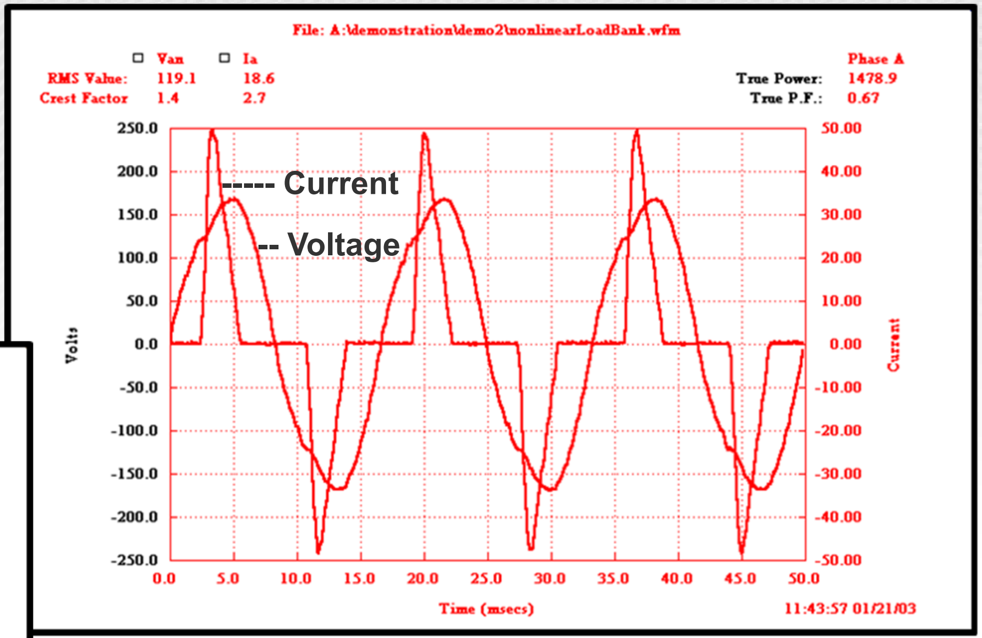


Negative Sequence
Harmonic Currents
(i.e. 5^{th} , 11^{th} , 17^{th} , 23^{rd} , 27^{th} --)

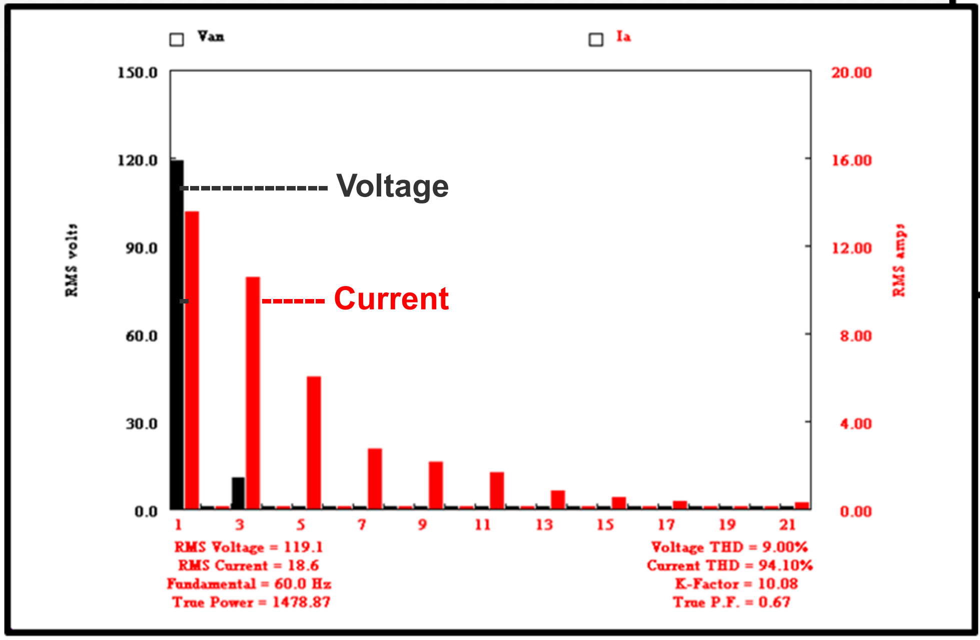
Zero Sequence
Harmonic Currents
(i.e. 3^{rd} , 9^{th} , 15^{th} , 21^{st} , 28^{th} --)

Harmonic Current Measurements

Phase-to-Neutral Connected Switch-Mode Power Supply's Harmonic Profiles



Voltage & Current Waveforms



Harmonic Voltage & Current Magnitudes

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IEEE Harmonic Current Values

IEEE 519-1992, Table 4.3
Spectrum of Typical Switch-Mode Power Supply

Harmonic	Magnitude	Harmonic	Magnitude
1	1.000	9	0.157
3	0.810	11	0.024
5	0.606	13	0.063
7	0.370	15	0.079

–Sequence

–Positive
–Negative
–Zero

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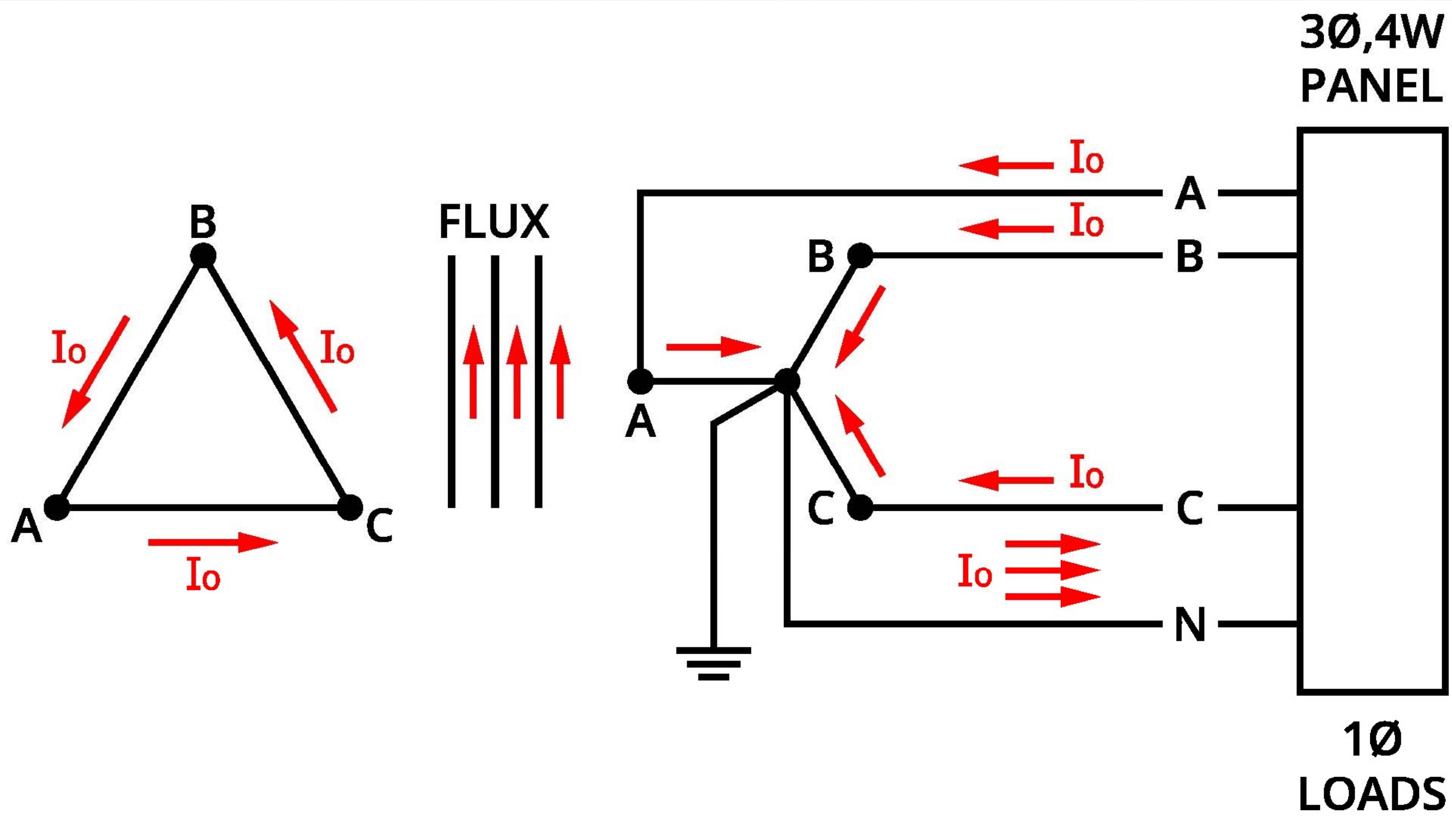
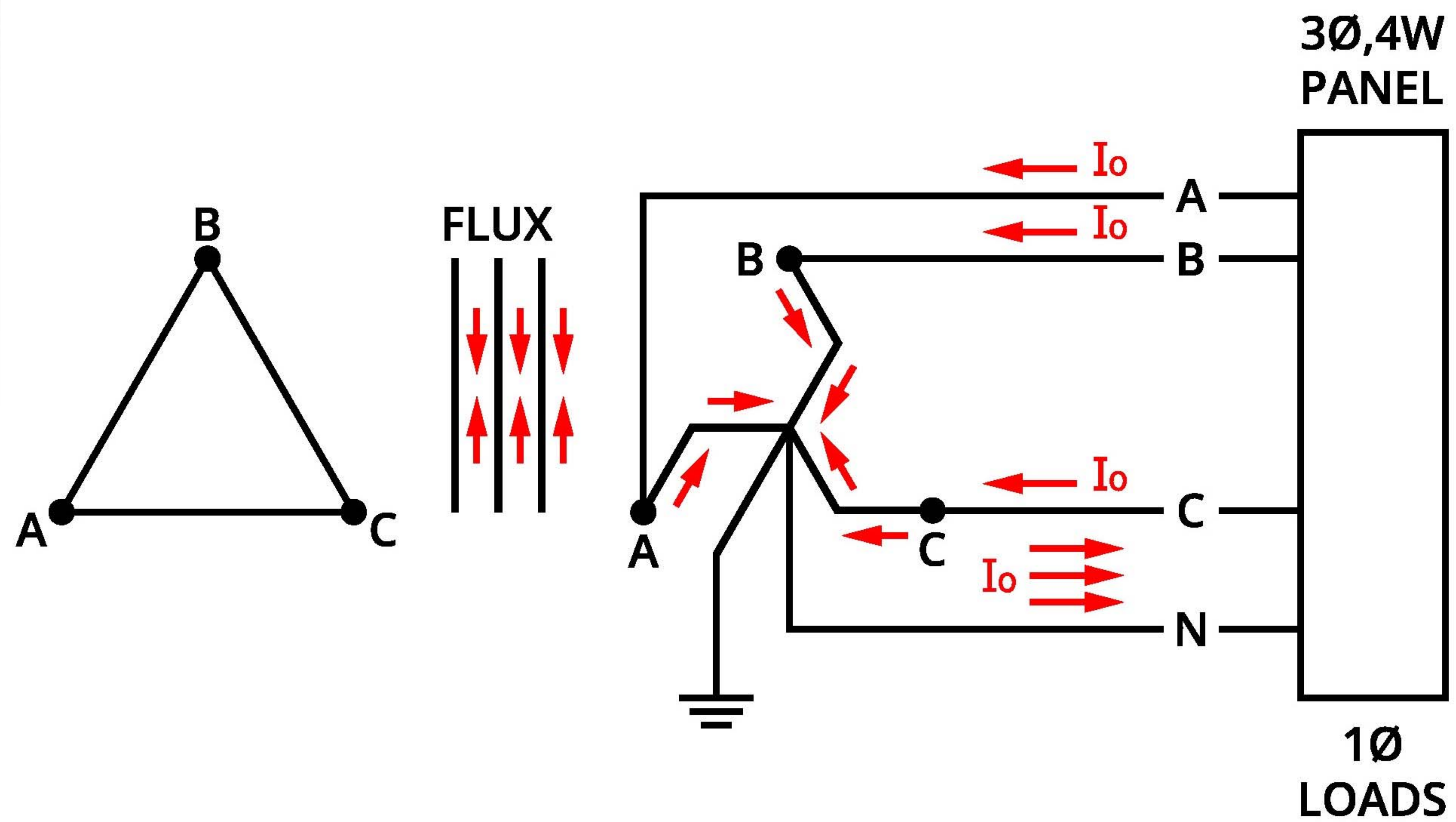
The Zero-Sequence Transformer Problems



The Zero-Sequence Transformer Solution



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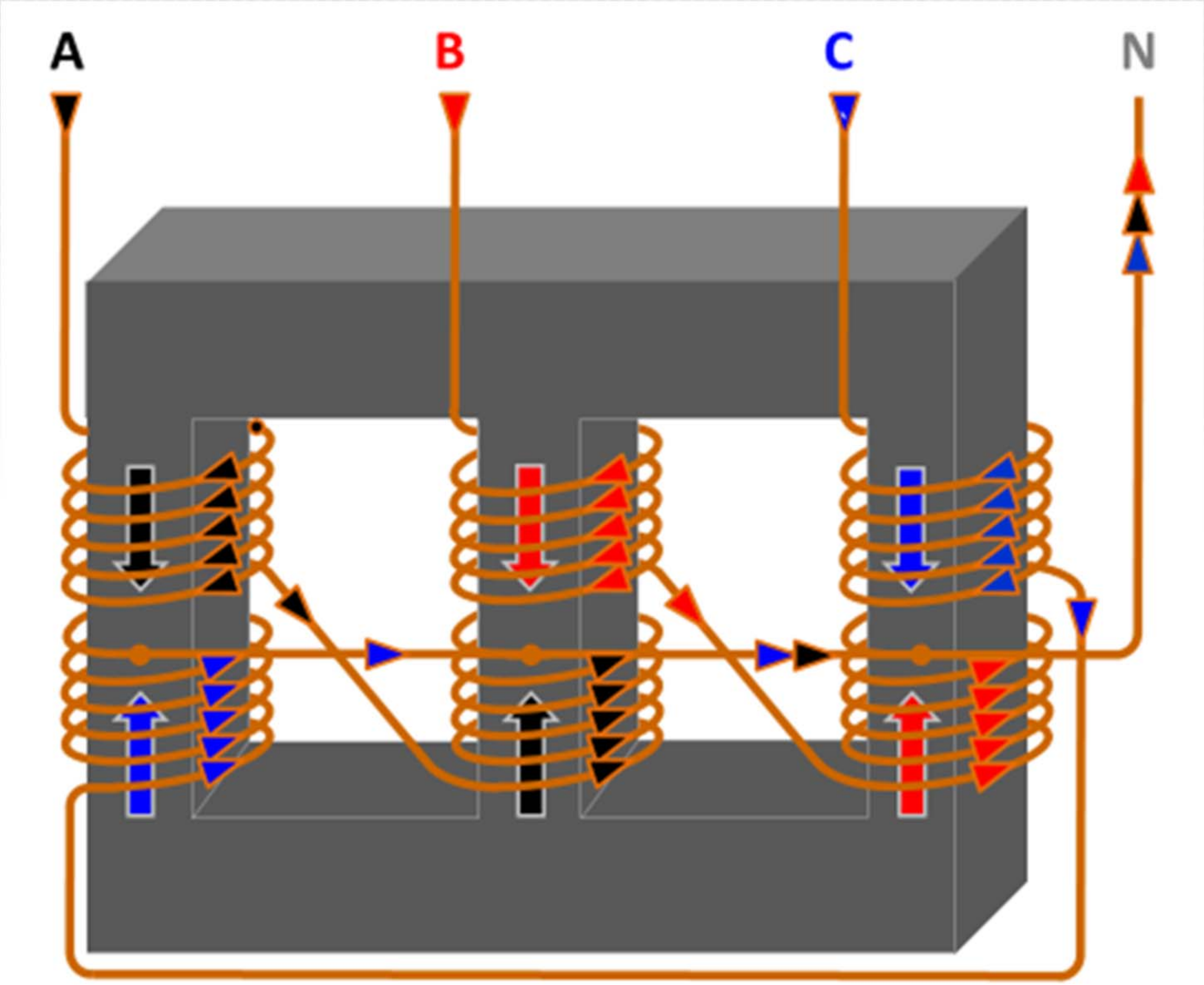
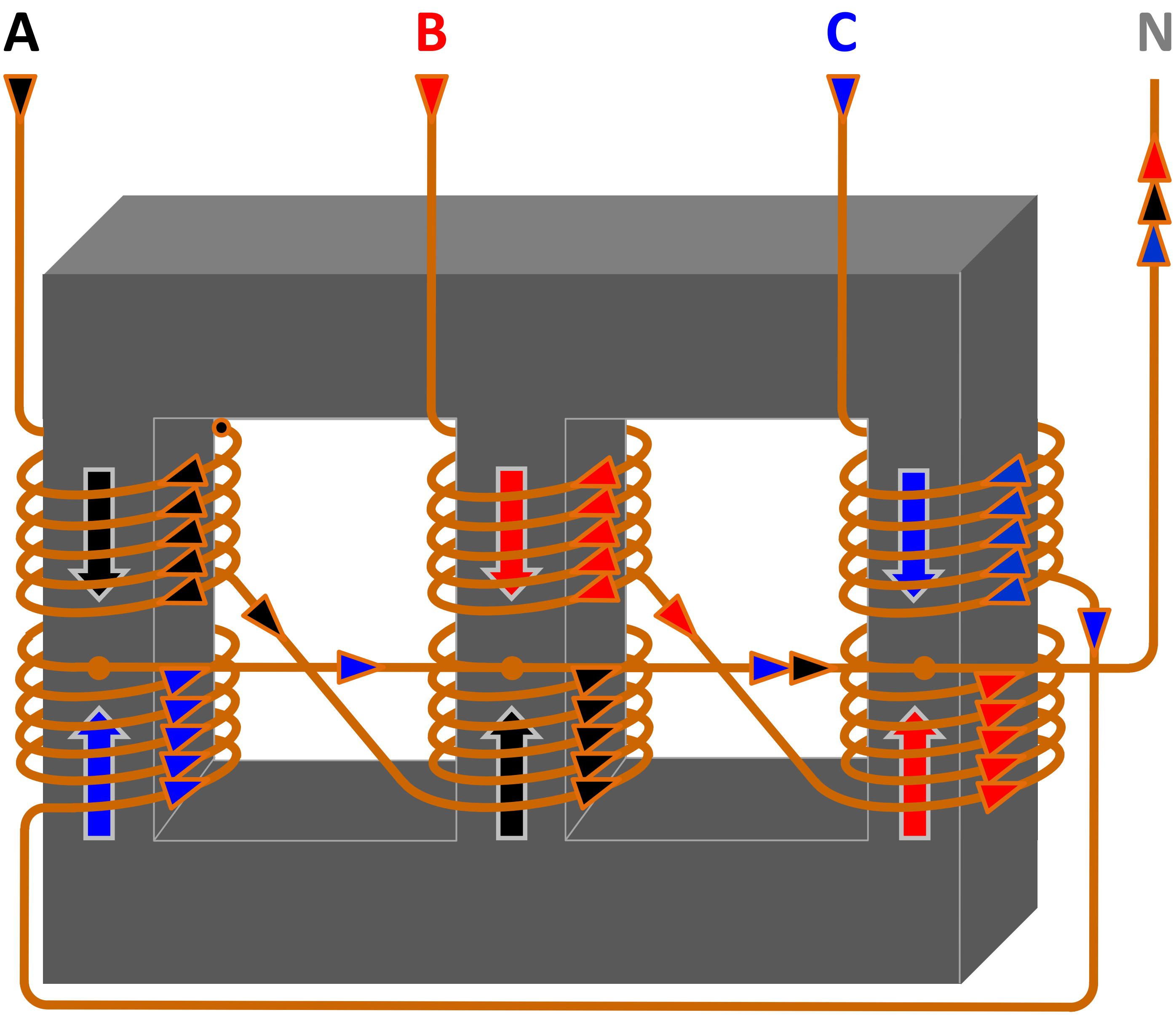
The Zero-Sequence Solution



The Zig-Zag Secondary – How Does it Work?



IEEE Std. 519-1992, Chapter 6

6. Effects of Harmonics

6.1 General. The degree to which harmonics can be tolerated is determined by the susceptibility of the load (or power source) to them. The least susceptible type of equipment is that in which the main function is in heating, as in an oven or furnace. In this case, the harmonic energy generally is utilized and hence is quite completely tolerable. The most susceptible type of equipment is that whose design or constitution assumes a (nearly) perfect sinusoidal fundamental input. This equipment is frequently in the categories of communication or data processing equipment. A type of load that normally falls between these two extremes of susceptibility is the motor load. Most motor loads are relatively tolerant of harmonics.

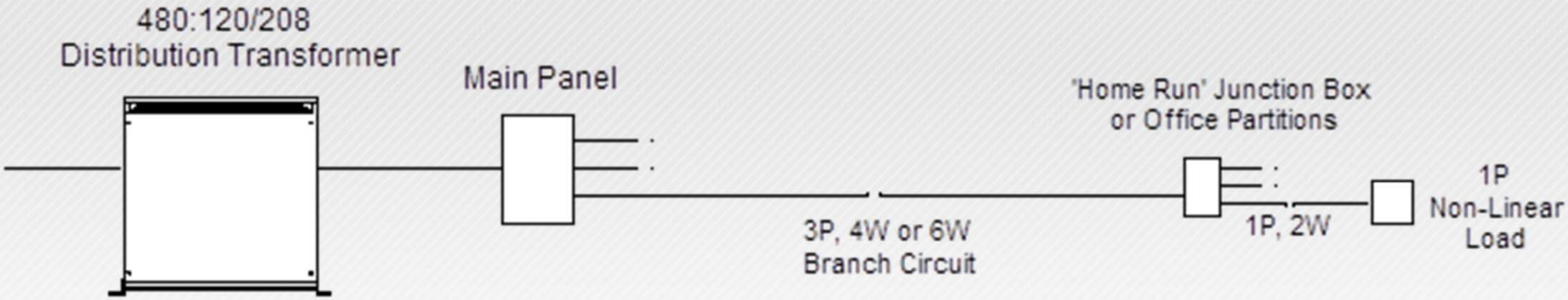
IEEE Std. 519-1992, Chapter 6

6. Effects of Harmonics

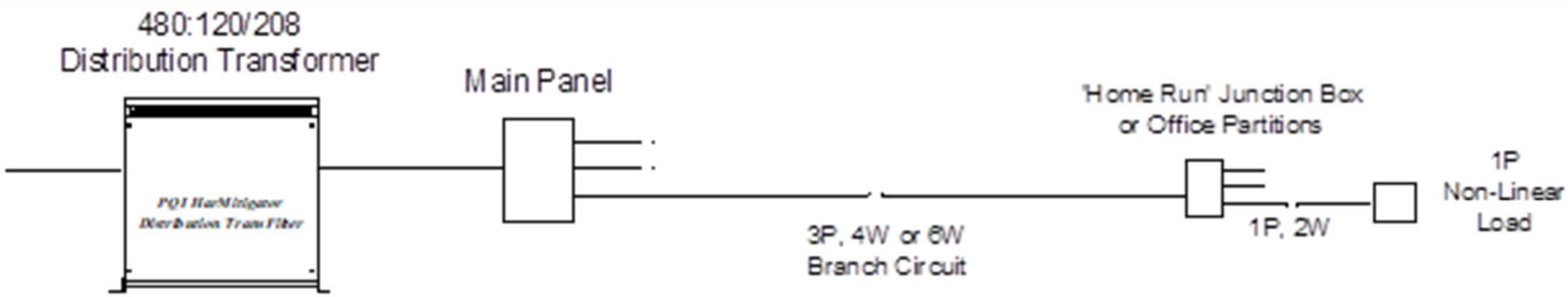
6.6 Electronic Equipment. Power electronic equipment is susceptible to misoperation caused by harmonic distortion. This equipment is often dependent upon accurate determination of voltage zero crossings or other aspects of the voltage wave shape. Harmonic distortion can result in a shifting of the voltage zero crossing or the point at which one phase-to-phase voltage becomes greater than another phase-to-phase voltage. These are both critical points for many types of electronic circuit controls, and misoperation can result from these shifts.

Other types of electronic equipment can be affected by transmission of ac supply harmonics through the equipment power supply or by magnetic coupling of harmonics into equipment components. Computers and allied equipment such as programmable controllers frequently require ac sources that have no more than a 5% harmonic voltage distortion factor, with the largest single harmonic being no more than 3% of the fundamental voltage. Higher levels of harmonics result in erratic, sometimes subtle, malfunctions of the equipment that can, in some cases, have serious consequences. Instruments can be affected similarly, giving erroneous data or otherwise performing unpredictably. Perhaps the most serious of these are malfunctions in medical instruments. Consequently, many medical instruments are provided with line-conditioned power. Less dramatic interference effects of harmonics can occasionally

Transformer Ratings ≤ 75kVA



Standard or K-Factor Rated



Type: DV0, DV30, DV15 or DV45 (Single Output)
Type: DV0/30 or DV15/45 (Dual Output)

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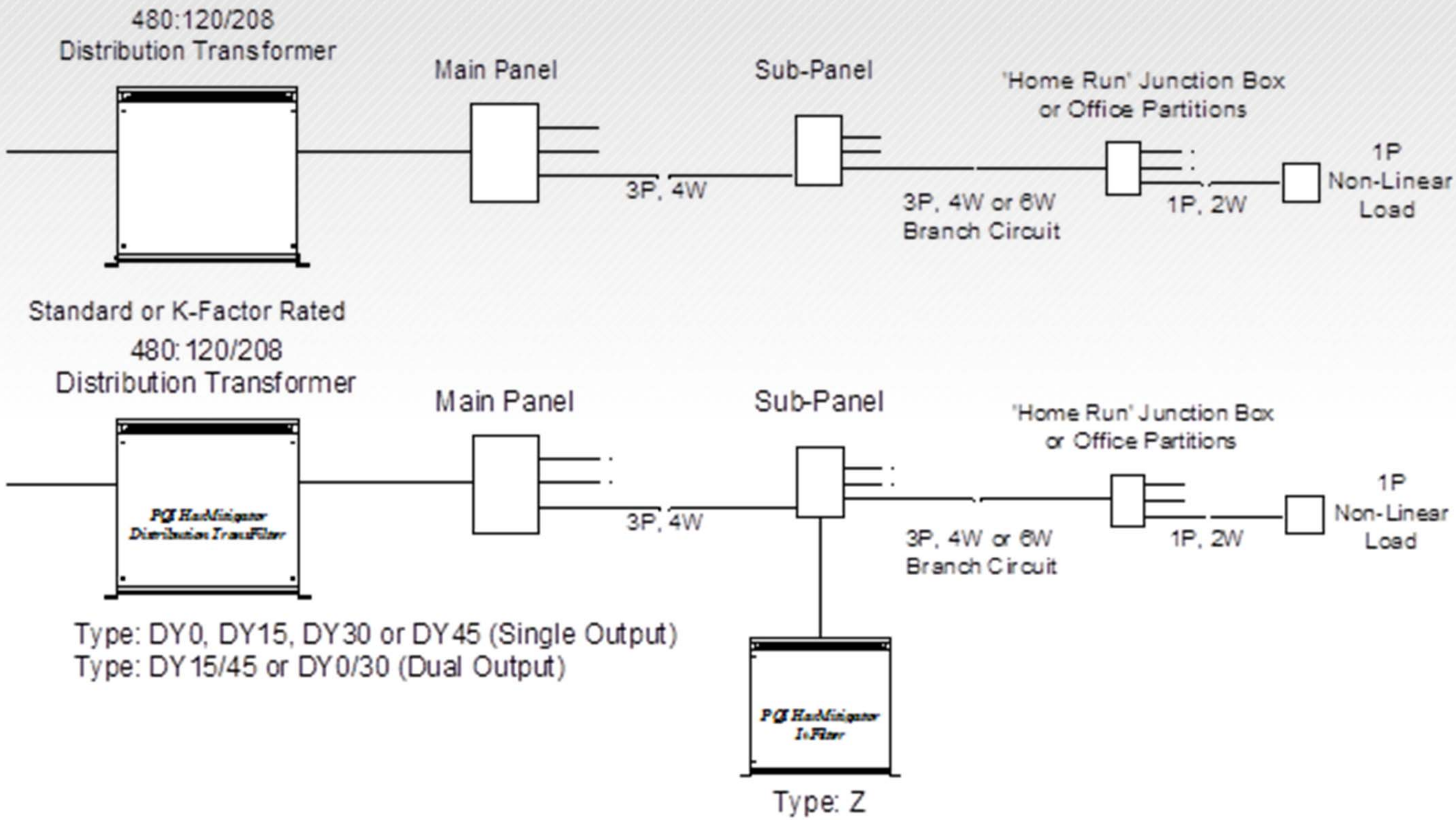
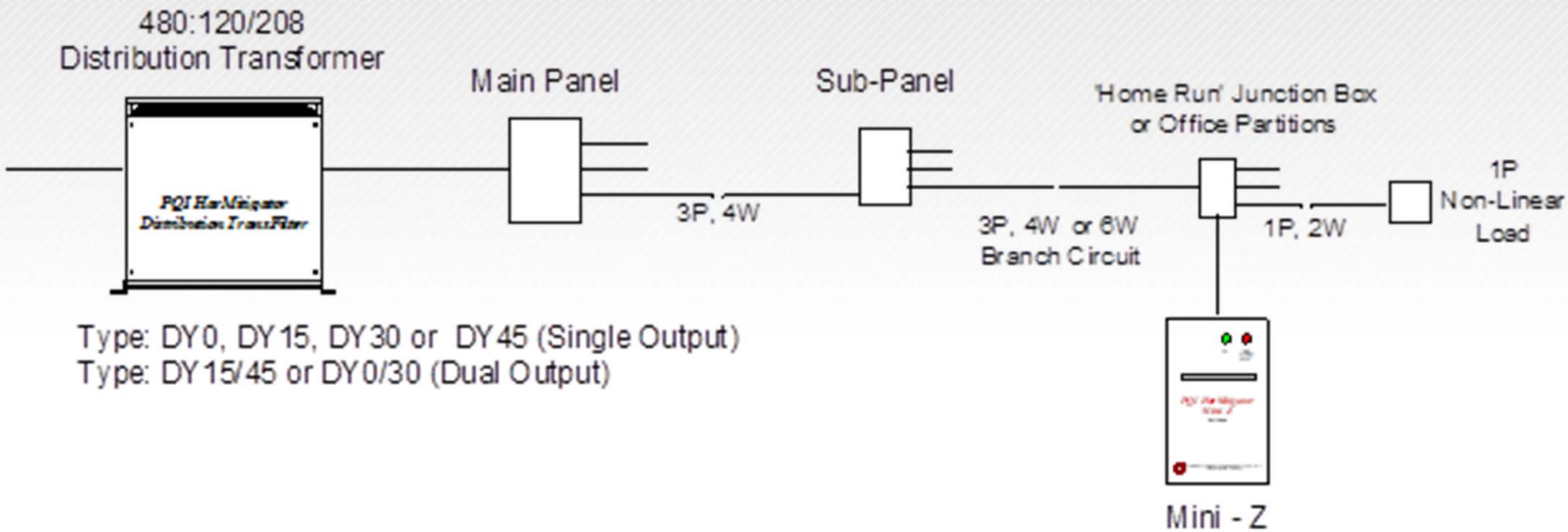
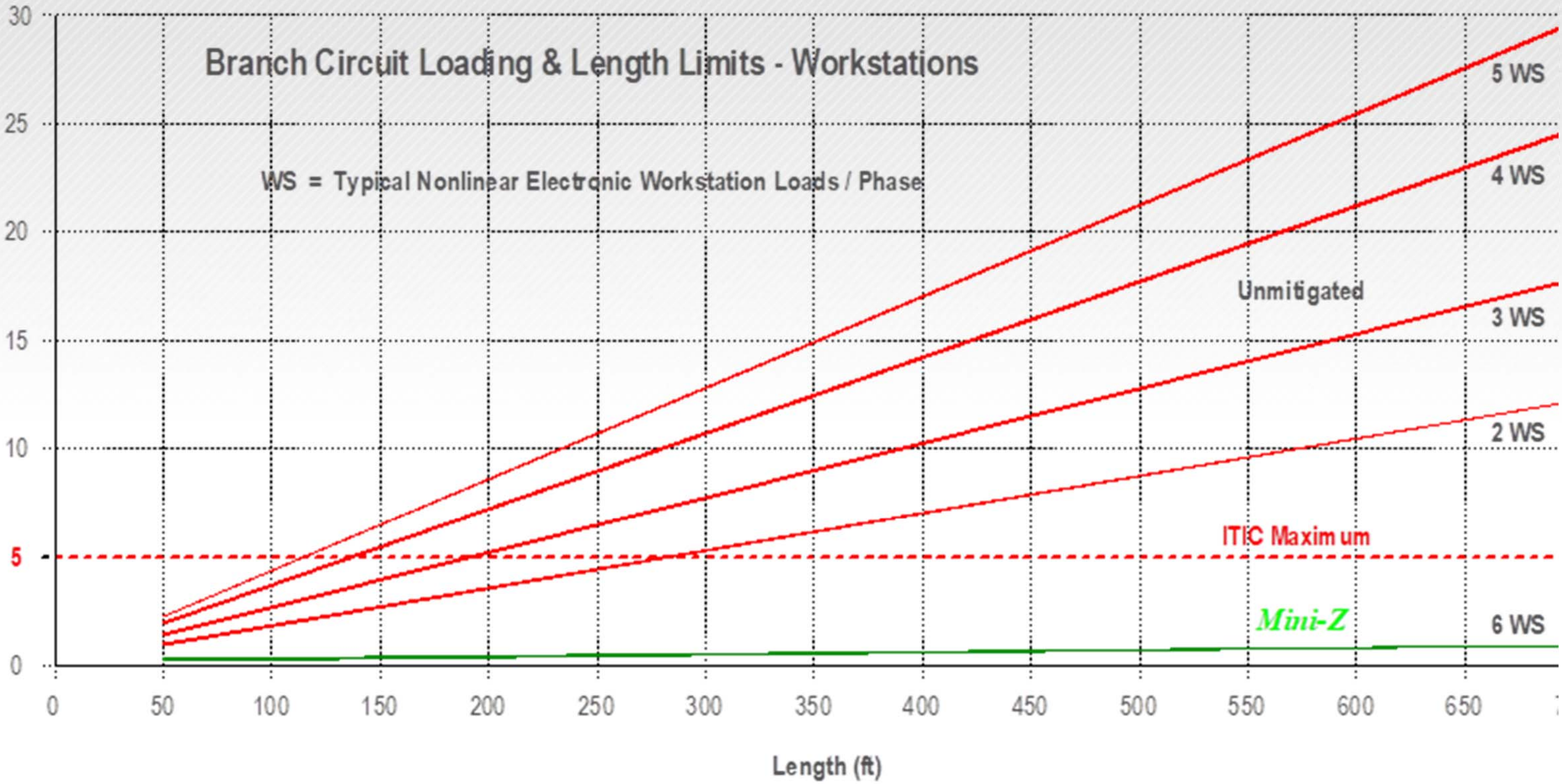
Transformer Ratings ≥ 75kVA



Transformer Ratings ≤ 75kVA



Neutral-to-Ground Voltage Limits



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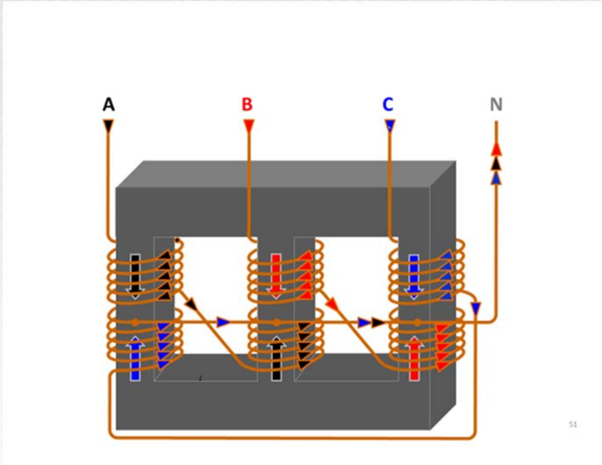
200’ 120/208V Feeder CIrcuit



Source	*Values*	*without I_0Filter™*	*with I_0Filter™*
Effective	47.3kW	904.0W	904.0W
Reactive	3.43kVA$_R$	4.7W	6.4W
Unbalance	20.4kVA	164.0W	4.8W
Distortion	1.59kVA	1.5W	0.6W
Neutral	45.4A	138.0W	3.2W
Total ‘Penalty Losses’		308.2W	15.0W [95% Reduction]

The Positive- & Negative-Sequence Solution

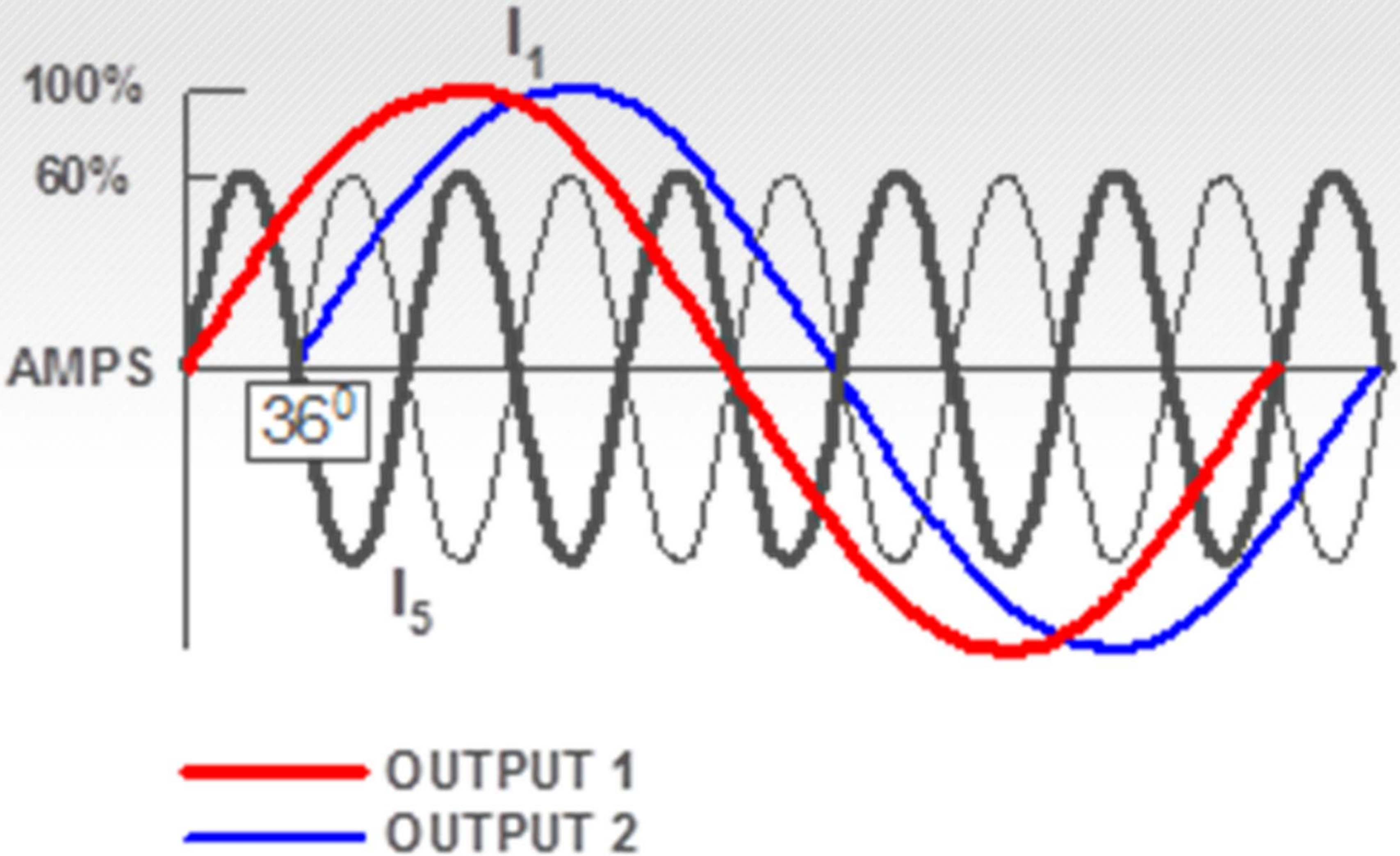
$$\text{Required } Ø\angle° = \frac{180° \text{ @ } 60\text{Hz}}{H} = 180° \text{ @ } H$$

where:

Ø∠° - The angle, in electrical degrees @ 60Hz, which is required between two separate sources of a particular harmonic current, in order to create a 180° phase-shift at that harmonic frequency.

H – The harmonic number of the targeted harmonic frequency.

The Positive- & Negative-Sequence Solution



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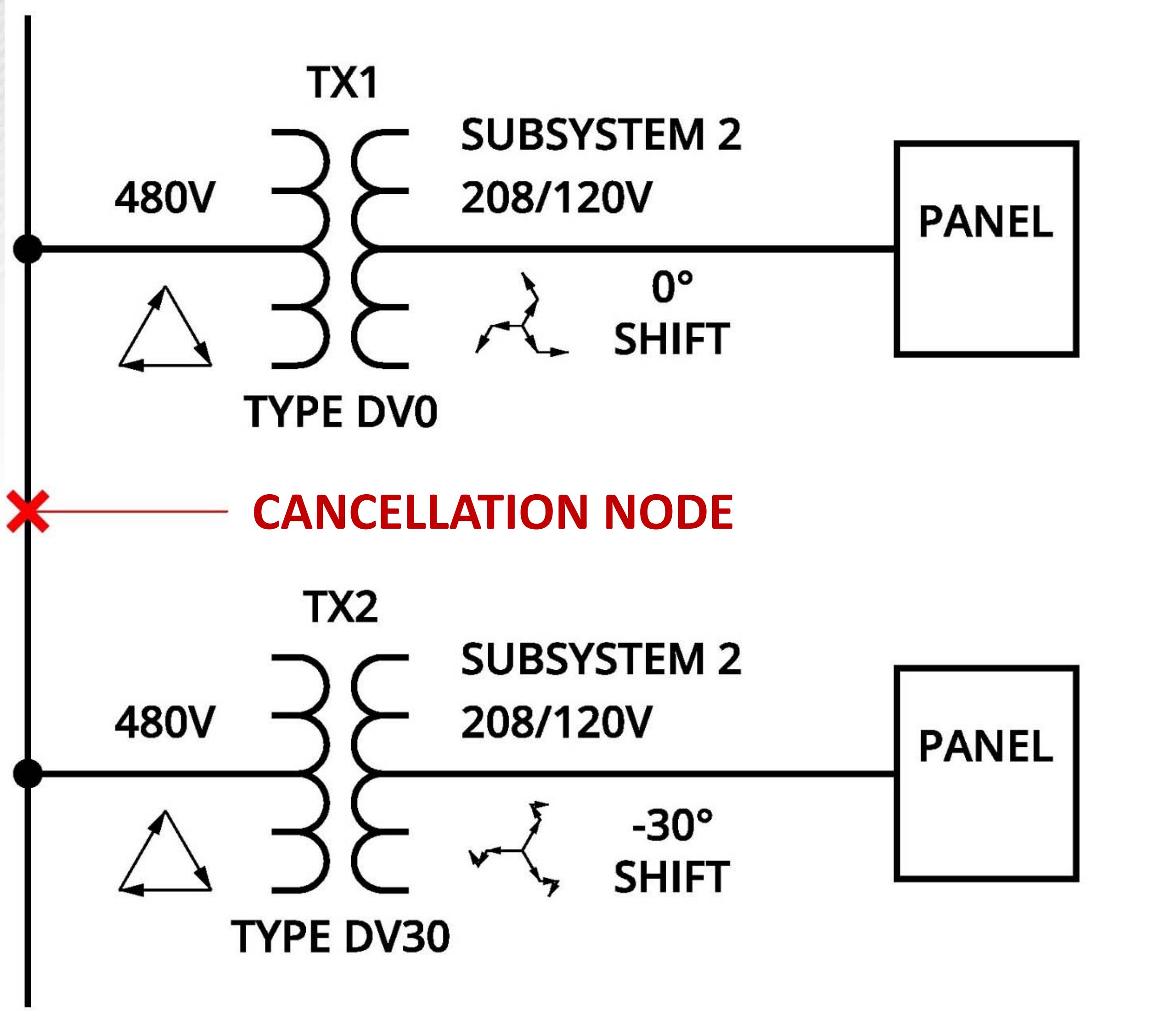
The Positive- & Negative-Sequence Solution



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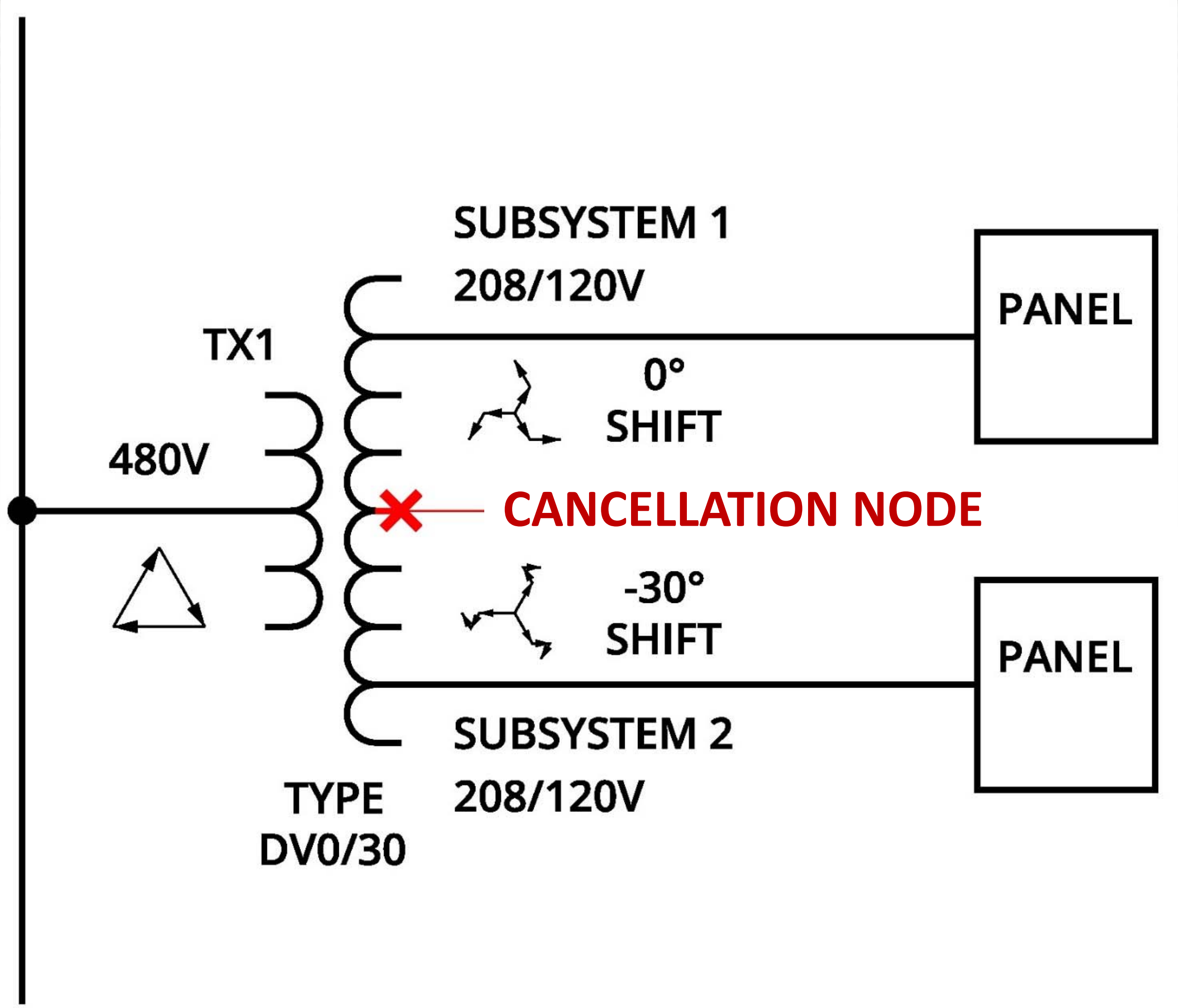
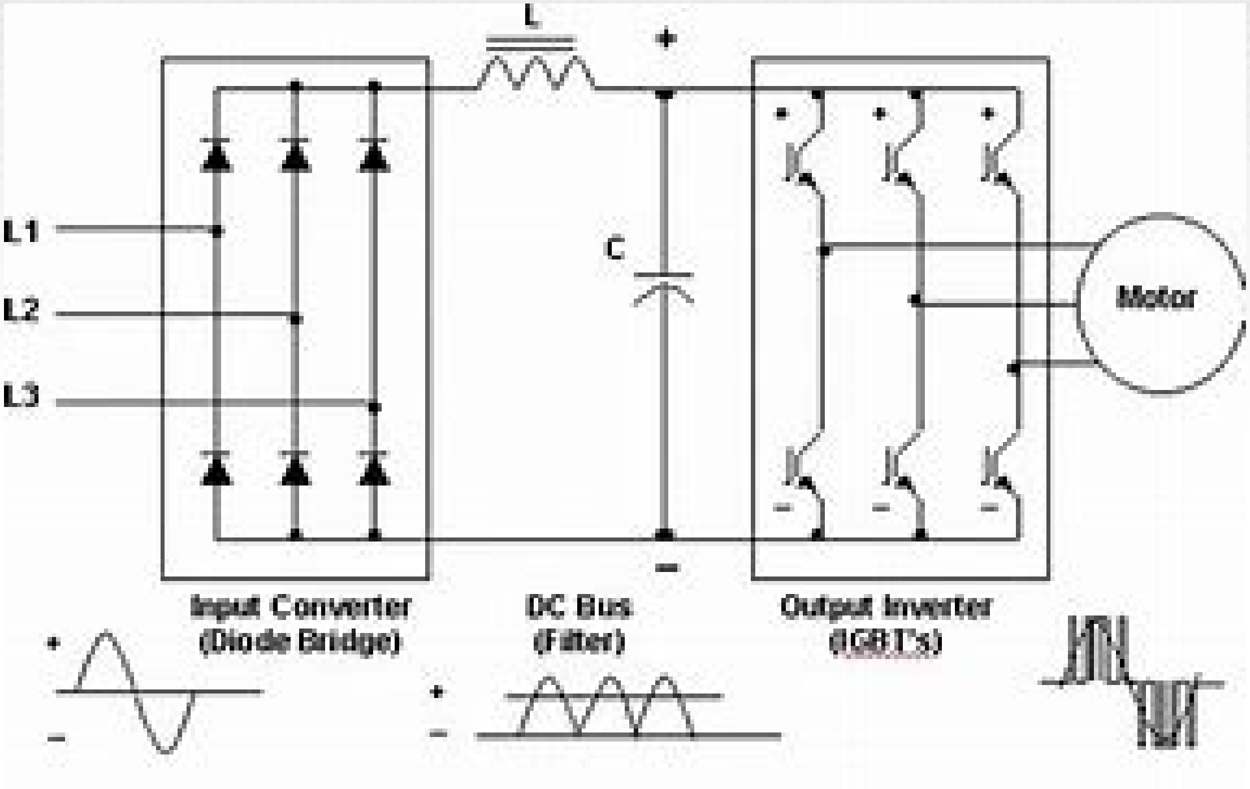
The Positive- & Negative-Sequence Solution

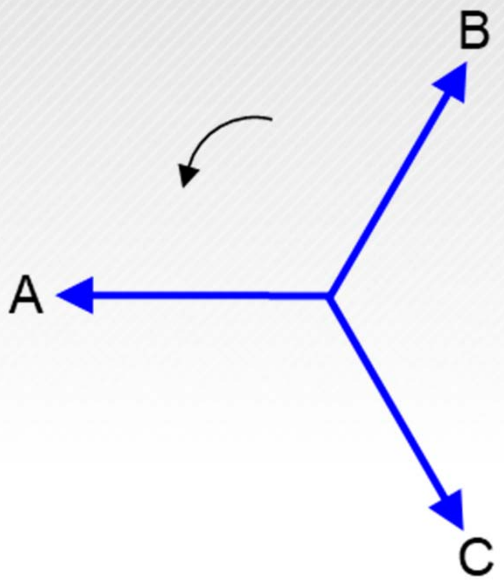


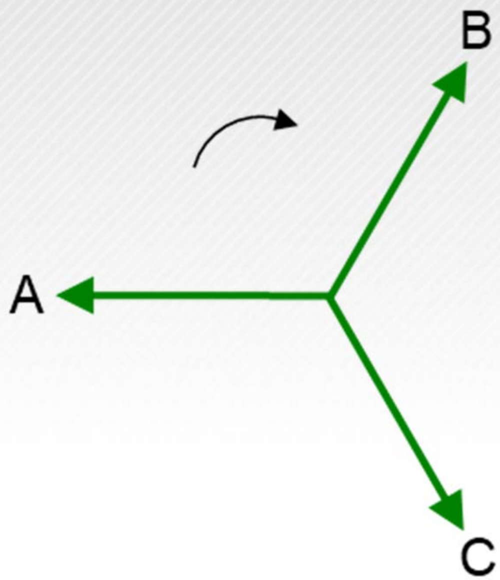
Three-Phase Nonlinear Loads connected to a Three-Phase, Three- or Four-Wire System

A Closer Look at the Harmonic Problem



Positive- & Negative-Sequence



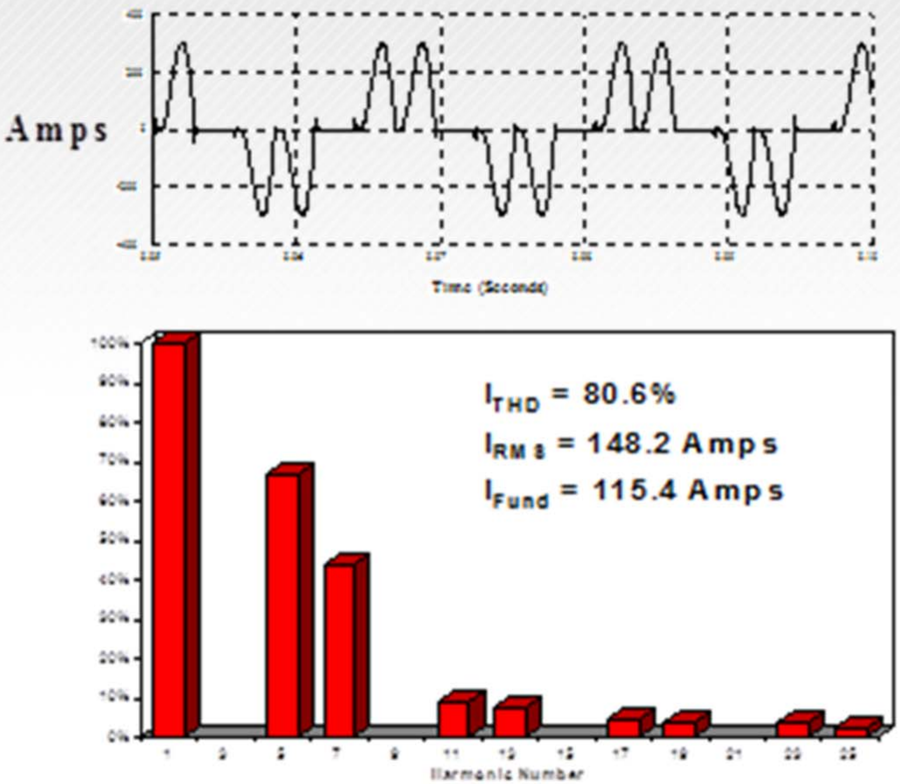


Positive Sequence Harmonic Currents
(i.e. 1^{st} , 7^{th} , 13^{th} , 19^{th} , 25^{th} , --)

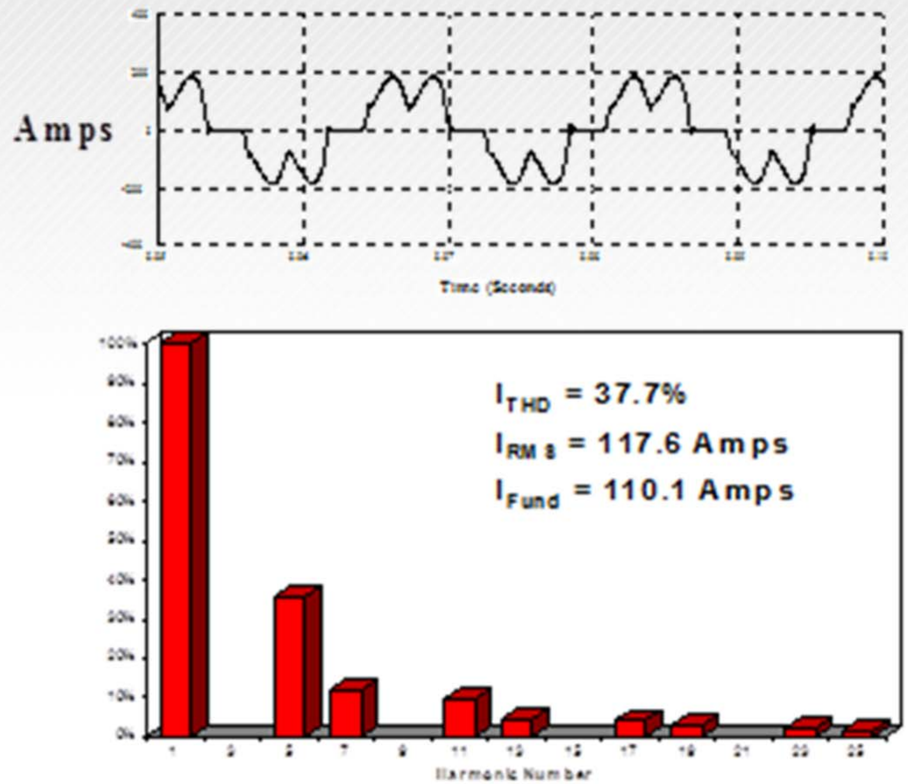
Negative Sequence Harmonic Currents
(i.e. 5^{th} , 11^{th} , 17^{th} , 23^{rd} , 29^{th} --

Positive- & Negative-Sequence

TYPE 1 Waveform
100 HP PWM ASD - No Choke



TYPE 2 Waveform
100 HP PWM ASD - 3% Choke



Harmonic Current Magnitudes

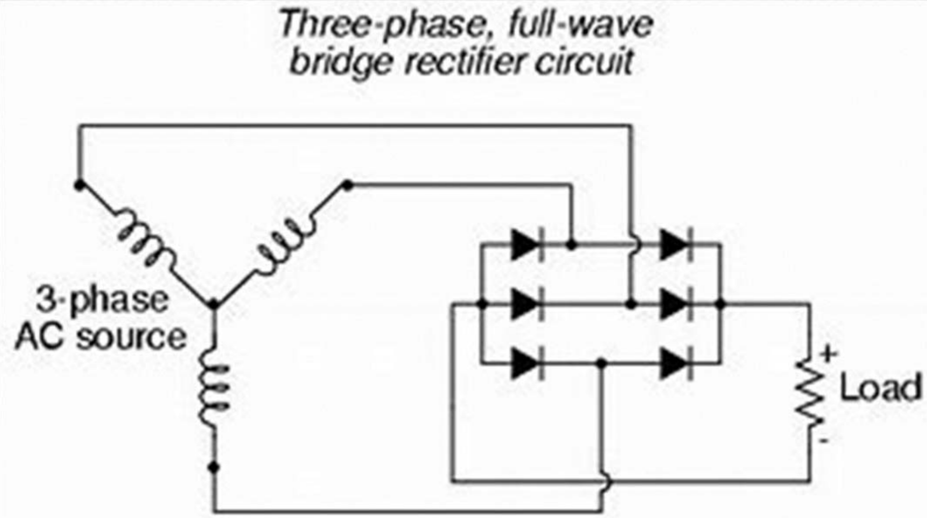
IEEE 519-1992
Spectrum of Typical 6-Pulse Rectifier

Harmonic	Magnitude	Harmonic	Magnitude
1	1.000	9	0.000
3	0.000	11	0.045
5	0.175	13	0.029
7	0.110	15	0.000

– **Sequence**

- –Positive
- –Negative
- –Zero

A 30MW, 150,000A DC Cell-Line



150,000A DC Sodium Chlorate Cell Line

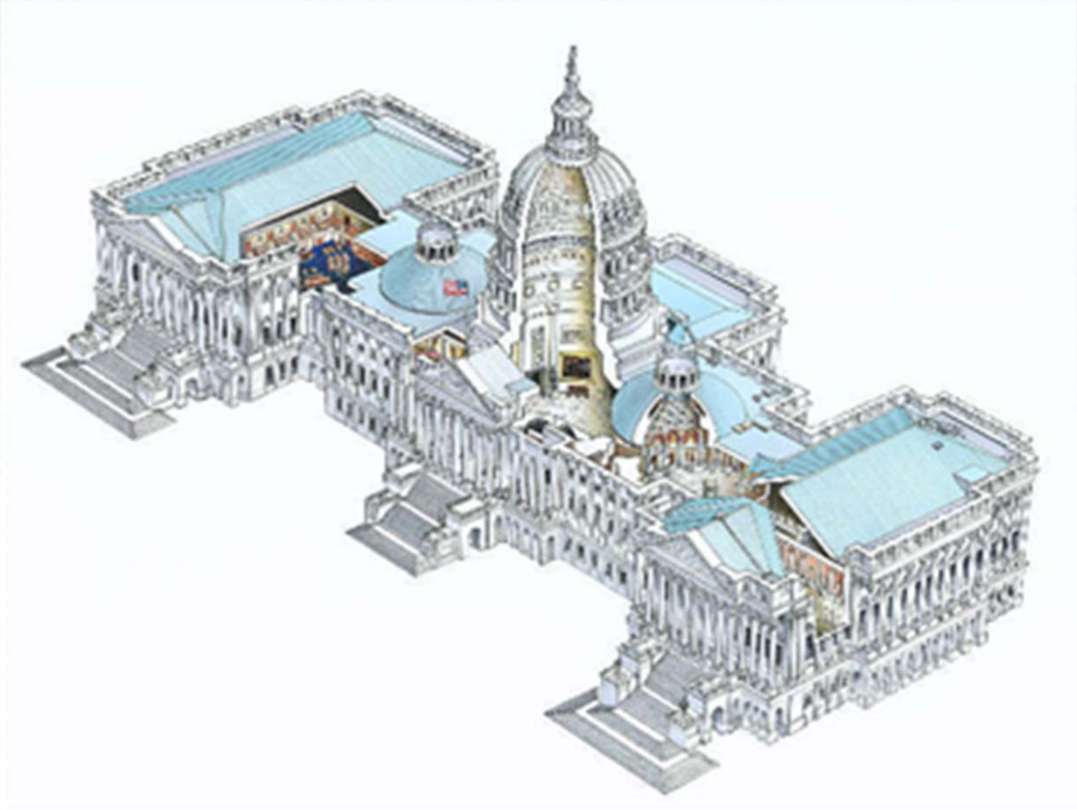
Distribution & Power TransFilters™

Low Voltage Dry-Type
PQI Type DY

Medium Voltage Dry-Type
PQI Type PY
VPI (Vacuum Pressure Impregnated) & Cast Coil

Medium Voltage
Dry-Type Enclosure

Measurement & Verification per DOE



**The US Capital Building
Washington, DC**

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THANK
YOU