

INSIGHT

WHY ELECTRICAL LOSSES MATTER

The Hidden Cost of Current, Reactive Power, Harmonics and Power Quality in Modern Electrical Systems

MASTER REFERENCE

A practical engineering and customer-education guide: where electrical losses occur, why they matter, how to measure them, and how power-quality improvement can reduce avoidable electrical-system burden.

Core engineering relationship

$$\text{Power loss} = I^2R = \text{Watts}$$

System framework

$$\text{Facility input power} = \text{useful process power} + \text{electrical losses}$$

Management objective

Measure → Correct → Verify → Improve

Prepared as a consolidated reference for customer education, engineering discussions, training and MPTS applications.

WHERE THE INPUT kW GOES**FACILITY INPUT**

kW from utility / source

USEFUL PROCESS

kW doing productive work

ELECTRICAL LOSSES

kW dissipated as heat / loss

$$P_{\text{facility}} = P_{\text{useful}} + P_{\text{loss}}$$

The loss term is measured in W or kW. Over time, those kW losses accumulate into kWh consumed.

WHY CURRENT MATTERS: I²R

Current	100%	90%	80%
I ² R loss component	100%	81%	64%

Example: if current through the same resistance falls 20%, the I²R component falls to $0.8^2 = 0.64$, or 36% lower. This is a reduction in that loss component—not automatically a 36% reduction in total facility kWh.

Loss mechanism	What creates it	Electrical result
Conductor / winding I ² R	RMS current through resistance	Real power dissipated as heat (W/kW)
Transformer core	Hysteresis and eddy currents	Real no-load/core loss (W/kW)
Harmonic-related	Additional RMS/high-frequency currents and stray effects	Additional real heating/losses (W/kW)
Motor	Copper, iron, stray-load, friction/windage	Input kW exceeds useful shaft output
Connections	Resistance at lugs, joints, contacts	Localized I ² R heat and real kW loss

Executive Summary

Electrical losses matter because a facility can consume electrical capacity and energy that do not directly contribute to useful production, comfort, computing, pumping, lighting, or other intended work. Some losses are inherent and unavoidable; others can be increased by excessive current, poor power factor, harmonic distortion, unbalance, voltage conditions, and equipment operating characteristics.

The most important starting point is simple: resistive heating rises with the square of current. Therefore, unnecessary RMS current can create disproportionate heating in conductors, transformer windings, busways, switchgear, and motor windings.

Power loss = I²R

A 20% reduction in current reduces the I² term by 36%, for the same resistance. This does not mean total facility kWh falls by 36%; it means the current-dependent resistive component is reduced by that amount.

THE CUSTOMER-FACING IDEA

Do not ask only, “How efficient is my equipment?” Also ask, “How efficiently is electrical power moving through the network that serves the equipment?”

Why this matters operationally

Lower avoidable heating can reduce thermal stress on electrical equipment.

Lower kVA and current can release usable capacity in transformers, feeders and switchgear.

Improved power factor can reduce reactive-current circulation and may reduce utility demand or power-factor charges where the tariff applies.

Lower harmonic current can reduce RMS current and harmonic-related heating in affected equipment.

Better power quality can support reliability, reduce nuisance problems and improve the quality of electrical capacity available to the facility.

A critical distinction

kVAR reduction, kVA reduction, current reduction, THD reduction, and kW/kWh reduction are related but they are not interchangeable. A technically defensible M&V program measures each quantity independently. THDi, for example, is a distortion metric; it is not a percentage of wasted energy.

1. Where Electrical System Losses Actually Occur

Electrical losses are distributed throughout the power path. The utility meter sees the aggregate result, but the heat and inefficiency occur locally in the electrical network and connected equipment.

Location	Loss / stress mechanism	What to examine
Conductors / busway	I ² R heating; voltage drop	RMS current, conductor size, temperature, connections
Transformers	Winding copper loss; core loss; harmonic-related heating	kVA loading, current, harmonics, temperature
Motors	Stator/rotor copper, core, stray-load and harmonic losses	Load, current, voltage quality, efficiency, harmonics
Switchgear / connections	Contact resistance and localized heating	Thermography, torque, current, imbalance
Neutral conductors	Triplen-harmonic accumulation in applicable systems	Neutral current, 3rd/9th/15th harmonics
Power electronics	Nonlinear current and conversion losses	VFD/UPS/rectifier spectrum, THDi, PF
Capacitors / filters	Losses, switching duty, resonance exposure	kVAR, harmonics, resonance, switching frequency
SYSTEM VIEW A facility can have highly efficient individual components and still have avoidable network losses or capacity burden between the service entrance and the loads.		

2. The Physics: Why Current Matters

For a resistive element, real power dissipated as heat is proportional to the square of RMS current. This is why current is such an important diagnostic variable.

$$P_{\text{loss}} = I^2R$$

Current change	Relative I^2 term	Change in resistive loss*
Baseline	1.00	Baseline
-10% current	0.81	-19%
-15% current	0.7225	-27.75%
-20% current	0.64	-36%
-25% current	0.5625	-43.75%

*For the same resistance and comparable operating conditions. This percentage applies to the I^2R component, not automatically to total facility energy use.

3. kW = Useful Work + Electrical Losses

A useful conceptual framework from our earlier engineering discussions is to separate the electrical input into the power that supports the intended process and the losses incurred in delivering and converting that power.

$$P_{\text{facility}} = P_{\text{process}} + P_{\text{loss}}$$

At an individual motor, the same idea can be written as electrical input = mechanical output + motor losses. At the facility level, the exact accounting boundary matters: measured kW includes the real-power consumption of loads plus real losses upstream of the measurement point.

IMPORTANT

Reducing reactive power alone does not equal an equal reduction in kW. The kW benefit comes from reducing real losses or changing real load consumption. That is why before/after kW and kWh must be measured rather than inferred from kVAR.

What “loss reduction” can mean

Reduced conductor and winding I^2R losses because RMS current is lower.

Reduced harmonic-related losses in transformers, motors or conductors.

Reduced cooling burden where electrical heat is rejected into conditioned space.

Reduced voltage drop and thermal stress, which can improve operating conditions.

Reduced real-power consumption of a process only when the process or equipment itself operates more efficiently.

4. Reactive Power, Power Factor and Capacity

Important: kVAR is not itself an energy-loss term in kW. Its financial and physical significance includes increased kVA/current and, where that current flows through resistance, additional real I^2R kW losses.

In a balanced three-phase sinusoidal system, real power P, reactive power Q and apparent power S are related by the power triangle. For a given voltage and useful real-power requirement, higher apparent power generally means higher line current.

$$S^2 = P^2 + Q^2$$

$$I \approx S / (\sqrt{3} \times V)$$

Balanced three-phase relationship; actual systems require appropriate measurement of voltage, current and distortion.

Reactive power is necessary for many electromagnetic loads, but reactive current flowing through upstream conductors and transformers contributes to RMS current and therefore to current-dependent losses and capacity utilization. Improving displacement power factor can reduce kVA and current for the same kW load.

CUSTOMER VALUE

Power-factor improvement can create value even when the utility does not bill directly for kVAR: lower current and kVA can release electrical capacity and reduce current-dependent losses. Billing savings depend on the specific tariff and measured kW/kWh behavior.

5. Harmonics: Distortion Can Add Current and Heat

Nonlinear loads such as rectifiers, VFD front ends, UPS systems, switch-mode power supplies and many electronic loads draw nonsinusoidal current. The RMS current includes the fundamental and harmonic components.

$$I_{\text{RMS}} = \sqrt{I_1^2 + I_2^2 + I_3^2 + \dots}$$

$$\text{THD}_I = \sqrt{I_2^2 + I_3^2 + \dots} / I_1$$

Harmonic current can therefore increase RMS current and create additional heating in conductors and equipment. NEMA motor guidance states that harmonic content increases electrical losses and motor temperature, reducing efficiency. NEMA transformer guidance also recognizes additional heating under harmonic/non-sinusoidal conditions. IEEE 519-2022 establishes steady-state voltage and current distortion goals at the point of common coupling (PCC).

What to measure

Current THD (THDi) and individual harmonic spectrum

Voltage THD (THDv) and individual voltage harmonics

RMS phase and neutral current

Total demand distortion (TDD) at the PCC when evaluating IEEE 519 current limits

Transformer loading and temperature

Power factor, kW, kVAR and kVA at the same time as harmonic measurements

DO NOT OVERSTATE THD

THDi is not “percent energy wasted.” It quantifies current waveform distortion relative to the fundamental. Energy-loss impact depends on the harmonic spectrum, RMS current, equipment impedance/resistance, loading and operating duration.

6. The Financial and Operational Consequences

Impact area	Why management should care
Energy	Real electrical losses are paid for as kWh when they occur downstream of the revenue meter.
Demand	Where kW demand is reduced, demand charges can fall; tariff structure determines value.
Power factor / kVA	Some tariffs penalize poor PF or bill kVA/kVAR; improved PF may directly affect billing.
Capacity	Lower current/kVA can release transformer, feeder and switchgear capacity.
Cooling	Electrical heat released inside conditioned space can add to HVAC load.
Maintenance	Excess heat and poor power quality can increase stress, nuisance events and troubleshooting burden.
Reliability	Better voltage/current quality can improve operating margin for sensitive equipment.

7. Connecting the Engineering to MPTS

The MPTS Power Management Controls System should be presented as a measured power-quality and electrical-network optimization system. The strongest technical story is not a blanket claim that every reduction in current or kVAR becomes kWh savings. It is that MPTS measures the electrical condition, applies correction, and verifies the before/after effect on the parameters that matter.

THE ACCENTZ PROMISE

Measure the electrical system. Identify and quantify the problems. Demonstrate the effectiveness of the solution with operating data. Provide engineering evidence for a confident decision.

Measure → Correct → Verify → Improve

MEASURE	CORRECT	VERIFY	IMPROVE
V, I, kW, kVA, kVAR, PF, vTHD, iTHD	Reactive power, distortion and other targeted PQ conditions	Before/after operating data with synchronized metering	Losses, capacity, reliability and operating cost where measurements support it

Recommended M&V metrics

kW: verify any real-power change directly.

kWh: normalize for hours, production, weather or occupancy when applicable.

kVAR and PF: quantify reactive-power correction.

kVA and RMS current: quantify released electrical capacity and current burden.

iTHD/vTHD and harmonic spectrum: quantify distortion change.

Temperatures or thermography: useful supplementary evidence for heating-related claims.

Operating state: use comparable MPTS ON/OFF or before/after conditions and document load changes.

8. Measured Examples: What the Data Can Demonstrate

The following examples are retained from prior ACCENTZ/MPTS case-study work. They illustrate measured electrical changes. They should be presented with the original source records when used externally, and causal or annual-savings claims should be limited to what the measurement boundary and normalization support.

Site	Before	After	Measured implication
NORAD	PF 0.298; 95 kVAR; 124.3 A	PF 0.811; 13 kVAR; 36.5 A	Large reduction in reactive burden and current; reported peak-demand and energy changes require the case-study measurement context.
Morgan County Prison	PF 0.73; 636.6 kVA; 563 kW	PF 0.98; 465.3 kVA; 444 kW	Measured PF, kVA and kW reduction.
Porterville Citrus / Rayo Packaging	562 kW; PF 0.77; 247 kVAR	425 kW; PF 0.99; 57 kVAR	Measured demand/PF/reactive improvement; performance previously documented as PG&E-verified in case-study material.
Summit Racing	131 kW	110.6 kW	20.4 kW measured difference in the referenced operating comparison.
Norfolk Iron & Metal DRV3	PF 0.718; 256.1 A avg	PF 0.984; ~187 A avg	PF improved; kVAR reduced 114 (76.9%); average current reduced ~27% in the referenced dataset.
USE CASE STUDIES CORRECTLY Case studies demonstrate what happened at a specific measurement point under specific operating conditions. They are evidence, not a universal guarantee. For new sites, establish a baseline and verify results with site-specific M&V.			

9. A Simple Customer Explanation

Every electrical system has losses. Some are unavoidable. But when a system carries more current than necessary because of reactive power, distortion or other power-quality conditions, that extra current can increase heat and consume electrical capacity.

That is why we measure more than kWh. We look at kW, kVA, kVAR, power factor, current, voltage and harmonics together. The goal is to understand how efficiently electrical power is moving through the facility and whether avoidable electrical burden can be reduced.

MPTS provides before-and-after measurement so the customer can see what changed. Where current, kVA, reactive power or harmonic distortion are reduced, the electrical network can operate with less burden. Where real kW or kWh is also reduced under comparable conditions, that improvement can be quantified financially.

SHORT VERSION

It is not only about how much electricity you buy. It is also about how efficiently your electrical system delivers that power to the work you need done.

10. Facility Electrical-Loss Assessment Checklist

Baseline metering

- ☐ Voltage and current by phase
- ☐ kW, kVA, kVAR and PF
- ☐ THDv, THDi/TDD and harmonic spectrum
- ☐ Neutral current where applicable
- ☐ 15-minute or finer trend data where useful

Electrical network

- ☐ Transformer loading and temperature
- ☐ Feeder/busway loading
- ☐ Voltage drop
- ☐ Connection hot spots / thermography
- ☐ Grounding and bonding observations

Load profile

- ☐ Motors and VFDs
- ☐ UPS / rectifiers / data-center loads

- ☐ Lighting and switch-mode power supplies
- ☐ Welders, furnaces and cyclic loads
- ☐ Production, occupancy, weather or other normalization variables

Verification

- ☐ Comparable before/after or ON/OFF periods
- ☐ Same measurement boundary
- ☐ Documented operating conditions
- ☐ Independent utility or revenue-meter data where appropriate
- ☐ Financial calculation tied to actual tariff

11. Technical Boundaries That Keep the Message Credible

Power factor correction can lower current and kVA without necessarily lowering the load's fundamental real kW by the same proportion.

A percentage reduction in current does not equal the same percentage reduction in facility kWh.

I^2R calculations describe current-dependent resistive loss; total system losses also include core, switching, stray and other mechanisms.

Harmonic mitigation can reduce harmonic-related RMS current and heating, but the kWh impact must be measured or calculated from an appropriate loss model.

IEEE 519 is principally a harmonic-control standard at the point of common coupling; it should not be used as a blanket equipment-efficiency specification.

Surge/transient mitigation, harmonic mitigation, reactive compensation and energy efficiency are distinct functions even when one system addresses more than one condition.

Claims about savings, equipment life or avoided maintenance should be supported by site-specific measurements and documented assumptions.

1. IEEE Std 519-2022, IEEE Standard for Harmonic Control in Electric Power Systems.

Establishes steady-state voltage and current waveform-distortion goals at the user point of common coupling for installations with harmonic-producing loads.

<https://standards.ieee.org/ieee/519/10677/>

2. IEEE PES Harmonics Working Group - IEEE 519 Standard Development.

Clarifies the scope and PCC application of IEEE 519 harmonic limits.

<https://sagroups.ieee.org/harmonicswg/ieee-519-standards-development/>

3. NEMA MG 1, Part 30 - Application Considerations for Constant Speed Motors Used on a Sinusoidal Bus with Harmonic Content.

States that harmonic content increases motor electrical losses and temperature and reduces efficiency.

<https://www.nema.org/docs/default-source/standards-document-library/mg-1-part-30-watermark.pdf>

4. NEMA US 80018-2022 - Transformers in DC Applications: Design Specification Considerations and Recommendations.

Discusses non-sinusoidal transformer loading and additional heating associated with harmonics.

<https://www.nema.org/docs/default-source/transformers-toolkit/nema-us-80018-2022-transformers-in-dc-applications-design-spec-considerations-and-recommendations.pdf>

5. ANSI/IEEE C57.110 (referenced by NEMA).

Recommended practice addressing transformer capability when supplying nonsinusoidal load currents.

See IEEE Standards catalog for current edition/status.

REFERENCE NOTE

Standards evolve. Confirm the current edition and the exact application point before making a compliance statement for a specific facility.

Takeaway

Losses matter because current creates heat: $P_{\text{loss}} = I^2R$.

Reactive power can increase current and kVA without increasing useful kW.

Harmonics can increase RMS current and equipment heating.

Lower current can reduce current-dependent losses and release electrical capacity.

kVAR, kVA, PF, THD, kW and kWh are different metrics; measure each independently.

The strongest customer story is measured before/after performance: Measure → Correct → Verify → Improve.