MEASURES FOR IMPROVING
Electrical System Efficiency and Performance in Facilities

Milhouse Engineering and Construction

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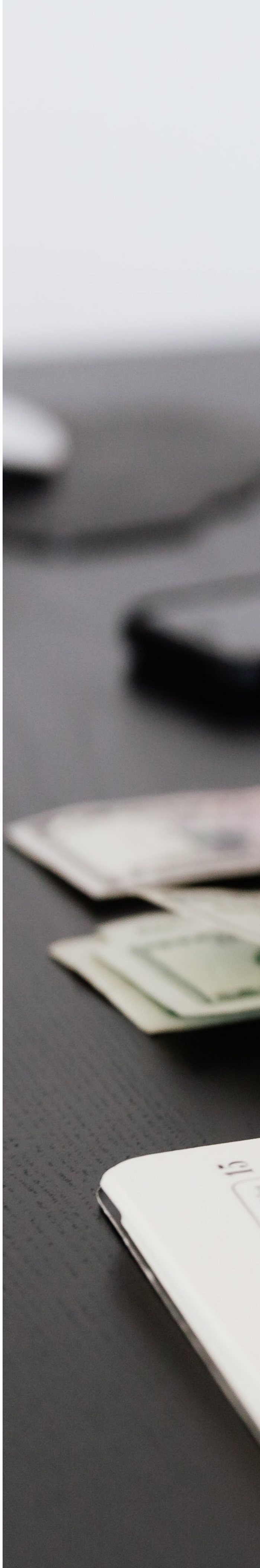
EXECUTIVE SUMMARY

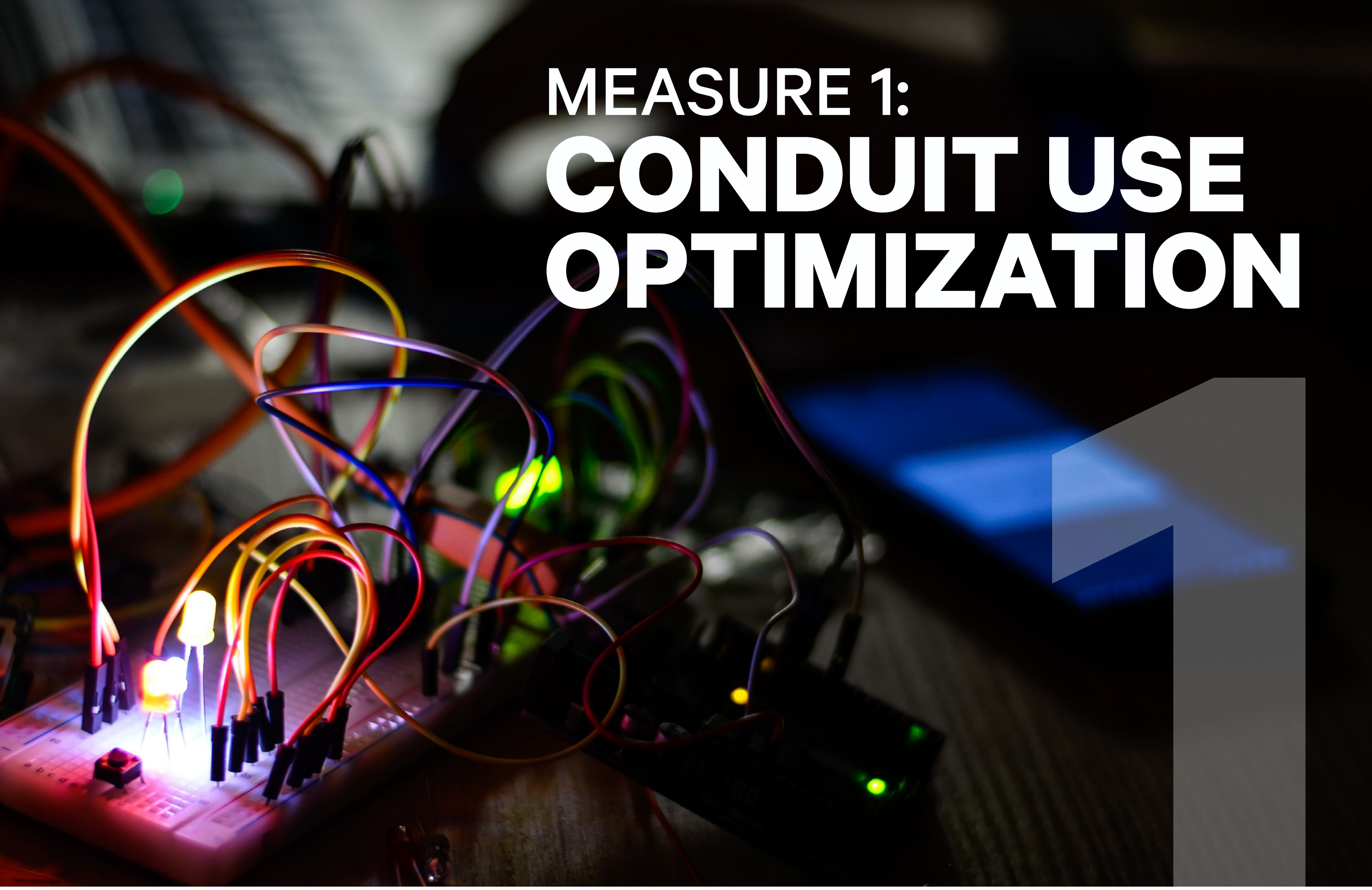
The purpose of this paper is to present several recommendations of measures for the reduction of energy use in facilities which in many cases are generally not considered in normal design practice. The paper does not focus on the obvious measures such as LED lighting or Adjustable Frequency Drives but more so on items such as conduit optimization as described below. Brief economic analysis based on typical 2021 costs of the measure implementation are included however each measure should be vetted through your estimate of implementation costs.



The Basis Calculations

Every measure presented in this paper requires analysis specific to the cost structure specific to the project including electric rate structure, labor costs and material cost. For this paper an electric utility rate of **$0.10 per kWh**, 24/7 operation assumed and pricing from various internet based suppliers was utilized.

MEASURE 1: CONDUIT USE OPTIMIZATION



Conduit optimization is the concept of using raceway capacity up to **40%** fill by upsizing conductors above code requirements based on the payback in energy savings resulting from lower losses in the conductors. The intention is not to increase raceway size to accommodate larger conductors but to utilize spare space within code complaint raceway fill to increase wire size. The benefit must be calculated on a case by case basis with most beneficial being **100%** duty cycle loads where code required conductor size results in less than **3%** voltage drop and conduit capacity for a conductor upsize exists. Load flow and conduit fill calculations are required for all electrical design, optimizing of wire size is relatively easy to accomplish with the software tools utilized to perform these calculations. Many optimizations may defined in the general specifications in tabular format.

The cost of an installed raceway can be up to five times the cost of the installed code required conductors making raceway excess capacity a potential asset for energy savings. Therefore, when there is an opportunity to install larger size cables without increasing the size of the conduit, it may be a cost effective method to improve the energy efficiency of the system.

Conduit Optimization payback varies case by case, depending on ampacity, distances, duty cycle of the load and return on incremental cost. For purposes of the below sample cases it is assumed that duty cycle of load is **100%,** voltage drop is limited to **3%** and ROI is **3** years maximum. Wire resistance is assumed to be at rated operating temperature. Increasing conductor size will result in lower operating temperature which improves payback as well as the life of the conductor.

1. Lighting Circuit Example:

a. Assume 7 amp lighting load, 100 feet from feeder breaker, 100% duty cycle
b. Code required wire gauge is #12, approximately $0.15 per foot
c. Wire losses at 10 amps for 200 feet (0.3862 Ohms) = 165 kWh annually
d. Replace with #10 conductors, approximately $.024 per foot
e. Wire losses at 10 amps for 200 feet (0.243 Ohms) = 104 kWh annually
f. Differential conductors cost = $18.00
g. Annual Savings of 61 kWh at $0.08 per kWh = $4.88
h. Simple payback not including demand savings – 3.7 years

2. Motor Circuit Example:

a. Assume 125 HP motor, 600 feet, 100% duty cycle.
b. Code required wire gauge is 3/0, approximately $2.94 per foot.
c. Wire losses at 156 amps for 1800 feet (0.077X.6X3 Ohms) = 29,547 kWh annually.
d. Replace with 250 kcmil at approximately $3.95 per foot.
e. Wire losses at 156 amps for 1800 feet (0.052*.6*3 Ohms) = 19,953 kWh annually.
f. Differential conductor cost = $1890.00
g. Annual savings at $.08 per kWh = $1596.00
h. Simple payback not including demand savings = 1.18 years

It is recommended that conduit optimization be considered on a case by case basis, dependent on analysis of ampacity, distances, duty cycle of the load and return on incremental cost. Whenever there is an opportunity to increase the size of the conductor without increasing the size of the conduit, the design engineer shall be encouraged to evaluate if it will be beneficial to increase the size of the cable. Conduit optimization is generally intended for continuous duty applications only. In addition to using the software tools (like SKM PTW 32) utilized for load flow and voltage drop calculations required for all electrical design work, it is recommended that the general electrical contract specifications include logic and tabular data defining common optimizations, which may include the following:

HVAC Control

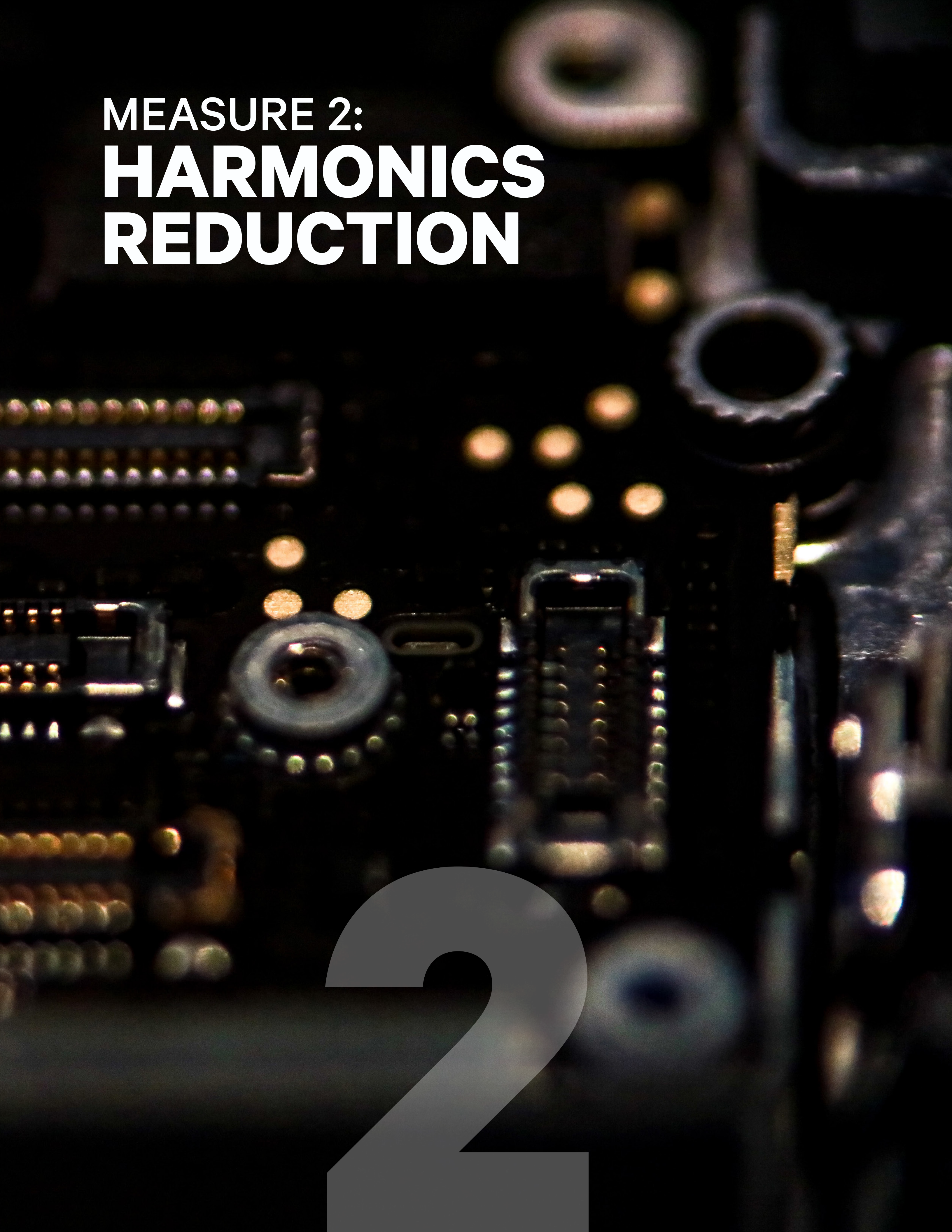
Lighting Control

Automation and Control Systems

Energy Management Systems

Variable Frequency Drives

MEASURE 2:
HARMONICS REDUCTION



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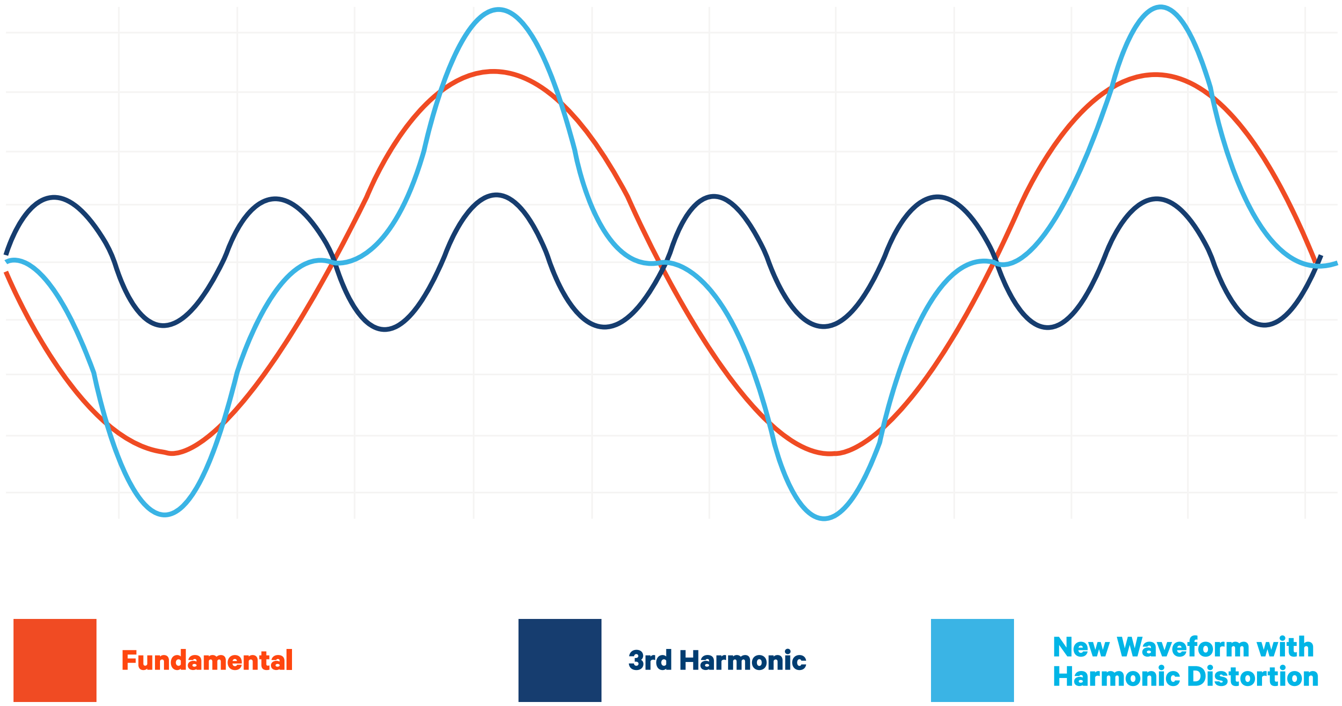
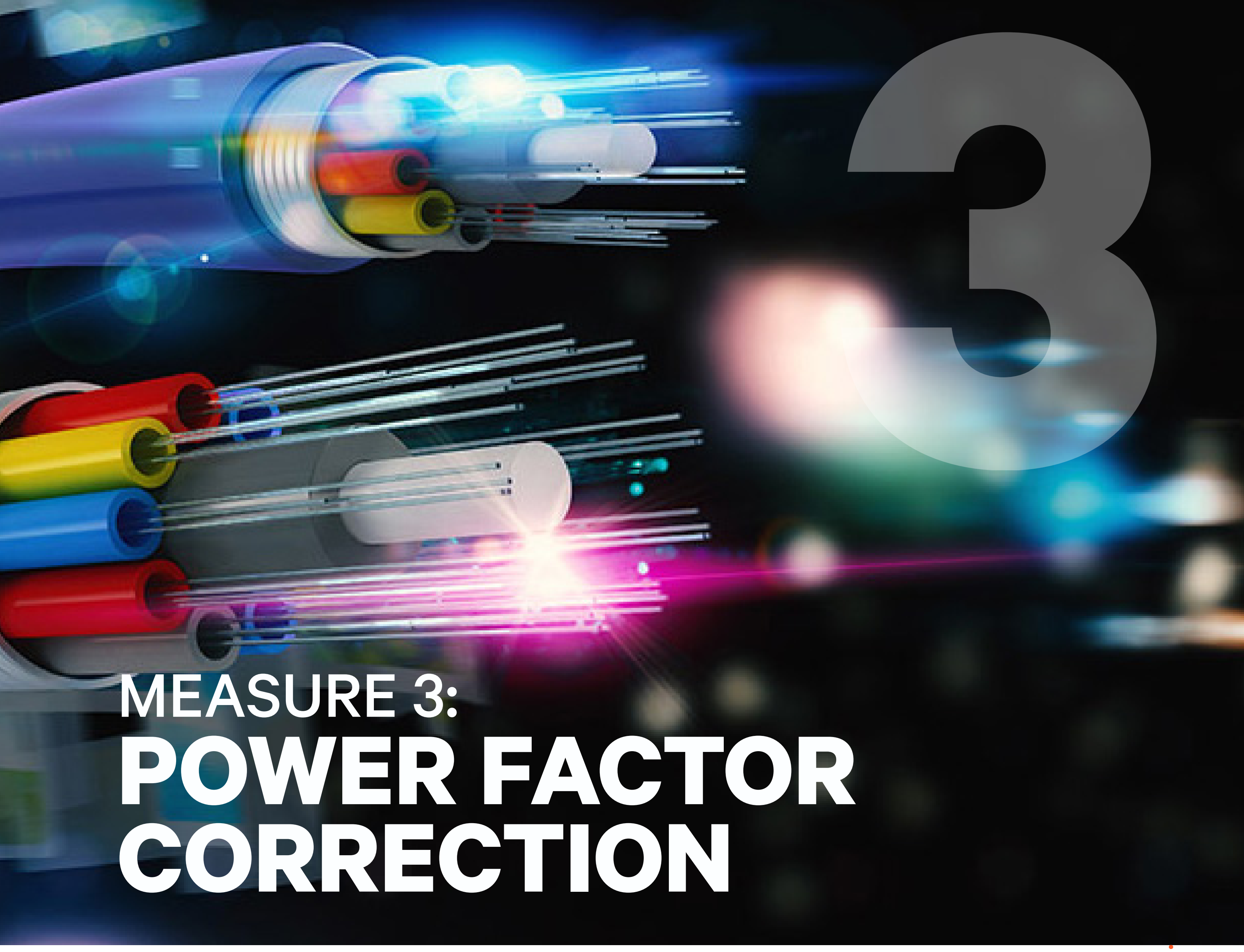


Power distribution systems are increasingly being loaded with non-liner loads from lighting ballasts, computer power supplies variable speed drives and other harmonics creating non- linear loads. High harmonic content increases the losses on conductors due the lessening of effective conductor area due to skin effect and also due to the increased RMS value of current waveshapes. Damage and premature failure of motors, transformers, capacitor banks, neutral conductors not sized properly, buzzing in telephone lines and nuisance tripping of ground fault relays are common effects of high harmonics power distribution systems.

Transformers loaded with high harmonics can see a 10 fold or more increase in eddy current losses resulting in a loss of efficiency and the potential for pre-mature failure. The issue is often resolved by the use of K rated transformers which are designed to carry high harmonics loads.

The results of one study show a **3%** loss in transformer efficiency with high harmonic loading. For a **75** kVA transformer the **3%** loss represents an increase of **25** Watts at **70%** load. This equates to **219** kWh or approximately **$18** annually at **$.08 per kWh**.

Based on the above analysis, harmonic correction may not be cost effective. However, harmonic correction may be required to prevent malfunction of sensitive electronic equipment and to satisfy power-utility's requirements.



MEASURE 3: POWER FACTOR CORRECTION

Power distribution systems operating below a **95%** power factor are considered to be inefficient due to excessive energy losses in conductors and transformers resulting from increased current flow. The benefits of maintaining power factors in the **95%** range include:

1. **Increased power distribution system capacity**
2. **Reduced energy losses in conductors and transformers.**
3. **Improved voltage regulation**

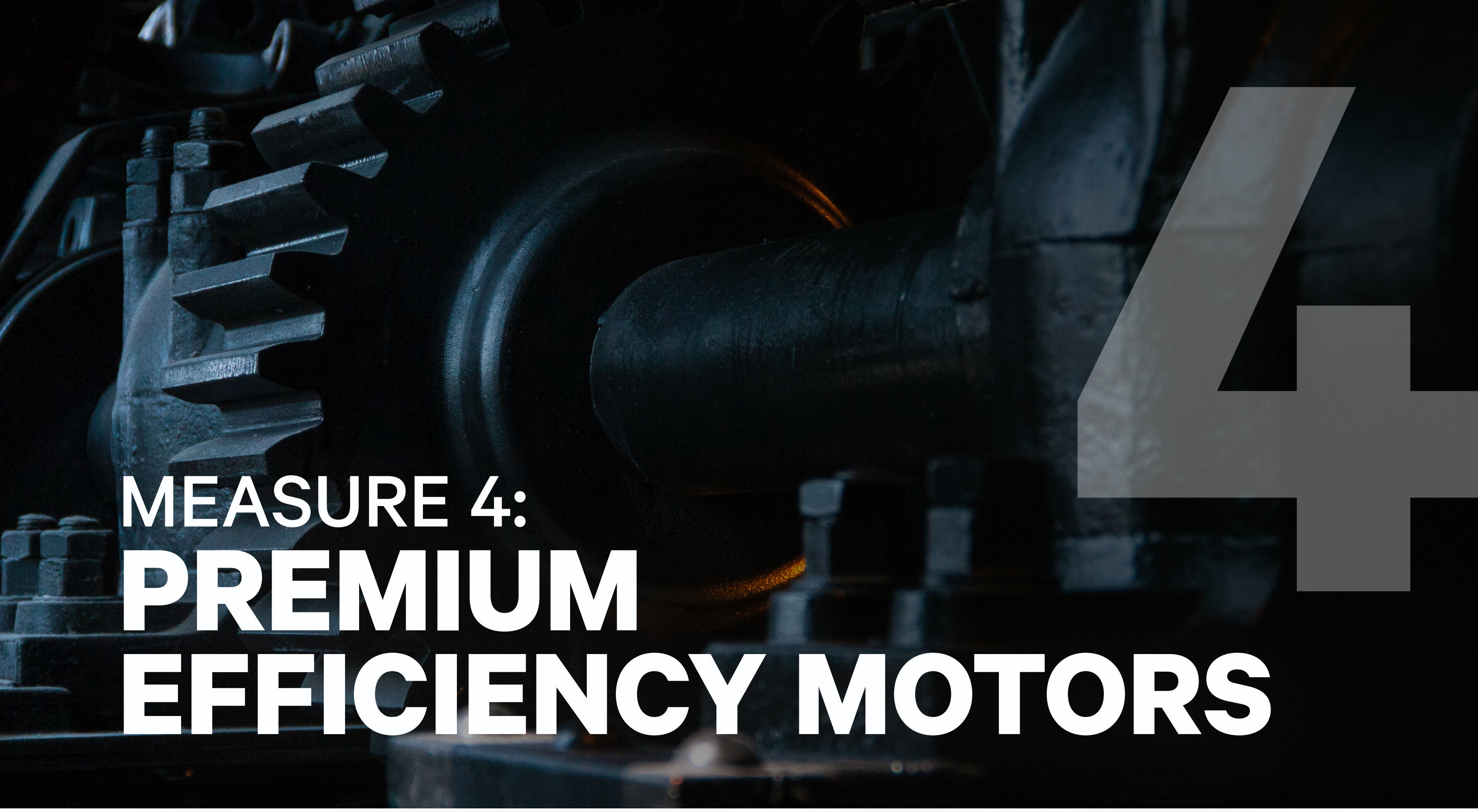
An example of the impact of power factor correction on an induction motor:

100 HP, 4 Pole, 460V, 124 FLA, 100% loaded
Recommended kVAr = 22.5
Current Reduction = 8% = 10 A
Assume 100 foot feeder length #2/0, Wire, .00097 ohms per phase
Feeder Transformer Efficiency = .985, Assume 1000 kVA, Full Load Secondary Amps = 1200, Total Full Load Losses Loss = 0.015 *1000,000 = 15,000 Watts

Conductor Loss Savings = 100*100*3*.00097*24*365 = 85 kWh Annually
Estimated Transformer Loss Savings = 10/1200 *(15000)*24*365 = 1100 kWh Annually
Total Annual Including Upstream Loss Reductions = 1185 kWh
At $.0.08 per kWh = $94 Annual Savings
Estimated Cost to Install 22.5 kVAr = $2,000
Simple ROI = 21 Years

Recommendation:

Based on low ROI it is recommended that power factor correction as related to energy savings initiatives not be considered.



MEASURE 4:

PREMIUM EFFICIENCY MOTORS

Motor efficiency types are classified as Standard and Premium efficiency. Standard motor efficiency has been improving over the years due to improved materials and manufacturing processes, such as smaller air gaps and reduced copper usage. Premium motor efficiency has been increasing to the point where further incremental increases in efficiency will be small and challenging to achieve.

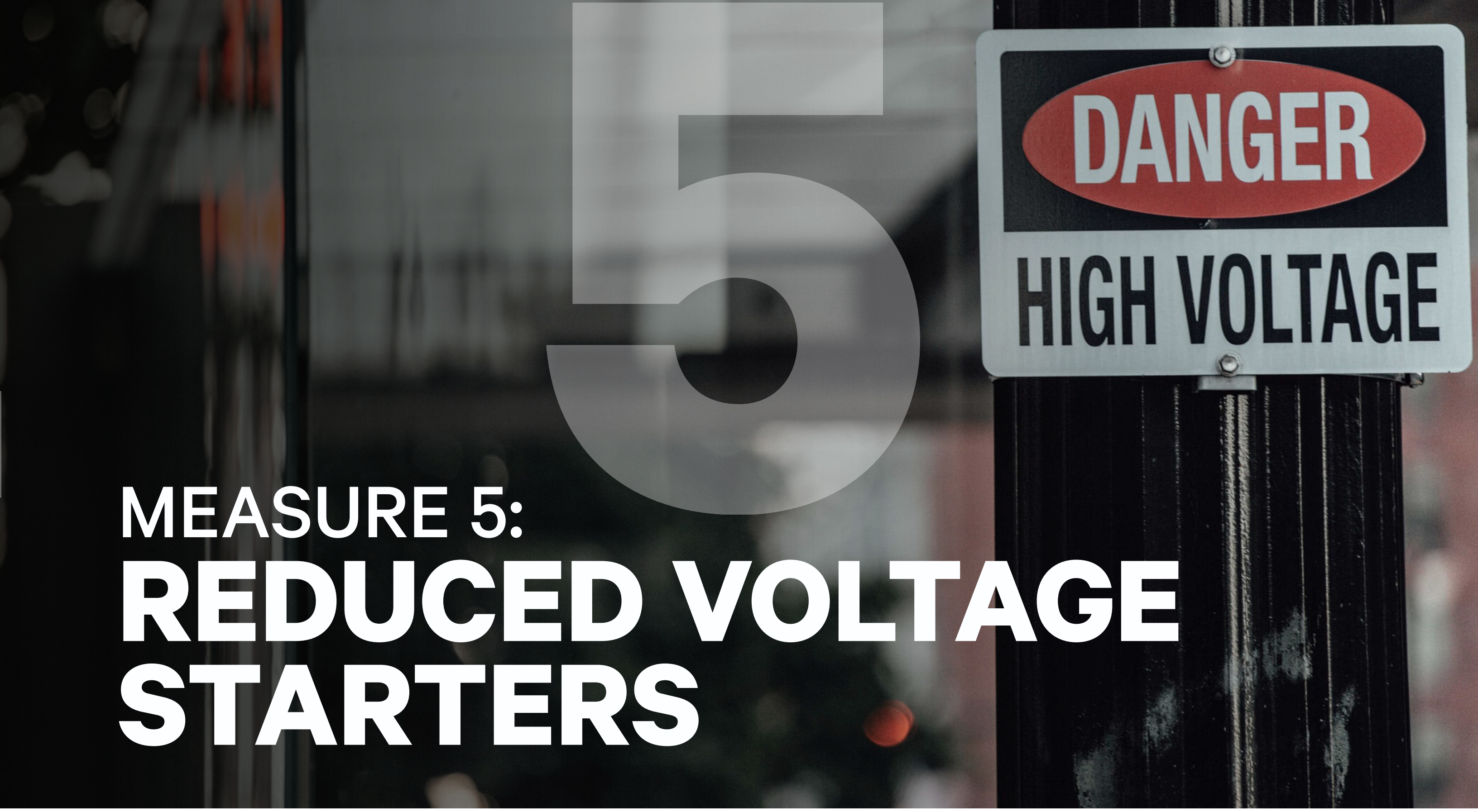
The below comparison demonstrates the energy differential between a Standard Efficiency motor and a Premium Efficiency motor.

Horsepower	Cost Per kWh	Standard Motor Efficiency	Standard Motor Full Load kW	Premium Motor Efficiency	Premium Efficiency Motor Full Load kW	kW Differential
300	$0.08	0.95	235.6	0.965	231.9	3.7

In general, the Premium efficiency motor will have a relatively rapid return on incremental cost, even when the differential efficiency is only **1.5%** as in our example.

Operating Hours	Energy Cost Savings	Motor Cost Differential	Simple Payback Years
8760	$2,566.22	$3,640.00	1.4

From an energy conservation perspective, the use of premium efficiency motors is recommended for all motors. In general Premium efficiency motor will have a relatively rapid return on incremental cost, even when the differential efficiency is small.



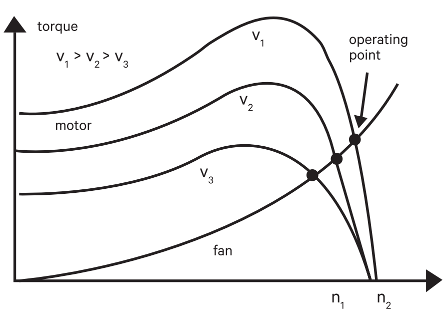
MEASURE 5:

REDUCED VOLTAGE STARTERS

Reduced voltage starters mitigate the impacts of voltage dips on plant apparatus as well as reducing the mechanical shock to the driven a pparatus. They also reduce the size of back-up generators because peak loads are related to motor starting.

The use of reduced voltage starters does not reduce the kWh required to accelerate a given load, it reduces the magnitude of the kW but increases the acceleration duration resulting in the same total kWh. This results in no energy savings benefit.

Due to the very low power factor of a motor while accelerating its load, the kilowatt power during acceleration is typically marginally higher than the motor full load watts.



It is recommended that reduced voltage starters be considered when:

1. Utility requires minimizing starting kVA based on voltage drop impact to upstream customers.
2. There is a benefit to reducing mechanical shock on the accelerated load. This would apply to soft starts and soft stops for reducing the shock impact of apparatus like check valves in pumping stations. WSSC uses reduced voltage starters on many water and waste water pumps. Gradual acceleration and deceleration of pumps prevents damaging water hammer and pressure surges.
3. Demand charge mitigation results in reasonable return on investment.
4. Generators are required in pumping stations. All process pumps should be specified with reduced voltage starters to reduce generator size requirements as well as reduce start and stop shocks to piping and check valve open/close operations. Careful consideration needs to be given to sizing the soft starters to the thermal limit based maximum starts/stops per hour of the pump motors and the acceleration/deceleration time frames.

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MEASURE 6:

TRANSFORMER TYPES

Contrary to intuition, the 80 degree Rise aluminum transformer has the best overall energy and cost performance versus 80 degree rise copper transformer. The results will vary from manufacturer to manufacturer and by size.

	80 Degree Aluminum	80 Degree Copper	150 Degree Aluminum	150 Degree Copper
Rating	75 kVA	76 kVA	77 kVA	78 kVA
Primary Volts	480	480	480	480
Secondary Volts	208/120	208/121	208/122	208/123
No Load Losses (Watts)	256	270	210	210
Full Load Losses	1066	1127	1941	1979
Calculated 70% Load Losses (Watts)	823	869.9	1421.7	1448.3
Annual Costs (70% Loaded & 0.08 kWh)	$577	$610	$996	$1,015
Cost of Transformer	$3,200	$5,100	$2,200	$3,700
Ret on Invest 150 Deg Alum vs. CU - Yrs	2.38	N/A	N/A	N/A

Recommendations:

1. Based on the Transformer Rating Table above, it is recommended that the standard design for transformers 200 kVA and below be aluminum 80 degree rise.
2. For transformers rated higher than 200 kVA it is recommended that similar typical data be obtained from the specified manufacturers to allow for a similar analysis.
3. Verify transformer efficiency rating for each transformer rating and each specified manufacturer, aluminum windings are more efficient in some cases.
4. kVA rating of transformer should not exceed next available rating above worst case highest load.
5. Analyze conductor materials, lamination options, temperature rise and transformer loss impact on building cooling and ventilation systems when specifying transformers rated above 200 kVA.

MEASURE 7:
LOAD BALANCING

Unbalanced voltages exceeding **1%** in magnitude in power distribution systems result in motor efficiency losses as well as potential damage to inductive apparatus. The percent of unbalance is defined as the percent deviation from the average voltage on a 3 phase system.

Unbalance can be caused by many factors including but not limited to:

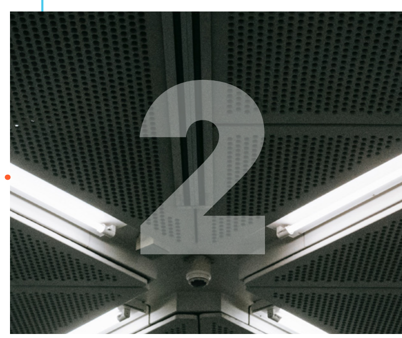
1. **Unbalanced utility supply**
2. **Unequal transformer tap settings**
3. **Large single phase transformers**
4. **Unbalanced loads on three phase lighting and auxiliary panels**

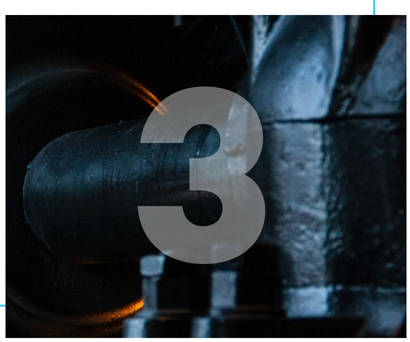
Voltage unbalance above **1%** can cause up to 10 times current unbalance in a three phase motor resulting in efficiency loss and damage to motor windings. An unbalance of **2.5%** will result in an efficiency loss of approximately **1.3%** in a typical 3 phase induction motor which can result in significant energy losses.

The following are recommended solutions to the issue of voltage unbalance:

Use three phase power for all large loads unless otherwise directed.

Require all three phase auxiliary and lighting panels be balanced to 1% deviation maximum under actual nominal loads, not connected loads.





Provide phase voltage transducers for incoming services and large internal distribution apparatus with alarm inputs to SCADA or BAS systems to allow for monitoring of phase balance.

Contact utility when incoming unbalance exceeds 3%.

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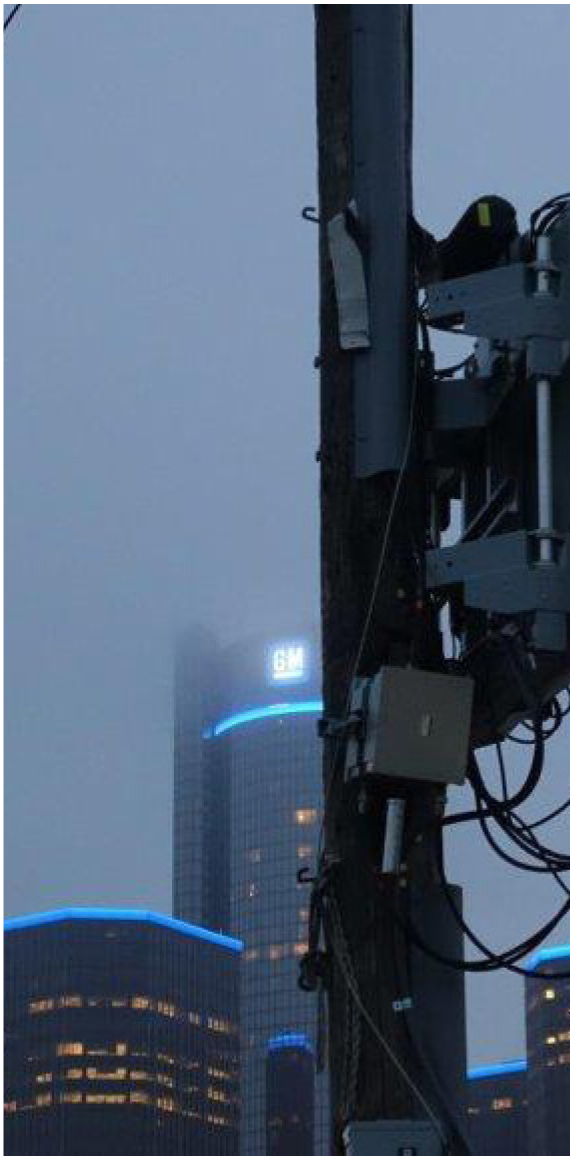
MEASURE 8:
METERING EQUIPMENT

The nature of electrical loads on substations has changed significantly over the last 20 years and continues to change in terms of the increases in non-linear loads. Many substations installed years ago and still in service were not designed for high non-linear load content.

Based on the impacts on energy and apparatus life due to poor quality electrical power distribution, it is recommended that Power Monitor Meters be installed at substations which have the capability to monitor and alarm power quality in terms of harmonics, K factor, voltage unbalance and voltage magnitude. The data should be utilized by SCADA or Building Automation Systems to optimize system efficiencies. It is recommended that facilities standardize on the Shark 250 Power Monitoring Transmitter or one with similar accuracy and capabilities.



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