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Energy savings—realistic expectations for commercial facilities

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Everyone wants to save money on their energy bill. Many facilities have mandates to save energy. Improving energy efficiency offers huge advantages to businesses—reducing the costs of energy and operations—and increasing sustainability.

Abstract

Through proven methods including variable frequency drives (VFD), LED lighting and conservation methods and control, many new and existing facilities achieve the savings that they expect. However, many solutions are overstated as energy savers including power factor (PF) correction, harmonic solutions and conservation voltage reduction (CVR). Some solutions may not specifically save energy, but offer financial savings for end users as an incentive or penalty avoidance. This paper will identify realistic levels of energy savings and expected financial benefits with proven methods in addition to identifying how to evaluate false energy savings claims.

Introduction: Saving money on your energy bill

Saving money on your energy bill is simple—either use less energy or pay less for the energy that you use. As ridiculous as this sounds, this oversimplification is exactly the point. Energy savings is hard work and a clear understanding of the energy you use and how you pay for it is critical to saving money. The focus of this paper is on electrical energy, although similar conclusions can be made for other sources of energy.

Understanding your electric bill

Generally speaking, your electric bill has four major components:

- Energy (measured in kWh)
- Demand (measured in kW)
- Penalties or other charges (PF, etc.)
- Taxes

Our intention is not to help you save money on the tax portion of your bill, but by identifying savings in the other three parts, you may also save on taxes.

Energy charges (kWh)

Energy, which is measured in kWh, is an accumulation of kW over time. Typical rates for kWh charges range from \$0.05/kWh to \$0.15/kWh but can be significantly higher in remote areas or during heavy energy demand periods. A simple example illustrating the cost of kWh is shown below.

Scenario 1: Using 10, 100 W incandescent light lamps for 24 hours would result in:

$$10\ lamps * 100\ W * 24\ hr = 24\ kWh$$

And the operation cost would be:

$$24\ kWh * \$0.12\ per\ kWh = \$2.88$$

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Scenario 2: Using the same 10 light lamps dimmed to 50% output power would yield half the usage (of course, the result would be less light/i.e., less work) and the cost would be $1.44 for the same time period.

Scenario 3: Negotiating a better rate for energy—for example, $0.12 during the day and $0.06 at night might result in the following cost:

$$10 \text{ lamps} * 100\ W * 12\ hr * \$0.12 \text{ per } kWh + \\ 10 \text{ lamps} * 100\ W * 12\ hr * \$0.06 \text{ per } kWh = \$2.16$$

Scenario 4: Changing the lights to a different type of light (CFL or LED) would provide a similar amount of light but for significantly less power. For example, using a 20 W LED equivalent to a 100 W incandescent:

$$10 \text{ lamps} * 20\ W * 24\ hr * \$0.12 \text{ per } kWh = \$0.58$$

Table 1. kWh charges for scenarios 1–4

Scenario	kWh used	Cost/kWh	Total cost	Light output
1	24 kWh	$0.12	$2.88	100%
2	12 kWh	$0.12	$1.44	50%
3	24 kWh	$0.12/$0.06	$2.16	100%
4	4.8 kWh	$0.12	$0.58	100%

Demand charges (kW)

Although demand charges are fairly straightforward, they are often misunderstood. Demand charges are not the instantaneous maximum kW (or MW) that a facility uses, but rather the kW demand is a rolling 15 minute average value (or 5 minutes or 30 minutes, for example, based on the utility tariff). The demand charge is a once-per-month charge based on the highest 15 minute window. Some utilities will add additional regulations and hold the highest demand for multiple months or even a full year. The purpose of the demand charge is to ensure that the utility is capable of supplying every customer with the peak kW required on a given feeder, substation or region based upon generation, transmission and distribution capacity. Typical kW demand charges are $5 to $15/kW, but may be significantly higher based upon location and customer electrical size.

As an example, an office building may use a base load of 300–500 kW continuously but during the summer months, may increase the “demand” on the utility by 300 kW for additional air conditioning required to cool the building. This additional 300 kW may only occur once per day as the building “comes to life” in the early morning but may cost the facility $3,000 per month (300 * $10/kW) as a result. Changing the pattern of usage or the peak demand period will change the total cost.

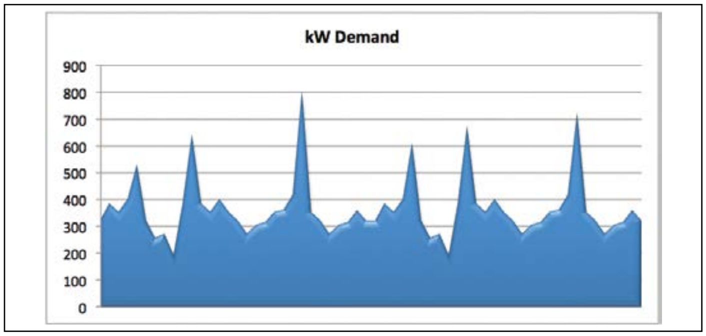


Figure 1. Sample kW demand

Similar to kWh charges, utilities will often give a break to end users utilizing power (kW demand) at a different time of the day (i.e., overnight or early/late in the day) to offset the total feeder or substation loading. Ideally, utilities seek a “flat demand” and will pay customers who can help them achieve this scenario either through incentives or penalty avoidance.

Scenario 1: 500 kW base load with 300 kW “peak demand” once per day. The total cost is:

$$\frac{\$10}{kW} * 800\ kW = \$8{,}000 \text{ demand charge}$$

Scenario 2: 500 kW base load with a negotiated rate of $10/kW during the day or $2/kW overnight. With ice storage, a facility could cool the building in the summer while using 800 kW overnight and 500 kW during the day (roughly).

$$\frac{\$10}{kW} * 500\ kW + \frac{\$2}{kW} * 800\ kW = \$6{,}600 \text{ demand charge}$$

The added storage saves $1,600 versus scenario 1.

Scenario 3: Pre-cool (with controls) at 3 a.m. when the overall building base load is less. Maximum demand during the day may reach 600 kW. Therefore the demand charge becomes:

$$\frac{\$10}{kW} * 600\ kW = \$6{,}000 \text{ demand charge}$$

Scenario 4: Facility is told that using a soft starter on the air handling system could save the peak demand. Unfortunately, this is not a true statement as the inrush current is primarily reactive current (kVAR versus kW) and the inrush generally lasts seconds (even on large motors), so the overall impact on a 15 minute window is negligible. Therefore, although the system would benefit (less voltage drop and impact on the motors), the demand charge would not reduce.

Table 2. kW demand charge for scenarios 1–4

Scenario	kWh demand	Cost/kW	Demand cost	Additional expense
1	800 kWh	$10	$8,000	None
2	500 kWh	$10/$2	$6,600	High
3	600 kWh	$10	$6,000	Minimal
4	800 kWh	$10	$8,000	Medium

Penalties and incentives—the carrot and the stick

Aside from fixed kWh and kW demand charges on an electric utility bill, utilities often charge for a poor power factor (PF) or excessive kWh or kW during peak usage periods. Whether you consider these costs or the avoidance of these costs “penalties” or “incentives”, utilities drive behavior of their customers based on them.

PF penalties

Power factor is a measure of the effective use of kW versus kVA.

$$PF = {}^{kW}/_{kVA}$$

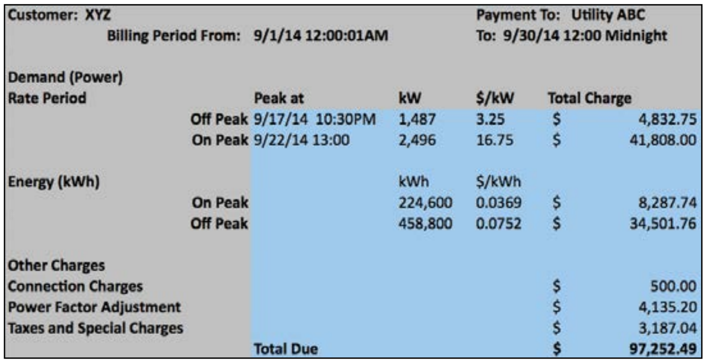
A low power factor indicates that a significant amount of reactive power is needed by the loads (usually motors) and without local compensation (usually accomplished with capacitors), utilities must provide more current and kVA than with an optimized system where the PF is 1.0 or nearly 1.0. Because power distribution equipment is rated in kVA and/or amps, utilities must oversize their equipment and conductors to accommodate poor power factor by their customers. For this reason, utilities often penalize customers with low power factors (essentially rewarding customers with high power factors). Some utility companies do not impose penalties but then, in fact, socialize the penalty by raising the kWh and/or kW demand rates for all customers because the utility must then install large PF correction banks in substations or on feeders to support the low PF of some customers.

It is not the intention of this paper to discuss power factor penalties in detail but rather to present an overview so that the reader will have a basis to investigate their utility bill. **Table 11**, in the appendix, shows a number of different types of power factor penalties [1]. Most are straightforward and can be analyzed to help determine how to reduce power factor penalties. Sometimes utilities will incorporate multiple methods of billing for low power factor, so several of the penalties in Table 11 may be applied.

Sometimes a power factor penalty is somewhat hidden. For example, in a straight kVA demand rate there is nothing that explicitly mentions a power factor penalty. But a poor power factor will result in a higher kVA for a given kW of load, so there is an implicit power factor penalty built into that rate. In other cases, the utility may give a rebate for maintaining a power factor above a given level. At a glance you might not think you are paying a penalty if you do not get this rebate. But you would be leaving money on the table if you did not take advantage of the rebate. It is functionally equivalent to a power factor penalty, just phrased differently.

Note that for most of these rates it is not practical to correct all the way to unity power factor. First of all, further improvement (above a power factor threshold level) costs more. Even if there is a unity power factor target (e.g., kVA billing), going closer to unity may cost more to achieve than will be saved. This could result in higher absolute dollars saved but a lower rate of return on the project (due to the higher initial investment). Secondly, going all the way to unity might require a switched capacitor bank, whereas applying a lesser amount of capacitance reduces the possibility of leading power factor (for which some utilities also penalize), or at least minimizes how far leading the power factor will go.

Many customers feel that they "don't have the money" to implement a cost savings/penalty avoidance plan but, in fact, they do as they "budget" every month for the penalties imposed by the utilities. Many PF penalties have a return-on-investment (ROI) of less than one year.



Customer: XYZ				**Payment To: Utility ABC**		
	Billing Period From:	**9/1/14 12:00:01AM**		**To: 9/30/14 12:00 Midnight**		
Demand (Power)						
Rate Period		**Peak at**	**kW**	**$/kW**	**Total Charge**	
	Off Peak	9/17/14 10:30PM	1,487	3.25	$	4,832.75
	On Peak	9/22/14 13:00	2,496	16.75	$	41,808.00
Energy (kWh)			kWh	$/kWh		
	On Peak		224,600	0.0369	$	8,287.74
	Off Peak		458,800	0.0752	$	34,501.76
Other Charges						
Connection Charges					$	500.00
Power Factor Adjustment					$	4,135.20
Taxes and Special Charges					$	3,187.04
		Total Due			$	**97,252.49**

Figure 2. Sample (simplified) electric bill

Measurements—verifying your bill

Generally speaking without measurements and verification, you can implement the best energy saving or demand reduction program but you may not fully appreciate the results or even achieve the results without a measurement and verification (M&V) program. Oftentimes, retro-commissioning programs looking for savings based on implementation of an energy savings initiative uncover final steps that were missed or savings left on the table. In addition, the authors have found discrepancy in billing where neither the utility nor the end user were aware of the difference. In one case, the savings was more than $10,000 per month.

The best method of verifying savings involves starting with a solid baseline and comparing estimated/calculated savings to actual savings. Of course, this is often easier said than done as loads change, weather changes and people's habits of usage change. Still, proven methods are available and required to optimize savings.

Solutions: Save money by saving energy

One of the best ways to save money on an electric bill is to reduce the amount of energy used in a facility, either through the use of energy-efficient devices, or through intelligent building control systems. Energy-efficient devices can range from variable frequency drives (VFDs) for motor control, to utilizing LED lighting, or high-efficiency motors and transformers. Intelligent building controls can leverage new or existing technology to reduce energy consumption through load management, lighting control and advanced thermostats. This section will explore, in detail, the methods available to save money through directly reducing energy consumption in facilities.

Three main load types dominate electricity use in commercial facilities. HVAC, lighting and plug loads (office device and computers) combine to represent almost 85% of all electric energy consumed by commercial customers.

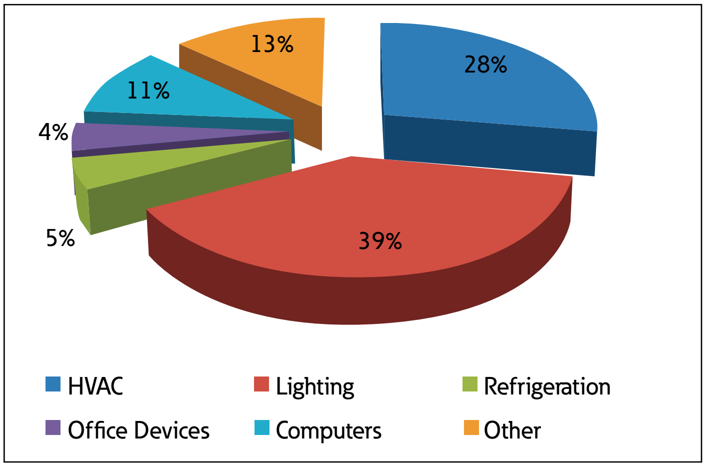


Figure 3. Commercial energy consumption by end use [2]

VFDs, LEDs and high-efficiency motors and transformers all provide excellent means of dramatically lowering the electricity demand for a commercial facility, either by making existing loads like HVAC run more efficiently, or by replacing existing loads like incandescent lighting or traditional motors with higher-efficiency technologies. However, one question that is often asked is how much energy will installing such devices really save, and how long is the return on investment from upgrading?

Variable frequency drives (VFDs)

Description: VFDs are advanced motor control systems that, when used on motors in variable torque applications, can save dramatic amounts of energy. They function by converting the AC line power to DC, storing it in large DC capacitors, and then using an inverter to convert back to AC power at a desired frequency. The layout of a VFD can be seen in **Figure 4**. This allows the frequency of the voltage and the current applied to a motor to be varied dynamically, depending on the requirements of the load. For variable torque loads, such as HVAC units or water pumps, VFDs allow the flow rate to be varied without having to physically restrict the air or water with a valve or damper.

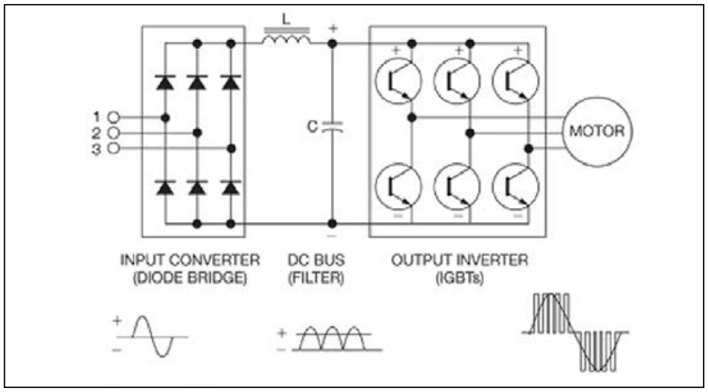


Figure 4. Circuit diagram of VFD [3]

Estimated opportunity: When applied to motors serving variable torque loads, VFDs can provide significant energy savings. In a traditional HVAC system, a mechanical damper is used to control the amount of airflow in the system. This means that if the building only requires 50% of the full capability of the system, the damper will close the duct halfway. The loading on the blower will decrease, as the amount of air being supplied to the intake is reduced. However, the motor still has to provide the full load of the blower, such that for 50% load, the system is still using over 75% of the rated energy. The loading for a damper controlled HVAC system is represented by the top curve provided in **Figure 5**.

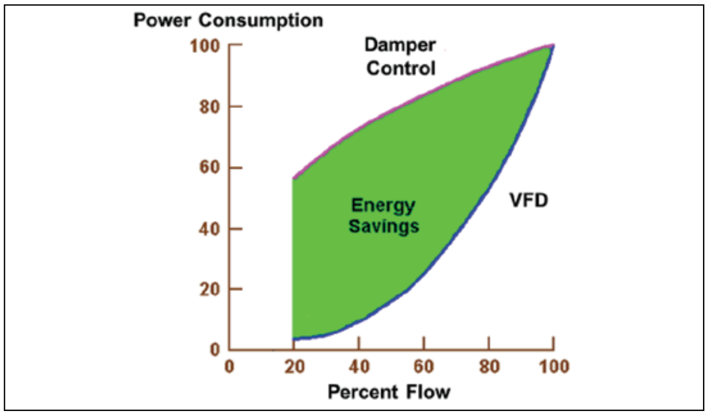


Figure 5. Damper control vs. VFD power consumption for HVAC systems

The bottom curve shows the energy used by the system when the fan is instead controlled by a VFD, and no mechanical damping is used. Rather than physically restricting air flow through the duct, the VFD directly controls the speed of the blower motor. To run the blower at half speed and achieve 50% flow, the VFD regulates the electric frequency of the motor to 30 Hz, or half of the nominal. This drastically reduces energy consumption, through what are known as affinity laws between motor speed (S), flow (F), torque (τ) and power (P), as described in the following equations.

$$F_1 / F_2 = S_1 / S_2$$

$$\tau_1 / \tau_2 = (S_1 / S_2)^2$$

$$P_1 / P_2 = (S_1 / S_2)^3$$

From these relationships, it can be seen that at 50% loading:

$$F_1 = (0.5 / 1) * 100\% = 50\%$$

and

$$P_1 = (0.5 / 1)^3 * 100\% = 12.5\%$$

That means that for half load the VFD uses only 12.5% of the full load power, providing more than 63% total energy reduction when compared to the damper-controlled system. This amount of savings will increase as the speed is reduced and will decrease as the system is operated closer to full load. At full load, the VFD will consume slightly more power, due to losses within the device. By allowing a VFD to dynamically control HVAC systems, dramatic energy reductions can be reached, while achieving the same heating or cooling as in traditional buffer-controlled systems.

Return on investment: The energy savings from using a VFD versus traditional control methods in variable torque applications can be determined through a set of calculations. By taking into account the cost per kWh of energy, the motor power, the motor efficiency, the VFD efficiency, the cost of the VFD, and the amount of time spent at various levels of output, annual energy savings and payback time can be found. For systems in which the speed is controlled frequently and to lower levels, as might be typical for HVAC applications, the savings are very large and the payback period can be as low as one to two years versus traditional outlet damper control or inlet vane control. For systems with less speed change, that payback period may extend somewhat; however, there are often incentives available from the electric utility for adding VFDs into motor systems, as will be discussed in the following section of this paper. An example calculation for a typical fan application for a VFD is shown below. **Table 3** describes the parameters for a typical fan application driven by a VFD, while **Table 4** describes the speed usage curve for the same system [4].

Table 3. VFD data for typical fan application

Parameter	Quantity
Annual operation time	2,880 hours
Cost per kWh	$ 0.10
Motor power	30.0 hp
Motor efficiency	95.0%
VFD efficiency	97.0%
Utility incentive	0.0 $/hp
VFD cost	$5,000.00

Table 4. Speed usage for typical fan application

Percent flow	Percent time
100%	1%
90%	2%
80%	9%
70%	17%
60%	24%
50%	17%
40%	13%
30%	11%
20%	6%
10%	0%

This data, when used to calculate drive payback [4], provides the following usage chart, showing the energy cost for operating a system using a VFD compared to an outlet damper or inlet valve. **Figure 6** shows the energy savings at each speed set point throughout the year.

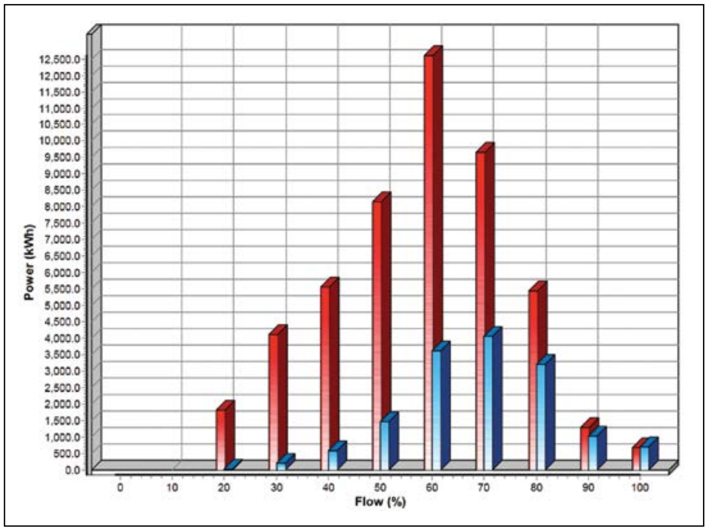


Figure 6. Annual energy use for VFD (blue) and outlet damper (red) on typical fan system [4]

The total energy savings for the VFD system equates to almost 35,000 kWh, or $4,127 per year. That means that for a $5,000 VFD, this results in a payback period of between one and two years, depending on use. Clearly, VFDs present a tangible and rapid payback, and are, when used in the proper applications, capable of saving large amounts of energy and money when compared with traditional techniques.

Light emitting diode (LED) lighting

Description: LED lighting fixtures are becoming increasingly common in installations in residential, commercial and industrial applications. They function by passing DC voltage and current through a P-N junction in a semiconductor material. When the turn-on threshold is passed in the device, light is emitted at a frequency and color based on the band-gap of the semiconductor used. The LED is housed within a reflective cap, and can then be mounted in any plastic housing that fits the application. A graphic of a typical LED can be seen in **Figure 7**.

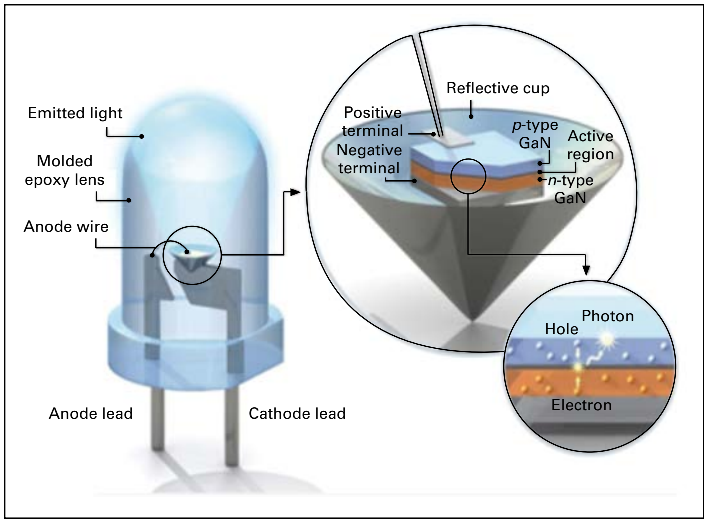


Figure 7. Typical single LED semiconductor and housing [5]

Applications for this technology range from surface-mount indicators for printed circuit boards to fully housed fixtures to replace commercial lighting units, as seen in **Figure 8**.

Figure 8. Commercial LED fixtures [6]

Estimated opportunity: When installed in commercial facilities, LED lighting fixtures provide dramatic advantages in both energy savings and maintenance requirements when compared with traditional incandescent, halogen incandescent or fluorescent lighting systems. A typical commercial facility can have hundreds or thousands of lighting fixtures, all of which consume an amount of power based on the type of luminous device used. Consider a single lighting fixture, such as one in a home. A single traditional incandescent lamp might use anywhere from 40 W to 100 W of power to provide higher or lower levels of light. One of the most typical specifications is for 100 W lamps, so let's use that for the sake of comparison. That means, if you were to run it for six hours every day for a year, the lamp would annually consume:

$$100\ W * 365\ days * 6\ hours/day = 219\ kWh$$

Almost 90% of this energy is lost in the form of heat, while only a small fraction goes to producing light [7]. A traditional incandescent light illuminated at 100 W produces approximately 1,600 lumens. Assuming that the goal is to achieve that amount of illumination, comparable lighting fixtures can be found in halogen incandescent, compact fluorescent and LED technologies, and energy use comparisons can be made. **Table 5** shows the same calculation shown above for the various lighting technologies, and the cost to operate a single fixture for a year.

Table 5. Annual consumed by 1,600 lumen lighting fixtures [7]

Technology	Rated power	Usage time	Energy consumed
Traditional incandescent	100 W	2190 hr/yr	219 kWh
Halogen incandescent	77 W	2190 hr/yr	168 kWh
Compact fluorescent	23 W	2190 hr/yr	50 kWh
LED	20 W	2190 hr/yr	44 kWh

Return on investment: The energy savings from using a LED in a fixture is clear to see based on the results in **Table 5**. Let's assume that a given facility has 100 luminary units. At $0.12 per kWh, 100 units of the 1,600 lumen LED fixture will cost $528 per year to operate. That is $72 less than the fluorescent fixture, $1,488 less than the halogen incandescent, and $2,100 less than the traditional incandescent annually.

The natural counterargument to that monetary savings, is of course, the initial cost of the LED units. For the single luminary unit from the previous example, the traditional incandescent lamp costs roughly $4.00, while the LED costs $40.00. At ten times the expense, factoring in only the energy savings, it would take only two years to pay off the cost of the LED fixtures, a very short return on investment.

What then, of the more efficient fluorescent lamp? Here, as well as in the comparison with incandescent technologies, another benefit of LED fixtures shines—they have a lifetime of approximately 50,000 hours [8]. That compares to roughly 2,000 hours for incandescent lamps and 10,000 hours for a fluorescent lamp [7]. Additionally, when an LED reaches its end-of-life, it simply becomes dimmer, rather than “burning out” like a traditional lamp. This drastically reduces maintenance costs at a facility. Not only are replacement lamps additional costs, but electrician hours must be billed to cover those replacements. In facilities with high ceilings and hundreds of lights, the costs can be dramatic. With LED fixtures, units need to be replaced much less frequently, resulting in much lower maintenance costs.

The combination of direct energy savings and fractional maintenance costs make LED lighting fixtures an attractive and economical way to save both energy and money in commercial and industrial facilities.

High-efficiency motors

Description: Induction motors are not new technology, they have been a staple of the electric power industry almost since its inception. They operate on the principle of electromagnetic induction, using the magnetic field of an energized stator winding to apply torque to a central rotor. That principle of operation has not changed much since Nikola Tesla’s original designs in 1887, as illustrated in **Figure 9**.

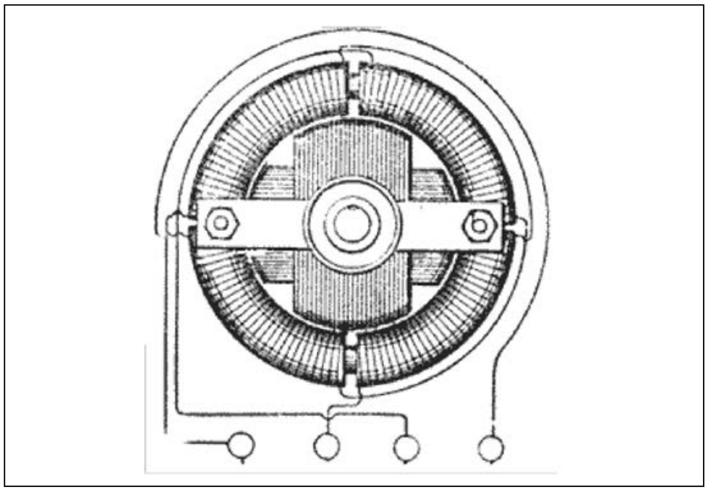


Figure 9. Early induction motor design, 1887 [9]

That said, the materials and techniques used in the fabrication of such systems has changed dramatically since then. The most recent standards change occurred in 2001, when the National Electrical Manufacturers Association (NEMA®) introduced their premium energy-efficiency motor standard [10]. This standard applies to low voltage induction motors with 2, 4 or 6 poles, rated for between 1 and 500 hp. Improvements over previous design standards include adding more copper to the windings, creating a longer stack and utilizing higher slot fill and lower loss premium steel in the rotor [11]. By employing NEMA Premium® efficiency induction motors, facilities can drastically cut their overall energy use, and quickly pay back the cost of the motor.

Estimated opportunity: NEMA Premium efficiency motors provide an excellent opportunity for industrial facilities to improve their energy usage. **Table 6** presents the energy savings incurred through the use of premium efficiency motors, as reported by the U.S. Department of Energy (DOE).

Table 6. Comparison of motor efficiencies [11]

hp	Old standard efficiency	Premium efficiency	Annual kWh savings
10	86.7%	92.2%	3,105 kWh
25	89.9%	93.8%	5,160 kWh
50	91.6%	95.0%	8,630 kWh
100	92.2%	95.3%	15,680 kWh
200	93.3%	96.2%	29,350 kWh

The added efficiency of these motors, and the prevalence of motor loads in electric power systems led to the inclusion of NEMA Premium efficiency motors in the Energy Independence and Security Act of 2007, which mandates the use of such motors for all applications below 1 kV and 200 hp [10].

Return on investment: The monetary savings from using a NEMA Premium efficiency motor are immense. Energy use accounts for approximately 88% of the total life-cycle costs of a motor, as seen in **Figure 10**.

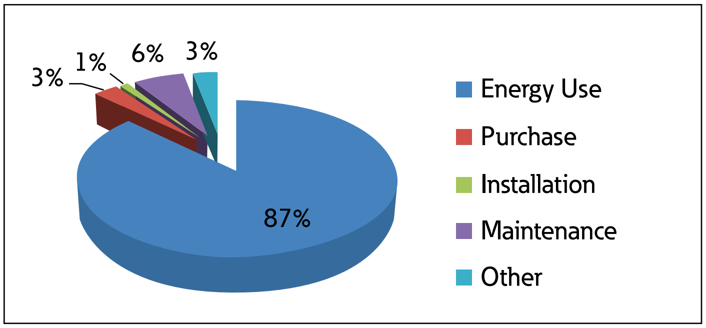


Figure 10. Percent costs of induction motors [11]

Based on the energy savings presented in **Table 6**, by using a NEMA Premium efficiency motor, we can calculate the annual and lifetime monetary savings gained. Annual calculations are based on 4-pole motors operating for 8,000 hours per year. For the sake of argument, let’s use the low-end of the life expectancy of an induction motor—10 years. The results can be seen in **Table 7**.

Table 7. Annual and lifetime energy savings

hp	Annual kWh savings	Annual monetary savings	Lifetime monetary savings
10	3,105	$372	$3,726
25	5,160	$619	$6,192
50	8,630	$1,035	$10,356
100	15,680	$1,881	$18,816
200	29,350	$3,522	$35,220

This leads to extremely rapid payback periods, as the increased costs of the motor, which are relatively minimal, are quickly dwarfed by the yearly energy savings. In many situations, it makes more economic sense to replace a standard efficiency motor that is already in existence with a NEMA Premium efficiency motor, especially if repair or rewinding is required to maintain operation. Premium efficiency motors represent an excellent way for an industrial facility to save both energy and money on a rapid basis.

High-efficiency transformers

Description: As with the induction motor, transformers have been integral components in power systems for over a century. They operate by energizing a primary winding wrapped around a metal core in order to induce voltage on a secondary winding, usually at a new level. NEMA Premium efficiency transformers, similar to the motors, improve the performance of dry-type transformers over previous standards. An example can be seen in **Figure 11** [12].

Figure 11. NEMA Premium dry-type transformer

Such transformers are extremely common in commercial and industrial settings. By employing improved magnetic windings and core materials, they drastically reduce losses when compared with their traditional counterparts.

Estimated opportunity: NEMA Premium efficiency transformers provide an excellent opportunity for industrial and commercial facilities to improve their energy usage. **Table 8** presents the energy savings of NEMA Premium efficiency transformers compared to NEMA TP-1 and a 96% efficient classic transformer. Transformer efficiencies are based on operating for 8,000 hours per year.

Table 8. Energy savings in premium efficiency transformers [12]

kVA	NEMA TP-1	NEMA Premium efficiency	kWh savings vs. 96% classic	kWh savings vs. TP-1
30	97.5%	98.25%	1,937	658
45	97.7%	98.39%	3,079	905
75	98.0%	98.60%	5,563	1,304
150	98.3%	98.81%	11,988	2,206
500	98.7%	99.09%	43,769	5,583

The added efficiency of the transformers and the commonality of transformers in electrical systems make it clear that through small improvements in loss efficiency, transformers can save enormous amounts of energy.

Return on investment: The monetary savings from using a NEMA Premium efficiency transformer for new construction is readily apparent. The cost is slightly higher than the mandated NEMA TP-1, and the efficiency gains are obvious. However, there are often transformers that have been installed in buildings for decades, most of which will be closer to the classic 96% mark shown in **Table 8**. These transformers present an excellent opportunity for replacement, as the amount of energy and monetary savings incurred through the use of a NEMA Premium efficiency transformer will pay the cost back quickly. Based on the data presented in **Table 9**, we can calculate the annual savings versus each less efficient transformer type.

Table 9. Annual monetary savings vs. other transformer types

kVA	kWh savings vs. classic	kWh savings vs. TP-1
30	$232	$79
45	$369	$109
75	$668	$156
150	$1,439	$265
500	$5,252	$670

Let's assume that a facility is thinking about upgrading an existing 75 kVA classic transformer with a NEMA Premium efficiency unit. The cost for a new transformer is around $4,500. Given the cost savings per year, the premium transformer will pay for itself in 7 years. Given that transformers can last 20–40 years, it is clearly a sound investment. However, if a NEMA TP-1 unit is already installed, it is most likely not a viable investment to upgrade.

High-efficiency uninterruptible power supplies (UPSs)

Description: Most, if not all, commercial buildings today have some uninterruptible power supply (UPS) units installed to protect critical loads in office and/or data centers within the facilities. For years, the justification for these battery backup systems was reliability and protection of the load. For large systems, this insurance policy was enough to justify the cost for most situations. High-efficiency UPSs offer an opportunity for additional savings and justification.

Estimated opportunity: The most common version of UPS, the "on-line" or double conversion UPS, has significant losses and the end user pays for the reliability benefit at the expense of operating costs. Ten years ago, typical efficiency for these units was 88–92%. Today, however, with ever increasing cost and operation consciousness, the efficiency of these UPS units has been questioned. Fortunately, significant improvements have been made and the efficiency of new UPSs ranges from 94 to 96% and up to 99% with special operating modes, while still maintaining high reliability. For a typical small data center in a commercial building, the savings could be $10,000 per year operating in this mode.

Figure 12. High-efficiency UPS [13]

Table 10. Energy savings opportunity with UPS

kVA	kW savings vs. traditional UPS	Savings/yr. high efficiency UPS	Savings/yr. premium efficiency UPS
100	1–2 kW	$750	$1,575
550	5–13 kW	$4,800	$10,510
1100	10–28 kW	$11,500	$25,230

Table 10 shows an example of typical savings possible with high efficiency and premium efficiency UPS units.

Return on investment: The savings from using a new high efficiency or premium efficiency UPS varies by size of the UPS and depends upon the unit that the new UPS is replacing. Because the ROI of UPS units were likely not initially based upon energy savings but instead on reliability (i.e., preventing electrical downtime), the energy savings from high and premium efficiency UPS units goes right to the bottom line. The choice of one type versus another can now be justified upon the savings (i.e., paying a premium price for premium efficiency) but the payback is generally less than 2 years.

Lighting control

Description: Lighting loads in commercial facilities represent almost 40% of the total load, which provides an excellent opportunity for savings via reduction in energy consumption. While the lighting fixtures can be replaced with highly efficient LEDs, as previously described, advanced lighting control systems are becoming increasingly prevalent, and can provide even further energy savings. Some potential solutions are:

- Occupancy/vacancy sensors—ensure that lights are not in use when rooms are empty
- Daylight harvesting—utilizes natural light to minimize artificial lighting requirements
- Personal dimming control—allows individuals in an office environment to control the lighting in their room or space
- Plug load control—ensures that devices are not powered when they are not in use
- Lighting control circuit breakers—allows for intelligent, building-wide control of lighting systems to reduce waste

Figure 13. Lighting controller and intelligent circuit breaker [14]

Estimated opportunity: Lighting control systems can provide excellent energy savings for various applications. By either ensuring that lights are off when they are not in use, or reducing the amount of power being consumed to light a given room, the added controls can provide enormous benefits. **Table 11** provides information on percent energy savings from various solutions.

Table 11. Potential energy savings from lighting controls [15]

Solution	Potential energy savings	Contributing factors
Occupancy sensors	20–60%	Rate of room use
Dimming control	10–20%	Lighting preferences
Plug load control	15–50%	Rate of device use
Controlled breakers	15–30%	Rate of room and facility use

Energy savings with these technologies are dependent on application and site-specific utilization rates. If a room is utilized 100% of the time, occupancy sensors will not reduce energy use. However, at 50% utilization, significant energy will be saved. Selecting the right technology for your application is key.

Return on investment: The monetary savings that accompany lighting control systems are again dependent on the application. However, most of the technology is inexpensive relative to the high cost of energy consumed by lighting loads, and generally has a 1 to 5 year return on investment.

Penalty avoidance: Saving money without energy savings

Peak demand (kW) reduction

Description: Because kW demand charges are often as much as half of the total cost of an electric bill, any reduction in demand will add to the bottom line. There are several opportunities to reduce your peak demand without significantly changing your operations.

Demand reduction techniques:

- Shift loads from peak periods to off-peak periods (requires controls)
- Curb demand with controls eliminating "less critical" loads during peak periods (requires monitoring and relatively simple controls)
- Change loading with less "demanding loads" (i.e., using variable frequency drives or LED lighting)

Special note on solar installations: Interestingly, many people install solar panels and are surprised when their demand is not reduced. Understanding that unless your solar panels offset your peak demand every 15 minutes, every day, every month and all year long, there will inevitably be a "cloudy day" where you set your peak demand and all of your demand reduction savings are lost.

Some energy storage methods that allow a consumer to shift loads to take advantage of "off peak" kW demand or "kWh" usage pricing include:

- Ice storage
- Battery storage
- Pump storage

Estimated opportunity: 5–25% of overall energy bill.

Cost of implementation/ROI: Demand reduction programs through your local utility can be done manually and can offer huge benefits (i.e., $50,000 for one/two times per year for a 150,000 sq ft commercial building). Other programs with controls require significant investment, but payback periods are on the order of 1 to 5 years.

Power factor correction

Description: Utilities often penalize commercial and industrial customers if their power factor (PF) is lower than a desired level (0.95, for example). Other utility tariffs reward customers who exceed a minimal level, so whether your facility is rewarded or penalized ("carrot or stick"), your bill can be significantly reduced by installing PF correction equipment. Note that tariff structures are often confusing and you (and even your utility representative) may assume that you are not paying a penalty for a low power factor but, in fact, you may be paying a hidden charge.

Power factor correction solutions:

- Fixed or switched capacitors—depending on load levels and load changes. Obviously, the more complicated the unit (switched), the higher the cost and longer the payback. An example of a fixed capacitor can be seen in **Figure 14**.
- Fixed or switched harmonic filters. Today, every power system has some level of harmonics. Applying standard capacitors for PF correction may result in blown fuses or failures of the capacitors. Harmonic filters or "detuned" capacitors offer a reasonable solution for this harmonic issue. However, the cost of implementation is typically 2 to 3 times the cost of standard capacitors.

Figure 14. Fixed capacitor [16]

Estimated opportunity: Roughly half of all U.S. utilities have a PF penalty. If a penalty is in place, typical savings are 1–15% of the overall energy bill.

Cost of implementation/ROI: Generally speaking, a 10% penalty has a 6–18 month payback depending on the need for more sophisticated equipment (switched or harmonic filters). The ROI for a 1–3% penalty (greater than 8–10 years) is typically beyond an acceptable ROI for most companies. Additional benefits (capacity reduction) may help justify the installation cost but more detailed analysis is usually required.

Harmonic penalties

Description: In 1981, the Institute of Electrical and Electronics Engineers (IEEE®) developed a recommended practice for harmonic reduction, which was updated in 1992 to IEEE Std 519-1992. In 2014, the recommended practice was again updated and re-released. The intention of the standard is to minimize the effect of one utility customer on another customer when one customer has significant harmonic loads (drives, rectifiers, etc.). Historically, utility companies have not imposed penalties on the offending customers, but there have been instances where the utility forced one customer to change its operations or filter the harmonics so they didn't affect the neighboring customers. With the ever-changing environment on the utility grid and with the new standard, it is possible that utilities could impose a penalty on offending customers but today a reduction in harmonics for a customer would offer little or no energy savings, and therefore no monetary savings, on their utility bill.

Harmonic solutions:

- Line reactors and/or phase-shifting transformers
- Fixed or switched harmonic filters. An example of a switched harmonic filter bank can be seen in **Figure 15**.
- Active filters

Figure 15. Switched harmonic filter [16]

Estimated opportunity: No appreciable energy or demand reduction or cost savings today.

Cost of implementation/ROI: The return on investment for end users is strictly problem avoidance today (i.e., a power quality issue). A very slight kWH/kW reduction is achieved by reducing harmonics, but it is generally on the order of 1% or less and the payback is 30 years or more.

False energy savings

Everyone wants to save energy—and why not? With the cost of energy rising at unprecedented rates, even a small amount of savings can be a significant amount of money. The problem is that in most cases, the "low hanging fruit" has already been picked. This leaves the door open to new/alternative energy-saving devices. One category of devices that claims to save energy is power quality (PQ) solutions. Several types of PQ devices "claim" to save energy—some more than others. While most reputable manufacturers and consultants can quickly see through the black smoke, some of the not-so-obvious techniques are running rampant and getting through to end users (commercial, industrial and even residential), tarnishing the reputation of the entire industry.

It is said that any "good lie" has an element of truth to it. Many PQ solutions that are promoted as energy-saving devices actually do save energy, but the claims for the savings are greatly exaggerated. Short of turning off loads or a wholesale change in the type of loads used (lighting fixtures, for example), it is nearly impossible to save the 20–30% stated by some of these vendors.

Why is it that this is a "new" technique in selling? It capitalizes on the reduction in technical staffing at most facilities evaluating solutions, and relies on the complicated nature of PQ solutions. It also fits well with the need to demonstrate a short payback period that is required by most companies today. Budgets are hard to come by and having a solution that shows a "real" payback in two years or less is an easy sell. PQ solutions have historically been sold as insurance policies to protect against the "next" damaging sag, surge or interruption without guarantee of the number of times where the benefits are hard to qualify. By contrast, energy savings offer easy justification. For more information on these issues, please refer to [1] for detailed discussion.

Power quality and energy conservation

PQ and energy conservation are topics that are often commingled in papers and conferences. Generally, there are two reasons for this: most times, loads used to conserve energy—for example, variable frequency drives and compact fluorescent lights—impact power quality. Secondly, energy conservation and power quality often involve end user concerns where electric utilities or the government take a leadership role in promoting new technologies or mandating technologies. Because these topics are often considered together, there is opportunity for confusion and misleading information regarding energy savings.

There are generally two categories of PQ solutions that claim to save energy.

PF correction equipment:

- Black/green boxes with capacitors in them
- PF correction capacitors
- Harmonic filters

Other PQ solutions:

- Soft starters
- Harmonic mitigating transformers (HMT)
- Conservation voltage reduction (CVR) equipment
- Surge protection devices
- "Smart" receptacles/plug strips to eliminate "vampiric loads"

The first category, "Power factor (PF) correction equipment", includes the most common solutions that provide real opportunities for savings. These solutions can provide energy bill savings, but the actual savings result from reduction in penalties, not real kW or kWh savings, generally. So, in short, you can save money but you really cannot save appreciable energy.

The second group, "Other PQ solutions", generally offers much less or no real savings but these are often promoted as significant savings in an effort to have a quick payback and return on investment (ROI).

Energy that is wasted

The Electric Power Research Institute (EPRI) has evaluated many of the claims of potential energy savings devices and has presented many times on the potential of energy savings and power quality. They make the seemingly obvious observation that "You can only save energy that is wasted" [17], meaning that power required to do work cannot be eliminated from your electric bill not matter what you do short of applying a generator or source of energy locally. This statement is especially appropriate with the PQ solutions that claim to save energy. If a device saves all of the "potential" energy on a power system that it could, it can only save the energy that is wasted in losses throughout the system. Therefore, with typical system losses on the order of 1–4%, devices that eliminate these losses, at best, can only reduce your bill by 1–4%. Obviously, energy conservation methods (turning off the lights) and purchasing loads that require less work/energy (LED lights) are very valid methods of saving real kW on your energy bill.

Confusion created by sales methods

Various sales methods are used in order to promote the savings involved with applying PQ solutions. One of the methods is to claim significant benefits associated with the equipment related to the payback. Many are so called "hard-savings" but many are "soft-savings" that are associated with or a side benefit of the solution. Many of these are real savings but often significantly overstated.

Hard-savings include:

- Reduced energy (kWh) usage
- Demand reduction (kW)
- Improved PF
- Reduction in taxes
- Reduction in I^2R in conductors
- Reduction in equipment losses (motors, transformers, etc.)
- Operating cost reduction

Soft savings include:

- Reactive power savings (kVAR) ①
- Apparent power savings (kVA) ①
- Lengthens electrical equipment life
- "Enhances" electrical equipment life
- Improves "performance" of equipment
- Protects sensitive electronic equipment
- Reduces equipment replacement parts
- Reduces required maintenance
- Space savings
- Don't have to oversize equipment (generators, etc.)
- Less HVAC required to remove heat
- Protects the environment by reducing generation, emissions and waste
- Improves safety

① May be hard or soft savings depending upon billing structure of the utility company.

Other PQ solution providers use one or combinations of the following energy savings selling techniques:

- Confusing percentages—You can actually reduce the losses in a transformer and make your system more efficient by replacing a transformer with 97% efficiency with a transformer with 97.8% efficiency (true statement). This is a 0.8% increase in efficiency, but you could also claim that you have reduced your losses by 27%. Saving 20–30% of losses (when the losses are 2.2% to 3.0% of the full load of the transformer) is not equal to saving 20–30% of the total energy used by the load
- Inferences and over generalizations from "similar" measurements. This is especially true for PF penalty savings. For example, just because the product saved 12% in Alaska doesn't mean that it will save the same amount in New York
- Lack of a practical method of showing the equipment in the circuit versus out of the circuit
- Inappropriate measurement duration—Taking a single snapshot or averaging a very long measurement are both opportunities to hide the truth in the numbers
- Hard to prove or disprove guarantees—One method of selling this equipment that has been successful (unfortunately for the end user) is locking in the sale of the PQ vendor's equipment only with a guarantee of energy savings. This pseudo "performance contract" sale means that the end user must purchase only the PQ supplier's equipment and not only that, usually, the PQ vendor insists that the end user must install the PQ solution at every "possible" location for savings. The catch in the guarantee is that the PQ vendor requires a substantial effort from the end user to prove that energy was not saved. Many of the guarantees are stated as guaranteed energy savings of "up to" some excessive value. For example, up to 35%, when in reality the actual savings for 99.9% of all facilities is much less than 5%
- The use of kVA versus kW is an easy method for a rep to make claims of significant improvement without having to "lie". It is not unrealistic to see a 20% savings in kVA for a poor power factor load but the actual energy savings is much less than 5%
- Most often, it is simply the passion of the rep selling the equipment that lends credibility to the energy savings story
- If the end user is not technical (ideal for the PQ vendor/rep), the PQ vendor may show apparent savings at a location in the customer's facility and then ask their most senior "technical person" sign off on the savings. Then the sales person goes to the company's financial representative to sign off to complete the sale

Solutions that claim to save energy

Below are several PQ related solutions that have either a primary or secondary claim of energy savings. A short paragraph with each item describes the claimed savings and details of why the claims are likely overstated. **Table 2** summarizes each solution with the claimed energy savings and the actual expected savings along with summary comments regarding the potential reasons for discrepancies.

"Black box" all-in-one solutions

Description: These are all-in-one solutions that claim to reduce your power bill by improving voltage balance, reducing transients and improving power factor. Some of these units are passive components (surge suppressors, capacitors, balancing reactors, harmonic filters) and some have power electronic components for voltage and current conditioning. The descriptions are very vague and difficult to understand for typical end users. Often times, these "black boxes" are painted "green," which apparently helps with the energy savings. Unfortunately, lately these companies have begun to prey on unsuspecting residential customers. These customers have little to no chance of understanding what they have purchased but are typically desperate to save money on any energy bills.

Stated/claimed savings or payback: Up to 35% energy savings.

Actual/realistic range of payback: Some of the claims are somewhat true but largely overstated. Unless the utility company imposes a PF penalty, realistic energy savings of less than 3% are typical. Residential customers actually save little or no energy because they install these boxes, usually containing a small PF correction capacitor, at their main service. Savings created by capacitors only impact the losses on the upstream feeders, saving a small amount of energy for the utility (in losses through the service transformer) but saving the customer nothing.

Harmonic filters and power factor correction

Description: A manufacturer of harmonic filters claims that their filter reduces currents and harmonic energy losses in the main transformer, resulting in significant energy savings to the facility.

Stated/claimed savings or payback: Reduces energy consumption significantly by several percentage points of the current energy consumption. The claim points out that the currents in the transformer are reduced significantly, and that harmonic heating in the transformer is reduced significantly. It points out that eddy-current related loss in the transformer is proportional to the square of the frequency.

Actual/realistic range of payback: The harmonic filter does reduce 60 Hz fundamental current in the transformer, which is the same benefit as ordinary power factor correction. However, these savings are much less than 1% of the energy load.

Harmonic mitigating transformers (HMTs)

Description: HMTs are phase-shifting transformers of various configurations (wye/zig-zag, delta/zig-zag, etc.) that allow recirculation of third harmonic currents on the secondary of the transformer (instead of allowing them to flow into the delta windings and cause additional losses in the transformer and upstream). They are typically low loss (winding and core) transformers and inherently save energy versus standard transformers. They are often used in pairs or multiple sets for higher order harmonic cancellation (5th, 7th, 11th, 13th, etc.). In this way, they eliminate the harmonic currents upstream of the transformer(s) and reduce I^2R losses.

Stated/claimed savings or payback: Up to 20% energy savings versus standard transformers or loss reduction of 30%.

Actual/realistic range of payback: Loss reduction is possible (based on example given earlier) but 30% loss reduction may equal 1–2% or so of actual energy savings (or points of efficiency).

Soft starters

Description: Many people believe that the use of soft starters will reduce the peak demand on their energy bill and many (unknowing) salesmen sell this benefit. Generally, we believe that it is an innocent oversight based on the lack of understanding.

Stated/claimed savings or payback: Reduces peak demand and reduces kW billing by a certain amount depending on the size of the motor versus the total load.

Actual/realistic range of payback: Soft starters reduce the peak draw of (primarily reactive) current during a motor starting condition that typically lasts 3–10 seconds. This short period is a small fraction of a 15-minute average demand window where the utility records peak demand. Soft starters are useful for reducing the voltage drop caused by large inrush currents to motors during the starting condition but do not save energy or demand.

Conservation voltage reduction (CVR) products

Description: For years, electric utility companies have practiced voltage reduction, often called "brownouts" to reduce load on their power system. The thought was that constant impedance loads would draw less current and, thus, less power. Simply stated, for many lighting loads (i.e., residential), this is true but it also results in lower light intensity, perhaps below acceptable levels. For other constant impedance loads that require a certain amount of heat generated (i.e., electric dryer, hot water tank, heater, etc.) the load may draw less kW instantly but will require longer thermal cycles to achieve the goal of heating or drying. For constant power (i.e., motor) loads, there is no savings benefit because if the voltage goes down, the current goes up. Also, from a utility point of view this increased current translates into a need to provide increased reactive power. On a stressed utility line, finding sufficient VARs is a problem. As a result, the action of reducing the voltage in this condition only exacerbates the problem. The concept of CVR has been instituted into electronic and magnetic component low voltage designs that are installed with the promise of significant energy savings.

Stated/claimed savings or payback: 3–13% of energy and demand.

Actual/realistic range of payback: Less than 2% on aggregate systems (i.e., multiple types of loads) and up to 13% in rare cases on a specific load. Typically cost per load installing it on a specific piece of equipment may be more economical building into the equipment or by using fixed tap regulation.

Proving the point—power quality lab

A power quality laboratory was designed and built near Pittsburgh, Pennsylvania as the ideal setting for testing and evaluating energy saving solutions. The lab is a significant part of a 14,000 square foot demonstration and test facility, the Power Systems Experience Center (PSEC) (www.eaton.com/experience) where most of the solutions mentioned in this paper have been evaluated.

Figure 16. Eaton's Power Quality Laboratory at the PSEC

The authors can confidently state that the information presented in this paper is an unbiased evaluation of these solutions. Future work at the PSEC will include further testing and optimization of energy-saving solutions for industrial, commercial, data center and residential applications.

One example of the testing that was done at the PSEC is shown in **Figure 17**. During this test, a 75 kVA transformer was subjected to 100% linear, resistive load and then to 100% harmonic load (computer power supplies). This figure shows that transformer losses, in this case, increased loading by approximately 1% across the loading of the transformer. This clearly indicates that there are some savings available by reducing harmonic currents on the power system but maybe not as much as some would claim.

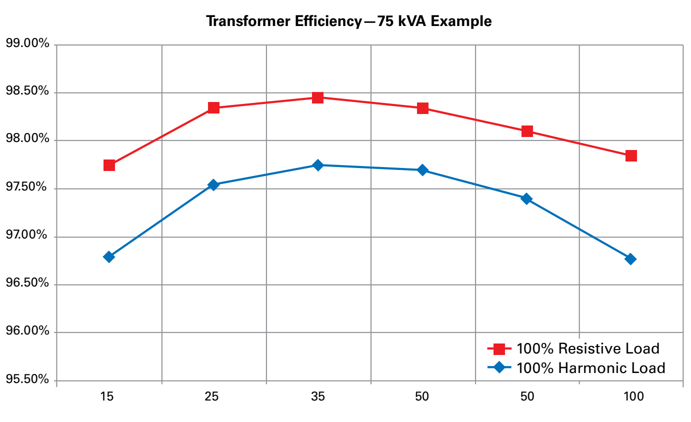


Figure 17. Transformer losses with 100% resistive load and 100% harmonic loads

Conclusion

There are many opportunities to save money by applying proven solutions to commercial facilities but buyer beware—if it sounds too good to be true, it probably is. The intention of this paper was not to argue the detailed technical aspects of each solution, per se, but rather to point out the pitfalls in believing the information publicized regarding these types of equipment. Using proven methods and measurement techniques, commercial facilities can save money on their electrical energy bill and improve their bottom line.

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Daniel J. Carnovale, PE, developed and is the manager of Eaton’s Power Systems Experience Center (PSEC—www.eaton.com/experience) in Warrendale, PA. The PSEC is a full-scale demonstration and test facility focused on power quality, energy management and arc flash safety. He has developed and teaches technical seminars on power systems and power system analysis, and he has conducted several hundred power quality site investigations for commercial, industrial and utility power systems. Prior to Eaton, Dan worked for Westinghouse Engineering Services and ABB Power T&D, where he performed power quality field investigations and electrical distribution system analysis. Dan received his B.S. in Electrical Engineering from Gannon University in Erie, PA, his M.S. in Power Systems from Rensselaer Polytechnic University in Troy, NY, and an MBA from Robert Morris University in Pittsburgh. *He is a registered Professional Engineer in the states of Pennsylvania, California and Alaska, a Certified Energy Manager (CEM), and a Senior Member of IEEE.*

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Ansel Barchowsky graduated from the University of Pittsburgh with a Bachelor of Science in electrical engineering. He is currently continuing his electrical engineering studies while working toward a PhD at the University of Pittsburgh. Ansel was previously an undergraduate researcher with the Mascaro Institute for Sustainable Engineering, performing research in smart grids and photovoltaic integration. He subsequently worked with Mitsubishi Electric Power Products Inc. as a system studies intern. He currently works as a design consultant for Eaton’s Power Systems Experience Center in Warrendale, PA. His research interests include integration of renewable energy sources, modeling and analysis of power electronics devices, maximum power point tracking in photovoltaics, and development of HVDC technologies. Ansel is a student member of the IEEE PES and IEEE PELS.

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Bri Groden is an engineer at Eaton’s Power System Experience Center based in Warrendale, PA. Her responsibilities include teaching power quality and power distribution topics, running demonstrations, and designing and managing the installation of new demonstrations and projects. Bri began her career with Eaton’s Global Sales and Marketing group in Philadelphia, PA, and participated in Eaton’s Leadership Development Program for Technical sales in Baltimore, MD. She then worked as a distributor sales specialist role with the Seattle sales team. Later she transitioned to project management, supporting Seattle’s project construction and industrial sales teams. Bri received her B.S. in Electrical Engineering from Syracuse University in Syracuse, NY, and certificate of Project Management from the University of Washington in Seattle, WA.

Table 12. Power factor penalties

Rate type	Description of PF penalty	Example
kVA (demand) rates	Penalty for < 1.0 PF; generally applied as a $/kVA	Demand = 800 kW; PF = 80%; kVA = 1000; demand charge = $10/kVA PF penalty = (1,000–800) * $10 = $2,000/month
PF (kVA) adjustment	When the PF is less than X%, the demand may be taken as X% of the measured kVA	When the PF is less than 90%, the demand may be taken as 90% of the measured kVA PF = 80%; kVA = 1000; demand charge = $10/kVA Billed demand = 0.90 * 1000 = 900 kW PF penalty = (900–1,000 * 0.80) * $10 = $1,000/month
PF ratio (kW demand) adjustment	If the PF is < X%, the demand will be adjusted by the following: X%/actual PF * actual demand = adjusted demand	If the PF is < 85%, the demand will be adjusted by the following: 85%/actual PF * actual demand = adjusted demand. Demand = 800 kW; PF = 80%; Demand charge = $10/kW Adjusted demand = (0.85/0.80)*800 = 850 kW PF penalty = (850–800)*$10 = $500/month
PF magnitude (kW demand) adjustment	PF adjustment increases or decreases the net (kW) demand charge X% for each Y% the PF is above or below the utility specified PF	Where the PF is < 85%, the net demand charges shall be increased 1% for each whole 1% the PF is < 90%; likewise, where the PF is higher than 95%, the demand charges will be reduced by 1% for each whole 1% the PF is above 90%. Demand = 800 kW; PF = 80%; demand charge = $10/kW Up to 90%, demand adjustment = 800 * 10% = 80 kW (from 80% to 90%) = net demand of 880 kW If PF is corrected to 1.0, PF adjustment (reduction) = 800 * 10% = 80 kW (from 90%–100%) = net demand of 720 kW Correcting PF from 80% to 100%, potential net savings is (880–720) * $10/kW = $1,600/month
PF multiplier (PFM)	Demand is increased (or decreased) by a calculated multiplier determined by a utility table or by a formula	Demand = 800 kW; PF = 80%; PFM = 1.086; demand charge = $10/kVA PF penalty = 800 * $10 * (0.086) = $688/month
kVAR demand charge	$X per kVA of reactive demand in excess of Y% of the kW demand	$0.45 per kVA of reactive demand in excess of 50% of the kW demand Demand = 800 kW; PF = 80%; kVAR demand = 600; excess kvar demand = 600–800 * 0.50 = 200 kVAR PF penalty = 200 kVAR * ($0.45/kVAR) = $90/month
kVARh charge	$X per kVARh	$0.000835 per kVARh kVARh = 500,000 PF penalty = 500,000 * 0.00835 = $417/month
kWh adjustment (note that this often applies where the kW demand is first adjusted)	$P/kWh for first Q*kWh*demand $R/kWh for next S*kWh* demand $X/kWh for next Y*kWh demand $Z/kWh for all additional	$0.040/kWh for first 100 kWh * demand $0.035/kWh for next 150 kWh * demand $0.025/kWh for next 150 kWh * demand $0.020/kWh for all additional kWh Actual demand = 800 kW; Adjusted demand = 1000 kW; kWh measured = 500,000 With penalty 100 * 1000 = 100,000 kWh @ 0.04/kWh = $4,000 150 * 1000 = 150,000 kWh @ 0.035/kWh = $5,250 150 * 1000 = 150,000 kWh @ 0.025/kWh = $3,750 (500,000–100,000–150,000–150,000)*$0.02/kWh = $2,000 Total = $15,000 Without penalty 100 * 800 = 80,000 kWh @ 0.04/kWh = $3,200 150 * 800 = 120,000 kWh @ 0.035/kWh = $4,200 150 * 800 = 120,000 kWh @ 0.025/kWh = $3,000 (500,000-80,000-120,000-120,000) * $0.02/kWh = $3,600 Total = $14,000 Penalty = $15,000–$14,000 = $1,000/month (in addition to demand penalty)

Table 13. Summary of claimed savings vs. realistic savings

Description	Primary PQ benefit	Stated EM savings and other benefits	Realistic EM savings	Reason for discrepancy
Products to address negative sequence currents	Negative sequence current reduction	Eliminates "reverse" rotation action on motors, yielding higher efficiency kW and kWh savings (usually >10%) Reduces heating Prevents premature damage	kW and kWh savings (usually <2%)	Hard to measure and disprove stated claims Easier to stretch the truth based on "some" savings
Products to address unbalanced voltages (including zig-zag reactors)	Negative sequence current reduction	Eliminates "reverse" rotation action on motors, yielding higher efficiency kW and kWh savings (usually >10%) Reduces heating Prevents premature damage	kW and kWh savings (usually <2%) May actually increase kW usage in some cases	Hard to measure and disprove stated claims Easier to stretch the truth based on "some" savings
Surge protection	Elimination of voltage transients	kW and kWh savings (usually >20%) Prevents damage Reduces need for maintenance Improves performance of equipment	0.000%	Uneducated consumers
PF correction	Reduce kvar flows on power system	kW and kWh savings (usually >20%) Prevents damage Reduces need for maintenance Improves performance of equipment	0.5–2% typical (excluding harmonics) If electric utility charges PF penalty, PF charges may actually save 10–30% or so (not kW or kWh savings)	Easy to show large kVA changes based on reducing kvar—salesmen may purposely interchange kVA and kW to cause confusion Note: PF penalty is not the same as kW or kWh savings even though a multiplier is often used on kW yielding a penalty
Harmonic filters (passive, active)	Control harmonic currents on power system. Reduce kvar flows on power system	kW and kWh savings (usually >20%) Reduce heating in equipment Reduces need for maintenance Improves performance of equipment	0.5–8% based on location—highest savings for filtering close to loads (plus PF savings)	Confusion created between eliminating harmonic currents and reactive (kVAR) power from load versus saving real kW or kWh—harmonics are reactive current/power
Black box solutions	Balance voltage, PF correction, harmonic reduction, surge protection, voltage regulation	Up to 30% kW and kWh Combinations of all other solutions including surge protection, harmonic reduction, phase balancing, etc.)	Less than 3% in most applications with typical combination loads	Hard to focus, measure and prove or disprove Often "not allowed" to see what is in the box (usually capacitors with MOVs)
Residential black box solutions	Eliminate "wasted" energy in the form of heat in your home	Up to 35% of your bill	Little or no savings because unit is a capacitor with MOVs installed at service entrance (only saving losses upstream) Typically <1%	Uneducated consumers Hard to disprove looking at month-by-month data—some months consumers will "believe" they saved energy but fail to consider variables like heating/cooling days, etc.
Harmonic mitigating transformers (HMT)	Do not allow third harmonic to circulate and/or pass through transformer windings. In combinations, cancel 5th, 7th, 11th, etc.	Up to 20% savings kW and kWh by reducing harmonic currents 30% reduction in losses Very low core losses Very low winding losses	kW and kWh savings are often significantly overstated Typical savings <4% Loss savings is correct but may be misleading	Confusion created by the numbers or use of kVA and kW savings Show very low loss (expensive) transformers in model and apply more typical TP-1 transformers
Neutral blocking filter	Eliminate third harmonic from transformer secondary and downstream to load	Reduces I^2R losses resulting from third harmonic from source to load up to 10% of energy from system Reduce current flow (increase capacity)	0.5–8% based on load mix (i.e., content of harmonic versus linear) Typically 1–3%	Need a bypass switch to prove with similar/same load
Soft starter	Minimizes voltage drop during motor starting	Eliminate peak demand (kW) demand during motor starting (up to 6X motor full load power)	Very close to zero (not perceivable in the big picture) because demand is 15 to 30 min average—motor starting is less than 10 seconds Motor starting is mostly reactive current anyway	Lack of education of consumers and sometimes salesmen
Conservation voltage reduction (CVR)	Regulate voltage at 5–10% lower than nominal to reduce load on power system	Up to 30% energy and demand savings Improved operation of equipment	Individual load basis, some loads exhibit up to 20% savings but on a normal power system, net benefit is typically less than 2% May reduce instantaneous power but more power is required to complete work (heat, etc.) May reduce light intensity below required value	Typically proven on one load and assumptions made on multiple loads Hard to measure and prove or disprove

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