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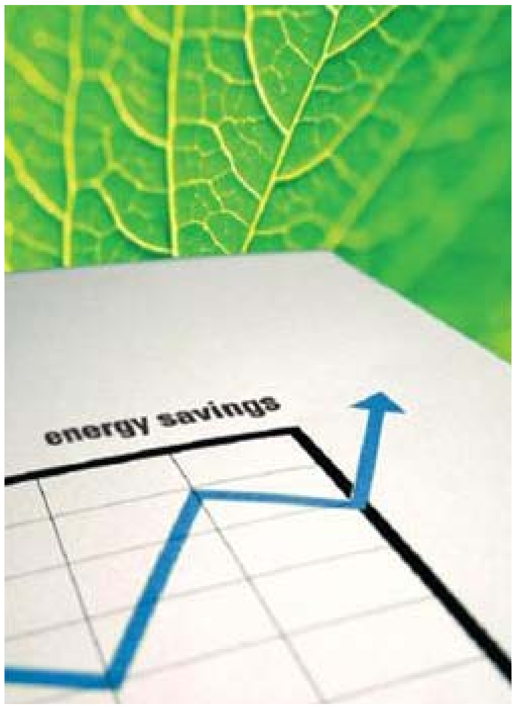
Power Quality Solutions and Energy Savings – What is Real?



ABSTRACT

One of the most significant changes in the Power Quality industry in the past five years is the method of selling Power Quality solutions. Originally, Power Quality solutions were sold as an insurance policy to avoid potential damage from power disturbances such as transients, voltage sags, interruptions or harmonics. Today, many Power Quality solution providers have found it more effective to promote energy cost reduction associated with their products rather than to deal with the soft savings associated with minimizing downtime or reducing damage to electrical equipment. The problem is that some of these solutions providers have significantly overstated the savings and the customers are deceived. While these solutions provide excellent protection, they often provide very little, if any, energy savings. This paper will discuss work being done to evaluate the actual savings expected from various Power Quality solutions and will give some guidance as to the selection of these solutions based on energy savings.

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Introduction

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 PQ devices "claim" to save energy – some more than others. The amount of savings "available" from these devices appears to be directly proportional to the mystique of the device and the passion of the salesperson representing the product. Some of the "black-box" PQ solutions available today apparently correct all known PQ problems while reducing energy costs by 10-30%. With a savings like that, why wouldn't a controller consider these solutions? While most reputable manufacturer 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 about it. Many Power Quality solutions that are promoted as energy saving devices actually do save energy, but the claims for the savings are greatly exaggerated, where the actual savings would be far less than the stated value. 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. This problem is expected to worsen as the current energy crisis is likely to result in intensified interest in energy conservation techniques.

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 capital payback period that is required by most companies today. Capital budgets are hard to come by and having a solution that shows a "real" payback in two years or less is an easy sell. Power Quality 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 offers easy justification.

In addition to these overstated claims, many times these so-called all-in-one solutions may solve one problem but tend to exacerbate another. They are applied without consideration for the system as a whole. For example, some "black-box" solutions correct power factor using standard low voltage capacitors but may do so without regard to potential overvoltage concerns or harmonic resonance considerations. This paper summarizes the authors' experiences with several of these equipment suppliers and the sales methods that they use to confuse the end users enough to close a sale.

Power Quality and Energy Conservation

Power Quality and energy conservation are topics that are often commingled in papers and conferences such as this conference. Generally, there are two reasons for this: most times, loads used to conserve energy – for example adjustable speed 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 Power Quality solutions that claim to save energy:

PF Correction Equipment

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

Other PQ Solutions

- Negative sequence current reduction
- Neutral blocking filter
- Surge protection
- Soft starters
- Zig-zag reactors
- Harmonic mitigating transformers (HMT)
- Conservation voltage reduction (CVR) equipment
- Green plug

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 and some of the opportunities are significant but the actual savings result from reduction in penalties, not real kW or kWh savings, generally.

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

"You can only save 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," [3] 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 (compact fluorescent lights) are very valid methods of saving real kW on your energy bill.

PF Correction and Your Utility Bill

Can capacitors and other PF solutions help you save a significant amount of money on your utility bill? Absolutely – IF you have a power factor penalty you can save on the order of 10-30% of your electric bill and have a 1-2 year payback! However, not every utility company charges a penalty for poor power factor.

How would you know if you are paying a penalty? It is not the intention of this paper to discuss power factor penalties in detail but rather to discuss the relationship between PQ and energy savings. This section of the paper simply presents an overview of power factor considerations so that the reader will have a basis to investigate their utility bill considering power factor penalties. Table 1 [12] shows a number of different types of power factor penalties. Most are straightforward and can be analyzed by engineers and end users 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 1 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. Many customers receive billing through the local municipality or Co-op. The power factor penalty may be levied by the power supplier to the Co-op and the penalty adjusted in the demand charge. It may look like a reduction in kW when the penalty is removed.

Again, all of these savings are based on the premise that the utility company charges a penalty. If not, it is still possible to save money but usually an order of magnitude less than with a penalty.

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)*
- Apparent power savings (kVA)*
- 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

* 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:

- A method that some salesman use or publicize in promotional marketing literature is to call upon stated "industry experts" or customer testimonies to sell the product. Giving third party accreditation (universities, government bodies, experts, newspaper articles, internet site, etc.) lends credence to a sales story. While most of these methods are credible methods of selling, in the context of promoting energy savings for PQ solutions these methods present a dilemma for the end customer and they are often "frightened" or "embarrassed" into purchasing the solution. References from sources such as the Department of Energy (DOE), Green Buildings, the US President (Executive Orders), FEMP and Energy Star carry significant weight in selling credibility. In addition, claims that the solution will "make them a hero to their boss" are often hard to dismiss and ignore. Sometimes seeing the name of a close competitor on a customer list provided by a PQ solution provider is incentive enough to believe the claims and move forward with using the product.
- 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.
- Faulty or questionable measurement and verification (M&V) – In many instances, these products are sold based upon hard-to-prove claims that are difficult to dispute. The measurement and verification methods can contribute to the ambiguity and confusion.

- Inferences and overgeneralizations from "similar" measurements – assumptions are made regarding the potential and actual savings that will result at a site without actually measuring the results. The power system components or the actual PQ solution may not exhibit the savings that are claimed. 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. As with any good marketing program, these vendors will only show the situations where customers saved significant money versus the many others who had little or no savings.
- Revenue grade metering – without using revenue grade metering (including CT's and PT's, where applicable), small inaccuracies in measurements can translate to large overstated claims. Especially under conditions where the load on a transformer, for example, is much less than 50% (a typical situation). This means that the difference in current or kW with and without the corrective equipment may be less than 1% of the full load capability. For example, if the load on a 75 kVA transformer is 15.1 kW and the measured load with the corrective equipment in service is 14.7 kW, this 400 W difference may seem significant but may be partially due to phase shift errors in the CT's especially when harmonic currents are involved.
- CT inaccuracies – low quality CT's or light loading on the system may yield phase angle errors that will contribute to PF difference and could translate into kW differences. This difference may yield false positive results between conditions where PQ equipment is installed and tested versus when it is out of the circuit.
- Lack of a practical method of showing the equipment in the circuit versus out of the circuit – many times, if the PQ equipment is connected in "series" with the load, there is not an easy method of showing the equipment in the circuit and then immediately out of the circuit (unless the equipment has a bypass switch). Therefore, it is very difficult to insure that the loading has not changed or some other important variable like ambient temperature has not altered the results and consequently, the measurements during the time it takes to add or remove the equipment for testing.
- Inappropriate measurement duration – taking a single snapshot or averaging a very long measurement are both opportunities to hide the truth in the numbers. The method that results in the highest "proven" savings is usually used regardless if, in reality, the savings are actually realized.
- 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. Basically, it works like this: end user XYZ purchases a "system" of black box solutions from the PQ vendor and the system consists of one piece per distribution panel in the factory. In the end, the end user purchases 35 pieces of equipment with the promise of energy savings for the installed "system" solution. 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. The PQ vendor will only pay the difference in the cost of the total installed equipment minus any savings that the end user can prove were NOT saved as a result of the installation of the PQ equipment! In the absolute worst case (for the PQ vendor), they lose their cost of the supplied equipment but it infrequently comes to this. To further complicate things, there are substantial data requirements left as a burden to the end user to determine (typically over a period of two or more years). The end user must research temperature and humidity information, electrical parameters of the loads and other difficult to find information in order to disprove any savings. Most customers simply either accept the savings as real (unfortunately) or write off the money spent on the solution and move on. Finally, 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 Safety Card" – If the PQ vendor has a marginally believable story regarding the actual versus potential energy savings, they may bring up enhanced safety as icing on the cake. Unfortunately, once the topic of safety is introduced, some managers feel compelled (or more likely trapped) into purchasing the equipment. Safety solutions basically eliminate the need for proving the payback.
- The use of kVA versus kW is an easy method for a rep to make claims of significant improvement without having to "lie". Equipment that corrects the power factor is capable of significantly improving the kVA but has minimal effect on kW. 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%. Unfortunately, a majority of the US utility companies bill on kWh and kW demand. Simple power factor correction methods (including harmonic filters) are generally the least expensive and practical method of improving the power factor for those instances where kVA rates are enforced.
- Most often, it is simply the passion of the rep selling the equipment that lends credibility to the energy savings story. Many times, non-technical representatives are recruited to sell these products. To further complicate things, unless the rep is an engineer and fully understands the claimed savings, they may not realize that they are selling snake oil and they believe the seemingly credible training and promotional information of the product manufacturer. The authors have actually been told by one of these passionate reps, "You are thinking like an engineer – it is likely that you won't understand how the savings works – it's almost like you are too smart to understand!" How do you respond to that statement?
- 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 guy" sign off on the savings. Especially in the case of kVA savings from PF correction, this is a relatively simple opportunity for confusing sales techniques. Once the "technical sign off" has occurred, the PQ vendor takes the opportunity to tell the end user that the equipment will offer very similar savings at all of the proposed locations in the plant. They often then move to the controller or financial person responsible for paying the bills with the "technical sign off" in hand. This limits the selling effort to the most probable and easiest to prove location in the facility, usually a small lightly loaded motor where power factor correction is a natural opportunity. For these shameless companies, as soon as they determine that you know Ohm's Law, they pack up and move on to the next customer.

Solutions That Claim to Save Energy

Below are several Power Quality 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 magical boxes 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 with fuel prices at all time highs.

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. See surge protection, PF correction, harmonic solutions and unbalanced voltage solutions for descriptions of components. 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.

Backup Information (test lab, papers, etc.): See Unbalanced Voltage Solutions, PF Correction, Harmonic Solutions and Surge Protection

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 60Hz 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.

Products that Reduce Negative Sequence Currents in Motors

Description: Voltage unbalance or negative sequence voltage harmonics (i.e. 2nd or 5th harmonic, typically) cause the rotor of an induction motor to resist its normal rotation. This resistance causes inefficient operation in the motor, vibrations and heat that may cause premature failure. Linear loads (motors) will draw a "non-linear" current with components of current proportional to the voltage distortion.

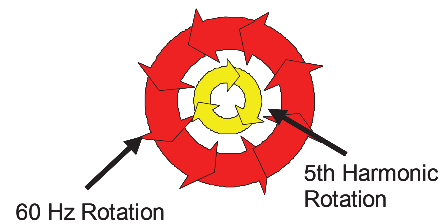


Figure 1. Negative Sequence Current and Motors

Stated/Claimed Savings or Payback: Improved motor efficiency and reduced failures by > 10%.

Actual/Realistic Range of Payback: Claims are primarily true but typically overstated. Unbalanced currents caused by unbalanced voltages, (see NEMA MG-1), are often 6 or more times the unbalanced voltage percentage. Therefore, the "system" will have more I^2R losses than with balanced voltages and currents. In addition, negative sequence harmonics, primarily 5th harmonic, causes an opposing force to the positive sequence (60 Hz) rotation. This is like driving with your foot on the brake while you are moving forward with your foot on the gas to overcome the brake resistance. It creates system losses, heat and premature failure but realistic savings is on the order of 2% or less.

Backup Information (test lab, papers, etc.): Reference [1], Reference [2]

(Balancing) Zig-Zag Reactors

Description: Zig-zag reactors have the effect of balancing voltages and canceling some harmonic current and reactive current from the loads. In general, under unbalanced voltage conditions, they reduce overall current flow from the load and can reduce I^2R losses upstream. When these devices are connected in series with the load, it changes the way power is drawn from the sources. It is often difficult to measure before and after installation (unless a bypass is available) to show savings under constant load conditions.

Stated/Claimed Savings or Payback: Up to 20% energy savings

Actual/Realistic Range of Payback: I^2R loss savings could be up to several percent. This particular device requires very highly calibrated equipment and CT's to measure savings since much of the difference with and without the equipment is shown via a PF benefit and reduction in upstream losses. Interestingly, sometimes a small amount of kW is saved when these devices are installed and sometimes a small amount of kW is lost when they are installed.

Surge Suppressors

Description: Surge protectors (transient voltage surge suppressors – TVSS or surge protective devices – SPD) equipment is installed at various locations throughout the facility to reduce "damaging" transients that "waste energy". Claim is that transients cause heat that wastes energy. Statements like, "every time you type on your typewriter, you create micro transients that waste energy….." are made and confuse non-technical end users.

Stated/Claimed Savings or Payback: Up to 20% energy savings if installed at all recommended locations.

Actual/Realistic Range of Payback: None, nothing, zero, 0.000%.

Backup Information (test lab, papers, etc.): Reference [7] and many Internet links including federal websites.

Harmonic Mitigating Transformers (HMT's)

Description: HMT's 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, 13, 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). With transformer designs (lower winding core losses) and harmonic reduction, improvements of 5% are possible. In ideal conditions, 8-10% energy savings are possible but very rare. Still, these devices will considerably improve the Power Quality of the system and over a 30-40 year life, these transformers will pay for themselves in savings 6-8 times with no maintenance. So, although they don't have a 2 year payback, these transformers are considered a very good investment.

Backup Information (test lab, papers, etc.): Reference [4], Reference [5].

Neutral Blocking Filters

Description: A 3rd harmonic high impedance blocking filter is inserted in the neutral connection of a 120/208 V transformer. This impedance does not allow 3rd harmonic current to flow in the neutral, thus, effectively eliminating it in the phase conductors and in the load. It is most effective in situations where a significant number of single-phase switch mode power supplies are installed. This reduces the rms current throughout the system and is unique in that it eliminates 3rd harmonics upstream and downstream.

Stated/Claimed Savings or Payback: Up to 8% energy savings

Actual/Realistic Range of Payback: Claims are true but are typically less (1-3%) depending on load mix.

Backup Information (test lab, papers, etc.): Reference [4], Reference [5]

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 of the salesman or end user but sometimes the salesman knows better.

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 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 LV 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: < 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.

Backup Information (test lab, papers, etc.): Reference [3] and many sources on the Internet.

Energy Saver Plug

Confusion in the evaluation of energy savings projects is not limited to industrial facility managers. The Canadian Office of Energy Efficiency provided cash awards to university student projects related to energy efficiency – specifically, how using energy wisely reduces greenhouse gas emissions that contribute to climate change. A 2005 award went to a project promoting the use of The Green Plug.

The project website [9] has this amazing text:

> *"The actual savings available through the green plug are difficult to measure, he added. But he estimated that power producers could expect to experience a drop of 10-20 percent in power and energy consumption if the green plug is used extensively."*

Wow! That's something. No wonder the project won an award. But what is this green plug?

> *"The Green Plug was invented by my thesis advisor, Dr. A.M. Sharaf," said René. "It's really a Modulated Switched Dynamic Filter Capacitor Compensator, a device designed to make existing power systems more powerful and energy efficient by reducing the amount of reactive energy and harmonic currents that are generated by electrical residential and commercial loads."*

Oops, we've heard some of this before. The "beauty" of the green plug is that it is hard to understand, and hard to measure the savings. But does it actually save significant energy? The troubling part of it is that the claims are reductions of reactive power and harmonic energy. It is hard to believe the energy savings are nearly as significant as claimed.

Authors' Viewpoint

We have done the calculations. We have done the measurements. We have talked to the vendors. We simply do not believe the excessive claims of real energy savings with PQ solutions. Can you save significant money with PF correction? Yes, IF there is a penalty. The authors strongly believe in the reliability improvements offered by well designed PQ solutions. However, we offer the information in this paper so that the reader can fairly evaluate these solutions for what they are instead of based on the energy they "save".

Power Quality Lab

A Power Quality Laboratory was designed and built near Pittsburgh, Pennsylvania. This lab has become the ideal setting for testing and evaluating PQ solutions especially as they relate to energy savings. The Power Quality Lab is a major component in an 8000 square foot demonstration and test facility/Experience Center (http://www.eaton.com/EatonCom/Markets/Electrical/ServicesSupport/Experience/index.htm) where most of these solutions mentioned in this paper have been evaluated. The authors can confidently state that the information presented in this paper is an unbiased evaluation of these solutions. Future work in the PQ Lab will include further testing and optimization of energy saving solutions for industrial, commercial, data center and residential applications.

Many Power Quality solutions have been tested in the PQ Lab over the past two years. These include capacitive devices, harmonic filters, surge protectors and black box combination solutions. In addition, tests have been performed on Harmonic Mitigating Transformers (HMT) and UPS solutions in an effort to determine what opportunities exist for energy savings based on design and harmonic loading. The graphs below summarize some of the results of these tests indicating realistic savings.

Figure 2 shows the results of a test where a 75 kVA transformer was subjected to 100% linear, resistive load and then to 100% harmonic load (computer power supplies). This figure clearly shows that transformer losses, in this case, increased loading by 1% across the loading of the transformer. This clearly indicates that there are some savings available by reducing harmonic currents on the power system.

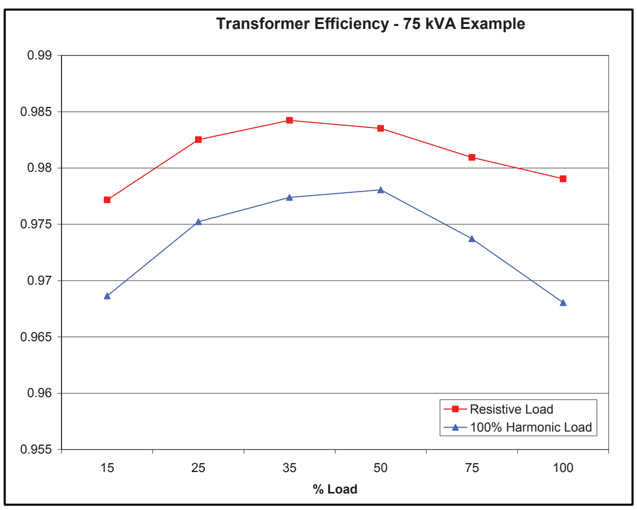
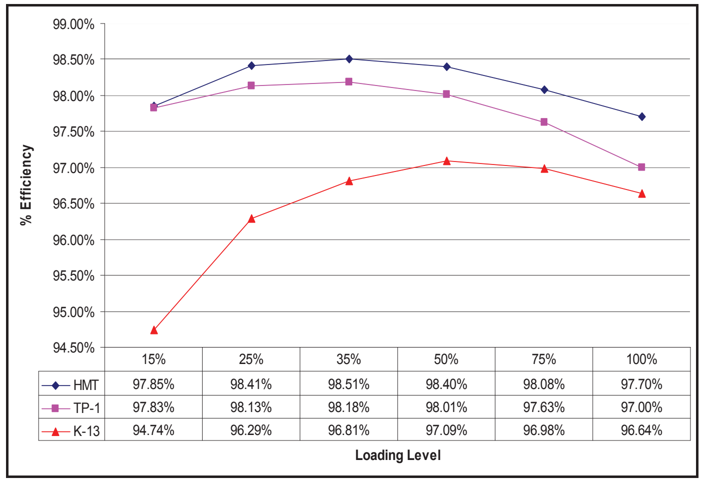


Figure 2. Transformer Losses with 100% Resistive Load and 100% Harmonic Loads

Figure 3 shows a comparison of various transformer types subjected to 100% harmonic load. Note the significant difference between the losses in an energy efficient (TP-1) and K-rated transformer versus a Harmonic Mitigating Transformer. These tests also indicate that there is a significant savings associated with the use of HMT transformers. Again, the savings are not 25% of the total load as some vendors may advertise but they are a steady 1-3% and will easily pay for the transformer many times over the life of the transformer. The infrascan in Figure 4 shows the thermal stress of harmonic heating on a standard transformer versus a HMT subjected to 100% harmonic load relating design to transformer losses.



	15%	25%	35%	50%	75%	100%
HMT	97.85%	98.41%	98.51%	98.40%	98.08%	97.70%
TP-1	97.83%	98.13%	98.18%	98.01%	97.63%	97.00%
K-13	94.74%	96.29%	96.81%	97.09%	96.98%	96.64%

Figure 3. Efficiency Curves for 75 kVA Family of Transformers under 100% Harmonic Load

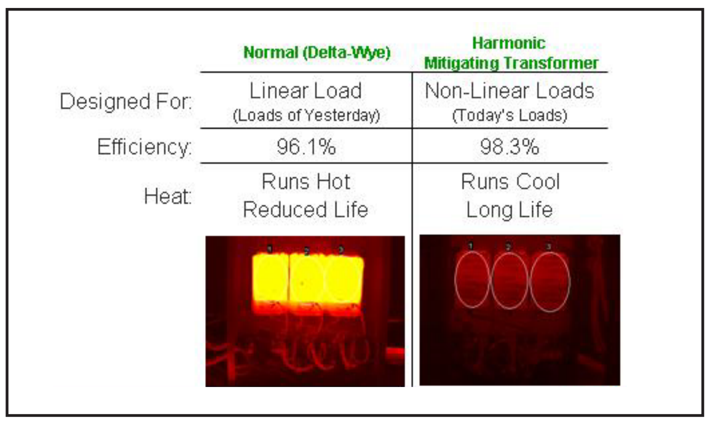


Figure 4. Infrascan of Standard TP-1 Transformer vs. HMT with 100% Harmonic Load

Figure 5 illustrates testing and modeling results of a power system where PF capacitors were applied illustrating the savings achievable versus kvar compensation.

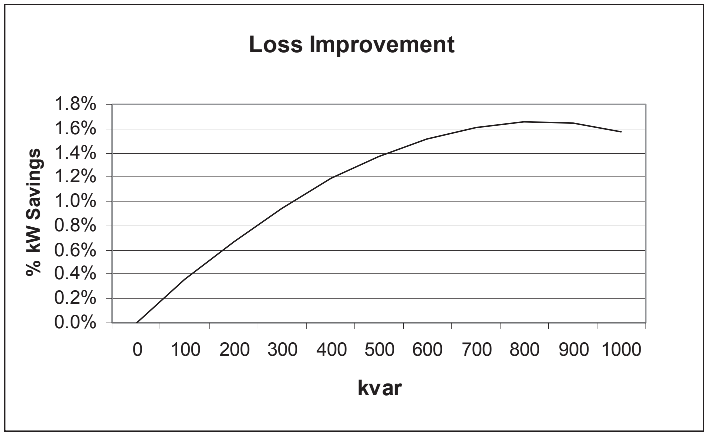


Figure 5. Loss Savings Opportunity using PF Correction Capacitors

Conclusions

Buyer beware – if it sounds too good to be true, it probably is! There are many opportunities to save money by applying Power Quality solutions by improving reliability. Many of these solutions provide some energy savings and other savings opportunities beyond their primary intention. However, it is important to recognize some of the significantly overstated marketing claims by manufacturers. The energy savings claims are often overstated by an order of magnitude (10X) or more. 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. In addition, this paper was assembled in an attempt to show the dramatic change in sales methods for Power Quality solutions over the past several years.

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Table 1. 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 = (1000 – 800)*$10 = $2000/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 – 1000*0.80)*$10 = $1000/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=850kW 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%=80kW (from 80% to 90%) = net demand of 880 kW If pf is corrected to 1.0, pf adjustment (reduction) = 800*10%=80kW (from 90%-100%) = net demand of 720kW Correcting pf from 80% to 100%, potential net savings is (880-720)*$10/kW = $1600/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 =200kvar 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 150kWh*demand $0.025/kWh for next 150kWh*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=$4000 150*1000=150,000 kWh @ 0.035/kWh=$5250 150*1000=150,000 kWh @ 0.025/kWh=$3750 (500,000-100,000-150,000-150,000)*$0.02/kWh = $2000 Total = $15,000 Without penalty 100*800=80,000 kWh @ 0.04/kWh=$3200 150*800=120,000 kWh @ 0.035/kWh=$4200 150*800=120,000 kWh @ 0.025/kWh=$3000 (500,000-80,000-120,000-120,000)*$0.02/kWh = $3600 Total = $14,000 Penalty = $15,000 - $14,000 = $1,000/month (in addition to demand penalty)

Table 2. 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 MOV's)
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 MOV's 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.
Green Plugs	Magic	• 10-20%	• None	• Uneducated consumers

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