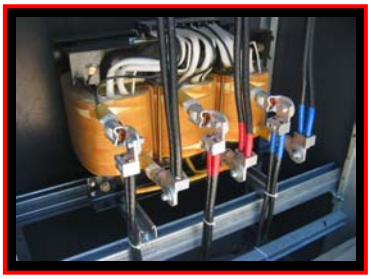
Customer Advanced Technologies Program
Technology Evaluation Report

The Electrical Harmonizer™



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About the Customer Advanced Technologies Program

SMUD's Customer Advanced Technologies (C.A.T.) program works with customers to encourage the use and evaluation of new or underutilized technologies. The program provides funding for customers in exchange for monitoring rights. Completed demonstration projects include lighting technologies, light emitting diodes (LEDs), residential building shell construction, geothermal heat pumps, indirect / direct evaporative cooling, non-chemical water treatment systems and a wide variety of other technologies.

For more program information, please visit: http://www.smud.org/education/cat/index.html

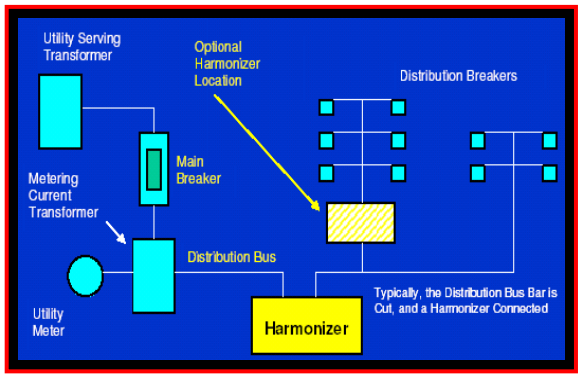
Introduction

Electric utilities strive to provide their customers with power at "acceptable voltage levels" at all times (e.g. nominal voltage plus or minus five percent). Practically speaking this means that some customers receive voltage at the higher end, while others will receive voltage at the lower end of the spectrum. Theoretically, customers receiving higher voltages are overdriving their equipment and 'wasting' energy. However, if the supply voltage is too low, electrical equipment may be severely damaged.

Canadian-based Legend Power™ recently installed a device known as the Electrical Harmonizer™ at two local customer sites. The Harmonizer™ is designed to optimize voltage levels, filter harmonics, improve power factor, and reduce phase voltage imbalance. Monitoring data from these two projects shows impressive energy savings of 5 to 12%. However, like the old saying goes - there's no free lunch: lowering voltage levels may have some potential risks. Care must be exercised to properly identify appropriate applications for this technology.

Technology Description: What Is It and How Does it Work?

The Harmonizer™ is listed under UL as "Industrial Control Equipment." It is essentially a high-tech, ultra low-loss, multi-tap transformer that incorporates proprietary circuitry to mitigate harmonics, reduce phase voltage imbalance and improve power factor. What makes the Harmonizer™ unique is the way that it is built. The configuration of the windings essentially form three single phase reactors on a common core, which drives three sets of regulating coils. The coils have taps to set the degree of regulation. The unit may be installed in series with the main electrical breaker or on a specific branch circuit panel (see diagram below).



Source: http://www.legendpower.com

The energy savings from this technology is based upon a strategy known as "Conservation Voltage Regulation" (CVR). The main concept behind CVR is that customers receiving voltage at the higher levels are overdriving their equipment and wasting energy. Generally speaking, most electrical equipment is designed to operate at nominal voltage levels plus or minus ten percent. By lowering the voltage to optimal levels, customers may be able to reduce energy consumption by anywhere from five to ten percent (depending on the original incoming voltage level and the type of load). However, it is important to note that simply lowering the supply voltage level does not necessarily improve the efficiency of motors, lighting systems or any other connected load. When supply voltage levels are reduced, these systems may produce less work (more on this later).

The most crucial aspect of implementing this technology is identifying appropriate applications and minimizing potential risks. For this reason, Legend Power™ has developed a rigorous qualification process that includes a thorough analysis of the building's electrical loads and existing voltage levels. This process helps Legend Power™ focus on customers who are receiving voltage levels that are at the higher end of the spectrum.

Potential Benefits

The Harmonizer™ is designed to reduce harmonics, improve power factor, reduce voltage phase imbalance, reduce maintenance costs and save energy. Although tests conducted by British Columbia Hydro & Power Authority (BC Hydro) support these claims, the scope of this report will be limited to a discussion of the Harmonizer's energy savings potential.

According to Legend Power's "Frequently Asked Questions" information sheet, users can expect the savings shown in the table below. However, actual savings will be entirely dependent upon the type of electrical equipment used in the facility and the existing supply voltage levels. For example: although two local SMUD customers both chose to reduce voltage levels by about six percent, their savings varied considerably. Why? The electrical loads were different. At first glance these facilities seemed to have similar lighting systems – T8 fluorescent lighting with electronic ballasts. However, closer investigation revealed that one of the facilities was using ballasts with active front-ends (i.e. fully electronic) while the other site utilized standard electronic ballasts. The fully electronic ballasts compensated for the lower incoming voltage and therefore produced little or no savings. This is the reason some lighting systems achieved savings of 11%, while others achieved only a 3-4% reduction. To accurately estimate potential savings, a thorough audit is required.

Incandescent, halogen and fluorescent lights	7 – 13%
Metal halide lights	6 – 10%
High pressure sodium lights	7 – 12%
Air conditioning	4 – 8%
Office equipment	2 – 10%
Refrigeration equipment	6 – 10%
Motors	5 – 10%

Source: http://www.legendpower.com

Fortunately, Legend Power™ recently developed a diagnostic tool known as the Conservation Voltage Reduction Tester (CVRT) that will enable more precise savings estimates. The device allows Legend Power™ to test circuits or specific equipment within the customer's facility to determine the energy savings potential. According to Legend, the CVRT allows a specific 120v low voltage circuit to operate at an optimized voltage, while remaining within the standard for utilization voltage levels. The built in power quality analyzer measures various electrical parameters with the CVRT disengaged from the circuit as well as in the voltage optimization mode. This allows the auditor to obtain comparative data needed to make accurate savings estimates.

Conservation Voltage Reduction Test Equipment Model No CVRT

The Process

What is entailed in obtaining a proposal for a Harmonizer™ and then completing its installation? Legend Power™ has developed guidelines and requires their local distributors and installers to closely follow them. According to **Quantum Lighting**, one of Legend's authorized dealers for the western region of the United States, the process involves three phases:

Phase 1: Pre-qualification

- Quantum Lighting obtains 24 months of the facility's electrical bills, or a 24-month billing summary (supplied by most utility companies upon request).
- Quantum Lighting briefly surveys the facility's electrical room to further qualify the facility.
- Quantum Lighting conducts a preliminary site audit to determine savings potential, analyze the electrical load breakdown, and determine the size of the Harmonizer™ required for the site.
- Quantum Lighting presents the preliminary findings to the customer.
- Customer decides whether or not to continue the process. If the customer decides to continue, the process moves into the next phase.

Phase II: Proposal Development

- Quantum Lighting completes a thorough technical walkthrough and detailed assessment of the facility's electrical room and electrical loads.
- Quantum Lighting contacts the local utility to determine availability of incentive funding (rebates).
- Quantum Lighting prepares a proposal, complete with return on investment (ROI) calculations.
- Customer decides whether or not to continue the process. If the customer decides to continue, the process moves into the final phase.

Phase III: Installation & Monitoring

- Quantum Lighting monitors the facility's electrical supply prior to engaging the Harmonizer.™
- Quantum Lighting completes the 'Rough-in' (installation of the Harmonizer™ with the exception of the live hook-up).
- Quantum Lighting performs the "cut-in" (live-hook up of the Harmonizer™, usually done at night).
- Quantum Lighting monitors the facility's electrical supply after the Harmonizer™ has come on line. Voltage levels are checked to ensure that adequate voltage is being supplied throughout the building. The customer is given a final report that includes savings estimates based upon the site measurements.

"Rough-in"

Important Things to Consider

Building Systems

Although this technology has the potential to save a significant amount of energy, lowering voltage levels may have the following effects:

- **Reduced illumination levels:** When the voltage supplied to a lighting system is reduced, there will be a corresponding reduction in illumination. For fluorescent lighting systems, the amount of light loss is usually directly proportional to the voltage reduction. Fortunately, since many commercial spaces are overlit, this may not be a significant issue. Furthermore, studies have shown that illumination level reductions of five percent or less are usually undetectable by building occupants (for more information, please download the report entitled "Lighting Circuit Power Reducers" available at the Customer Advanced Technologies program web page: http://www.smud.org/education/cat/index.html)

- **Fully electronic ballasts:** Lowering voltage levels to fluorescent ballasts with active front-ends (i.e. fully electronic) will produce little or no savings since these ballasts compensate for the lower incoming voltage. However, these types of ballasts are relatively uncommon for most commercial lighting applications. Customers should check with ballast manufacturers or an electrical contractor to determine which type of ballast they are currently using in their facility.

- **Potential for increased motor amperage:** When the voltage to a motor is reduced, it may draw more amps. If the voltage level is reduced too much, the motor may overheat and cause damage to the motor windings. To help avoid this problem, supply voltages should be checked at the motor terminals before and after installation of the Harmonizer™ to ensure adequate voltage levels. Unfortunately, none of the motor manufacturers we contacted would provide an opinion on this subject. More research is needed in this area to adequately determine the effects of implementing conservation voltage regulation.

- **Sensitive equipment:** Elevators, fire detection systems and security systems may be sensitive to voltage levels. Customers should check with system manufacturers before installing the Harmonizer.™

- **Step down transformers:** Large buildings often have several transformers to step-down voltage levels (e.g. from 277 volts to 120 volts). These transformers may need to be adjusted or replaced to compensate for the lower incoming voltage levels.

- **Office equipment:** Although computers, copiers, fax machines and other equipment with internal regulating power supplies should be able to compensate for lower incoming voltage levels, the long-term effects upon these devices is presently unknown.

Potential Risks

As mentioned earlier, electric utilities strive to provide adequate voltage levels at all times. When voltage levels fall below required minimum levels (i.e. an electrical brownout), serious damage to electrical equipment may occur.

Although Legend Power™ has established rigorous qualification and post installation protocols to avoid installing the Harmonizer™ in inappropriate applications, the fact remains that actual voltage levels supplied to a facility may vary considerably. This is due to a variety of reasons including:

- **Storms:** Outages or damage to the electrical distribution systems caused by falling trees, high winds or lightning.
- **Load fluctuations:** Industrial customers have large machines that require considerable amounts of power. As these systems are switched on and off, they often affect voltage levels on the utility company's distribution system – especially for other customers in close proximity.
- **Vehicle and construction accidents:** When the electrical distribution system is damaged by vehicles or construction equipment, utilities will often reroute power around the affected area to restore power to as many customers as possible until repairs can be completed.
- **Weather:** During hot weather, SMUD's electrical load nearly doubles due to customers using their air conditioners. This places considerable strain upon electrical distribution systems and may reduce voltage levels to minimum requirements.
- **Distribution system fluctuations:** The distribution and delivery of electrical power is a complicated process. System operators routinely reroute power. This may cause considerable voltage fluctuations - especially for other customers in close proximity to substations and capacitor banks.

To help address these risks, Legend Power™ has implemented the following policy:

"The qualification criteria for customers' supply voltage specifically requires the Harmonizer™ Distributors to identify only those facilities in the high end of the supply standards, as stated in ANSI C84.1 and CAN3-C235-83. By identifying potential customers in this upper limit, the Harmonizer™ can be installed and set to optimize voltage by 6%, while maintaining sound service voltage entry and utilization levels. The qualification criteria are required to allow for fluctuations in supply voltage and allow for the sags that may appear on the system. To give further confidence to our customers that the facility will remain unaffected by under-voltage conditions, it is recommended that a voltage-sensitive monitor be installed at the output of the Harmonizers, set to alarm as the voltage approaches the "B" zone, as stated in the voltage supply standards. The alarm should be configured to notify appropriate personnel at the customer's site (e.g. able to interface with the customer's energy management or building automation system). A further drop in supply voltage could mean that the monitor signals the protection ahead of the Harmonizer, to disconnect the facility from the supply. Qualification should also take into account the day-to-day and seasonal variation of supply voltage that may exist on a feeder circuit. Consultation with the utility companies is advised, as are regular checks by the facility on supply levels."

Although this is certainly a step in the right direction, customers who choose to install the Harmonizer™ should seriously consider installing an electrical bypass. Otherwise, they may face the risk of an electrical outage during conditions that normally may not have affected their operations. Consider the following *hypothetical* example:

An office building is presently receiving voltage at the higher end of the spectrum: 504 volts (480 volts plus 5%). A representative from Legend Power™ conducts an audit and identifies the facility as a potential candidate for the Electrical Harmonizer™. The office is used by an engineering firm and includes the following electrical loads:

- T8 fluorescent lighting (277 volts)
- Rooftop air conditioning units (208 volts)
- Two elevators
- Desktop computers, fax machines, copiers and other common electronic devices (120 volts)

The customer decides to proceed with the project but decides not to include an electrical bypass due to first cost considerations. Legend Power™ Systems installs the Harmonizer™ and the voltage detection system described earlier. The customer chooses to have the Harmonizer™ set to reduce the voltage levels by six percent (new voltage level = 473 volts). The voltage levels are checked throughout the building and are found to be within acceptable limits. The customer realizes an overall energy savings of eight percent. Everything is running smoothly until the first hot summer day…

The area where this building is located has been growing rapidly. Several large office buildings, a grocery store, two restaurants and a gas station have been built since the Harmonizer™ was installed. It's 105°F outside and the weather forecast is calling for more of the same.

Due to added load of the new buildings and the heat wave, the incoming voltage drops to 456 volts (480 volts minus five percent). As designed, the Harmonizer™ reduces the voltage by an additional six percent (new voltage = 428 volts). Unfortunately, the electrical equipment within the building is now receiving voltage at levels that are at least eleven percent less than nominal. Possible results:

- The lighting systems compensate for the lower voltage levels by producing less light. Since the facility is still well lit, this does not cause any problems.

- Since the computers and office equipment have their own internal power supplies, they should be able to compensate and continue to operate. Again no problem.

- The compressors within the air-conditioning system are working very hard to cool the building. When the voltage is reduced, the amperage increases. This causes the compressor motors to overheat and trip offline. The office is now without cooling until the compressors cool down. Eventually the compressors restart but quickly overheat again. This cycle repeats throughout the summer and eventually causes damage to the compressor motor windings.

OR….

- When the voltage first begins to drop, the voltage detection system sends an alarm to the Building Manager, who unfortunately is away on business. When the voltage levels continue to drop, the system triggers the protection ahead of the Harmonizer™ and turns the power to the facility off. Since the customer chose not to install a bypass, the power remains off until the incoming supply voltage is above the set point of the controller.

Fortunately, the situation described above represents a worse case scenario and, to our knowledge, has not occurred. This is due largely to Legend Power's qualification process. However, customers must weigh the potential benefits and risks when considering implementing this technology and should give serious consideration to installing an electrical bypass to reduce their risk.

Showcase Project

Project: County of Sacramento Administration Building
700 H Street, Sacramento, CA 95834

County of Sacramento Administration Building

Background: The Sacramento County Administration Building is a 250,000 square foot headquarters building that is the seat of county government. It houses a 3,500 ton central cooling and heating plant that serves approximately 1.2 million square feet of institutional, office and special function facilities in the downtown complex.

Customer Comments:

The following comments were provided by **Mr. Randal Angeloni**, Energy Manager, County of Sacramento.

Reason for installing the Harmonizer™: "The County Administration Building has one of our largest electrical loads and the possibility of reducing the demand by 5% to 10%, reducing total harmonic distortion and improving the power factor along with a short payback seemed almost to good to be true. The building has two electrical meters that we closely monitor. The house meter includes most of the equipment outside of the central plant and the central plant meter. The Harmonizer™ was installed on the house side of the meter that includes lighting and other loads (computers, coffee pots, air handlers etc)."

Lessons Learned: "The Harmonizer™ works: it has increased the power factor and reduced harmonics as well as saved on energy consumption. How well the product will work depends on the following factors:"

- **Proximity to the main utility distribution station:** "If a facility is located close to the utility distribution point, the utility would have a difficult time reducing the output voltage very much and still deliver the required voltages to the most remote areas. Proximity is very important."

- **The regulated load:** "If the facility has electronic ballasts that are active front end (will automatically regulate incoming voltages) as opposed to standard electronic ballasts (which do not). This is a big issue. Ballasts that are rated at 10% THD (Total Harmonic Distortion) or better almost always have active front ends. Electronic ballasts that are rated at 20% THD or more are almost always non-active front-end ballast. Lighting is where the Harmonizer™ may have a significant impact by reducing energy and peak demand, improving power factor and reducing total harmonic distortion."

"Desktop computer equipment usually has active voltage regulation as well as most modern building control systems. Depending on the nature of the building and how modern the primary equipment is, the Harmonizer™ could have a very positive impact on your electric bill. A decrease of 5% to 10% across the board can be significant."

- **An accurate load survey is critical:** "The survey of equipment and proximity will define the potential savings. If done properly there could be significant savings with a quick payback. Do not forget to assess down-line transformers that may be affected. We had numerous transformers that needed to be adjusted for the lower incoming voltages."

The survey should include:

1. The facility's proximity to utility substations.
2. Specific equipment and voltage tolerances.
3. Amount of load that has voltage-regulating, active front-end equipment.
4. Down line transformers that may be affected (especially if they are already on the low end).
5. Method of monitoring and verifying the results.

Project Summary

- Project cost = $131,993
- Customer Advanced Technologies Program grant = $10,000
- Net project cost = $121,993
- Harmonizer™ set point (voltage level reduction) = 4%

  Note: the Harmonizer™ was originally set for a 6% reduction but had to be re-adjusted later to provide a 4% reduction to accommodate some of the step-down transformers within the facility.

- Estimated electrical demand reduction = 50 kW
- Estimated annual energy savings = 552,000 kWh
- Estimated cost savings = $48,000
- Simple payback = 2.54 years

The Harmonizer with remote disconnect

Conclusions and Recommendations

- The Electrical Harmonizer™ has demonstrated the ability to reduce energy consumption and improve power quality. The amount of savings will depend upon the incoming voltage levels and the type of the electrical equipment being controlled. In particular, the Harmonizer™ may be an effective energy-saving technology for locations where the incoming supply voltage levels are consistently high. Customers should contact their local electrical utility to discuss their particular situation.

- A thorough audit of all electrical loads is a must to properly assess potential savings and to ensure that adequate voltage levels will be provided to all building systems. Do not forget to include step-down transformers, elevators, fire detection and security systems.

- Incoming utility voltage levels fluctuate due to a variety of reasons. For this reason, customers should seriously consider incorporating an electrical bypass into the system to protect themselves from possible 'brown-out' situations and unnecessary power outages.

- Since regulating voltage levels does not necessarily improve the efficiency of motors, lighting systems or any other connected load, customers should first evaluate and upgrade these systems before considering technologies such as the Harmonizer™. Once these systems have been addressed, the Harmonizer™ may provide an opportunity to achieve an additional five to ten percent in energy savings that was previously too cost prohibitive or unattainable to achieve through other measures.

Technology Transfer

The results of this project will be forwarded to SMUD's Commercial Services Department for their consideration – mainly whether or not to incorporate this technology into existing energy efficiency programs. No additional demonstration projects are planned for this technology at this time.