At Load Power Factor Correction
Phase 1: Apartments

A Pilot Project to determine the feasibility and economics of small scale "At Load" Power Factor Correction

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1.0 Introduction, Objectives, and Overview of Phase 1 Results

Power Factor is the ratio of the power needed to do the work within customer premises to the power delivered by the utility. A power factor of 1.0 is ideal. Equipment located in customer premises emits reactive power that lowers the power factor. There are devices that can be attached to the loads to raise the power factor and reduce the amount of energy lost as heat on the wires in buildings and on the electrical distribution system.

This paper presents the background information, method, and results from Phase 1 of an eighteen month long pilot project designed to determine the economic feasibility of "At Load" power factor correction in various scenarios as a method for improving efficiency and reducing losses on the electric utility system. "At Load" power factor correction will be analyzed in apartments, residences, commercial and industrial settings. As power factor correction is not a new concept, the project has four objectives. For all phases of the project, our first objective was to measure the power factor in the different environments. This involved creating data bases to simplify handling of the vast amounts of data being collected. Second, we wanted to gain a better understanding of the reactive loads in the different environments. That understanding includes the age of the appliances or equipment discharging the reactive power and the types of installations involved. Our third objective was to correct the power factor in the most cost effective manner possible. Our final objective was to measure the effect of our installation and determine the cost versus benefit of the installations. Benefit is measured in Kilowatt Hours (KWH) saved.

While the results presented for all of the test environments will be similar, they do vary from environment to environment. Also, the volume of data being collected and the timeframe of the data collection at the different sites mandate that we divide the project and reports into three phases. This phase of the project focused on "At Load" power factor correction in apartment complexes.

A 1991 census stated that there were between 17,000 and 20,000 buildings of 50 or more units within New York State. That provides a large "market" on which to implement this process. While much of this documentation will reference the New York Metropolitan Area as the work was done here, it is applicable to other areas of the country as well. Conclusions that we have drawn from the work completed to date are the following:

- The power factor is sufficiently low in the apartment environment that improving it will result in a substantial energy savings throughout the entire utility system, when measured in KWH.

- We can cost effectively improve the power factor for existing apartment buildings in the near term.

- Standards need to be modified so that new apartment complexes are designed with a high power factor and a balanced load as part of the design criteria. Compliance should be verified prior to a Certificate of Occupancy being issued.

- Standards need to be modified so that new appliances are required to have a high power factor as part of the design criteria. This includes refrigeration and especially, air conditioners. Some of the newer 220 volt air conditioners operated with a power factor near 0.99. None of the 120 volt air conditioners operated with a power factor above 0.92, including the newest units that were less than a year old. Most of the measurements were taken on hot days, so the units would have been operating as efficiently as possible.

- Standards need to be modified so that new appliances and other electrical devices to be attached to the utility have more strict limits on the amount of electrical harmonics that they generate per watt of consumption. In particular, this will apply to computers, televisions and fluorescent lighting. Harmonics, oscillations induced in the electrical power system, adversely effect electrical efficiency. Furthermore, harmonic mitigation can be very costly to implement.

- Power Factor Correction in this environment does not measurably increase the amount of harmonics measured at the utility transformer.

- Power Factor Correction must be load based and must only operate when needed. Excess capacitance connected to the utility system can be as detrimental as excess inductance. Furthermore, in the event of a blackout, the excess capacitance would add extra impedance that would have to be energized, applying extra load to the system during a restart.

2.0 Background

Power Factor is the ratio of the power needed to do the work within customer premises to the power delivered by the utility. The power needed by customer premise equipment to operate is measured in Kilowatts (KW). The amount of power delivered by the utility is measured in Kilovolt Amperes (KVA). KW divided by KVA is the power factor. A power factor of 1.0 is ideal. Appliances and machinery within customer premises discharge reactive power, measured in Kilovolt Amperes Reactive (KVAR). More KVAR present on the utility system results in a lower power factor, and higher currents (I) present on the wires. Because thermal losses on the wires are proportional to the square of the current, a 12 % increase in current will result in a 25% increase in thermal losses related to the increased current. (1.12 x 1.12=1.25). Similarly, a 10% current reduction will result in a 19% drop in thermal losses and provide the corresponding energy savings (0.9 x 0.9 = 0.81). Additional information explaining power factor and the associated energy losses can be found on-line at www.wikipedia.org or on our web site, www.powerfactorcorrectionllc.com .

Historically, utilities have implemented power factor correction at their substations by installing banks of capacitors. The substations are where the utilities reduce the voltage (usually greater than 110,000 volts) from the transmission wires to lower voltages (4,100 volts or 13,000 volts) for distribution throughout the service area. The voltages are further reduced to the range of 208 volts to 480 volts at the transformers on the utility poles or in underground vaults located near the customer premises. The problem with implementing power factor correction at the substations is that the reactive power present on the distribution system, not serviced by those capacitors, is inducing thermal losses. Furthermore, the distribution system with its lower voltages and higher currents already accounts for the majority of the losses on the system. In addition, more thermal losses occur on the customer side of electric meter, within the customer premises. On the Transmission and Distribution System, 50% of the energy lost and almost 75% of the "Accounted For" energy losses occur on the lower voltage Distribution Portion of the system (See Figure 1). Those figures do not include losses from reactive load that occur after the customer meters. While the utility does not bill for reactive power in most cases, excess thermal losses after the meter caused by reactive load would be measured in watts and would be billed. The losses, while relatively small in any single apartment or domicile, when aggregated throughout the New York Metropolitan Area are significant.

Traditional thinking, as evidenced in articles written as recently as May 2007 [1], assumes that the losses only occur in the wires. Calculations have been done on the losses based on the ohms per foot of a length

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1 "Is Power Factor Correction Justified for the Home", William Rynone, President, Rynone Engineering, Power Electronics Technology, May 2007 http://www.powerelectronics.com

of copper wire. However, in many buildings, especially older buildings, the majority of the losses occur at the junctions. These include screw connections on switches, receptacles, and breaker panels, the metal-metal interface of a switch or of a plug in a receptacle, circuit breakers, and wires in junction boxes connected by wire nuts. As these copper and copper alloy connections age, they oxidize. During the course of installing devices in some of the apartments, we encountered plugs that had so much oxidation that they had a green patina. The associated receptacles were significantly warmer than other receptacles where oxidation was not present.

In 1999, a survey done by the U.S. Department of Housing and Urban[2] Development determined that of the 115,253,000 estimated housing units in the United States, 32,155,000 (27.9 percent) were less than 20 years old and were built after 1979. Those units are now 30 years old. However, more than 10 million housing units (8.8 percent of all units) were built before 1920. More than 30,542,000 housing units, one-quarter (26.5 per-cent) of the housing stock were at least a half-century old in 1999; that is, more than one out of four housing units were built prior to 1950. While those figures were for the entire country, a disproportionate amount of the older housing units would be in the Northeast United States, including New York, as this part of the country was developed earlier. The apartment complex that we used for the trial was built circa 1965. Many apartments still have the original air conditioners.

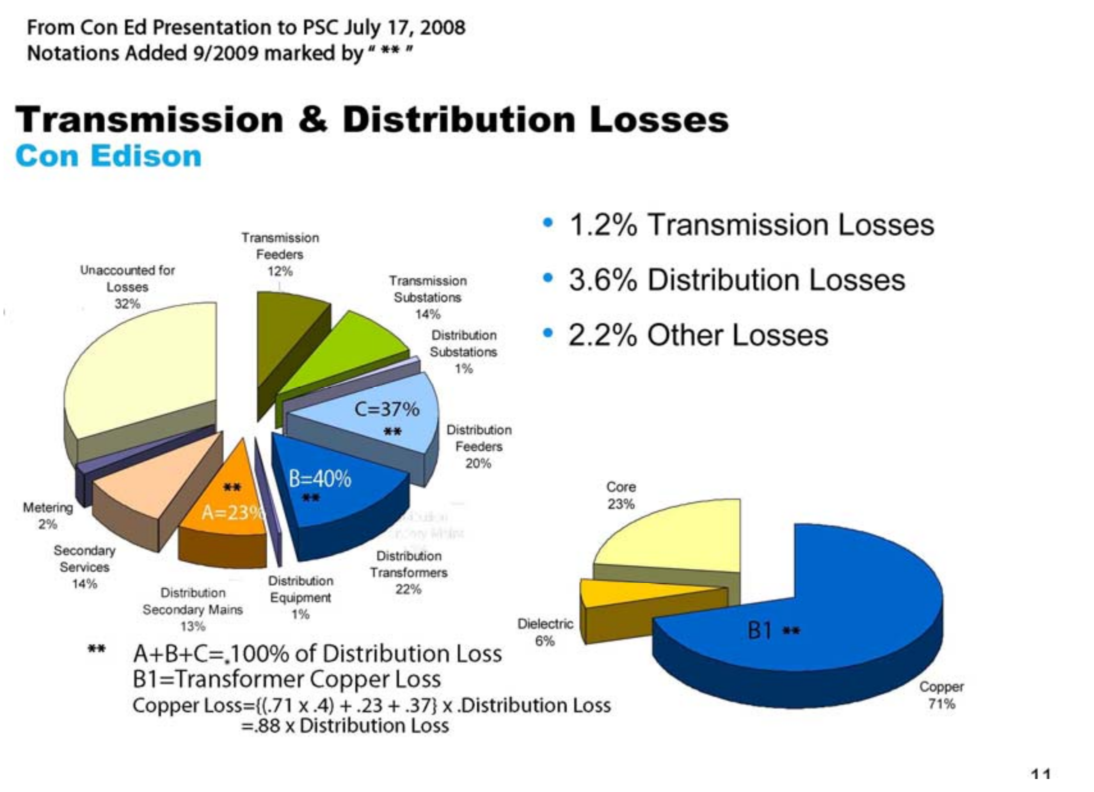

Figure 1: Excerpted from Transmission and distribution Losses. Consolidated Edison. Originally presented July 17, 2008 Percentage Notations added September, 2009.

2 "U.S. Housing Market Conditions, Third Quarter 2000: Summary, How We Are Housed", US Department of Housing and Urban Development. http://www.huduser.org/Periodicals/ushmc/fall00/summary-2.html

As much of the housing stock in New York is older, the connections will have more oxidation and higher resistances (R). That will result in higher I^2R (thermal) losses at those connections. Any system that can reduce currents in the aging wires and connections will result in an energy savings. As higher operating temperatures in system components causes more rapid aging of those parts, reducing currents and the associated heat will also add longevity to the system and devices attached to it. By reducing the currents at the load, the savings accrue from the load all of the way back to the first substation where power factor correction is traditionally employed. In addition, by increasing the power factor on the distribution system, existing capacitance is freed at the substation to be used to further raise the power factor on the transmission system on hot days when there are increased loads. That would yield additional energy savings on the transmission system.

According to Figure 1, 7 % of the energy that enters the transmission and distribution system is lost before it reaches the customer. The national average is 7.2%. Of that 7.0 %, 3.6% is lost on the distribution system that is not serviced by the utility's capacitors. We are primarily concerned with those losses and the losses after the customer's utility meter. In Figure 1, transformer losses are shown in the pie chart at the lower right. 29% of the losses in the transformer are "no load" losses and are related to eddy currents in the iron core of the transformer and dielectric losses. Those losses are fixed for a given transformer and will not vary with current. The segment marked "B1" represents the copper losses. Those losses occur in the wires of the transformer and will increase with increasing current.

In Figure 1, according to the pie chart on the upper left, on the distribution system 23% of the losses occur in the secondary mains, 37% of the losses occur in the distribution feeders, and 40% of the losses occur in the transformers. 71% of that 40% occurs in the transformer copper, resulting in 28.4% of distribution losses occurring in the transformer windings. The result is that 88% of distribution losses, and 3.17% of all energy generated is lost as heat in the wires of the distribution system that is not serviced by power factor correction. On the 13 Gigawatt Con Ed system, that 3.17% translates to 412 megawatts on a day with peak load. To put that into perspective, the new NYPA (New York Power Authority) combined cycle gas turbine power plant in Queens, N.Y. generates 500 megawatts at peak output.

Depending on the type of fossil fuel generation being considered, power plant efficiencies can be as low as 25% to 30% for the older coal power plants to 55% for the new combined cycle gas fueled generating plants[3]. The average efficiency of delivered energy to the customer, after factoring in generating losses and

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3 Electric Generation Efficiency, Working Document of the NPC Global Oil & Gas Study, Made Available July 18, 2007, NATIONAL PETROLEUM COUNCIL , POWER GENERATION EFFICIENCY SUBGROUP OF THE DEMAND TASK GROUP OF THE NPC COMMITTEE ON GLOBAL OIL AND GAS

transmission and distribution losses is approximately 33%. Of every three watts of energy consumed at the generating plant, only one watt reaches the customers meter. More energy is lost through inefficiencies after the meter, within the customer premises. Any system that can reduce load, including load caused by distribution losses, will save approximately three times that amount of energy at the generating plant. Associated greenhouse gas production will be reduced proportionally.

Figure 2 shows the average losses in summer versus winter and the seasonal net energy usage. It can be seen that losses during the summer months are 2.2 times higher than during the winter months. The higher summertime electric load results in heating of all components of the transmission and distribution system. In addition, there is less ambient cooling of components as a result of the higher ambient air temperatures. More direct sunlight and more hours of daylight result in a far greater solar load. When all of these factors are combined, the result is that the entire system operates at an elevated temperature. As the temperature of

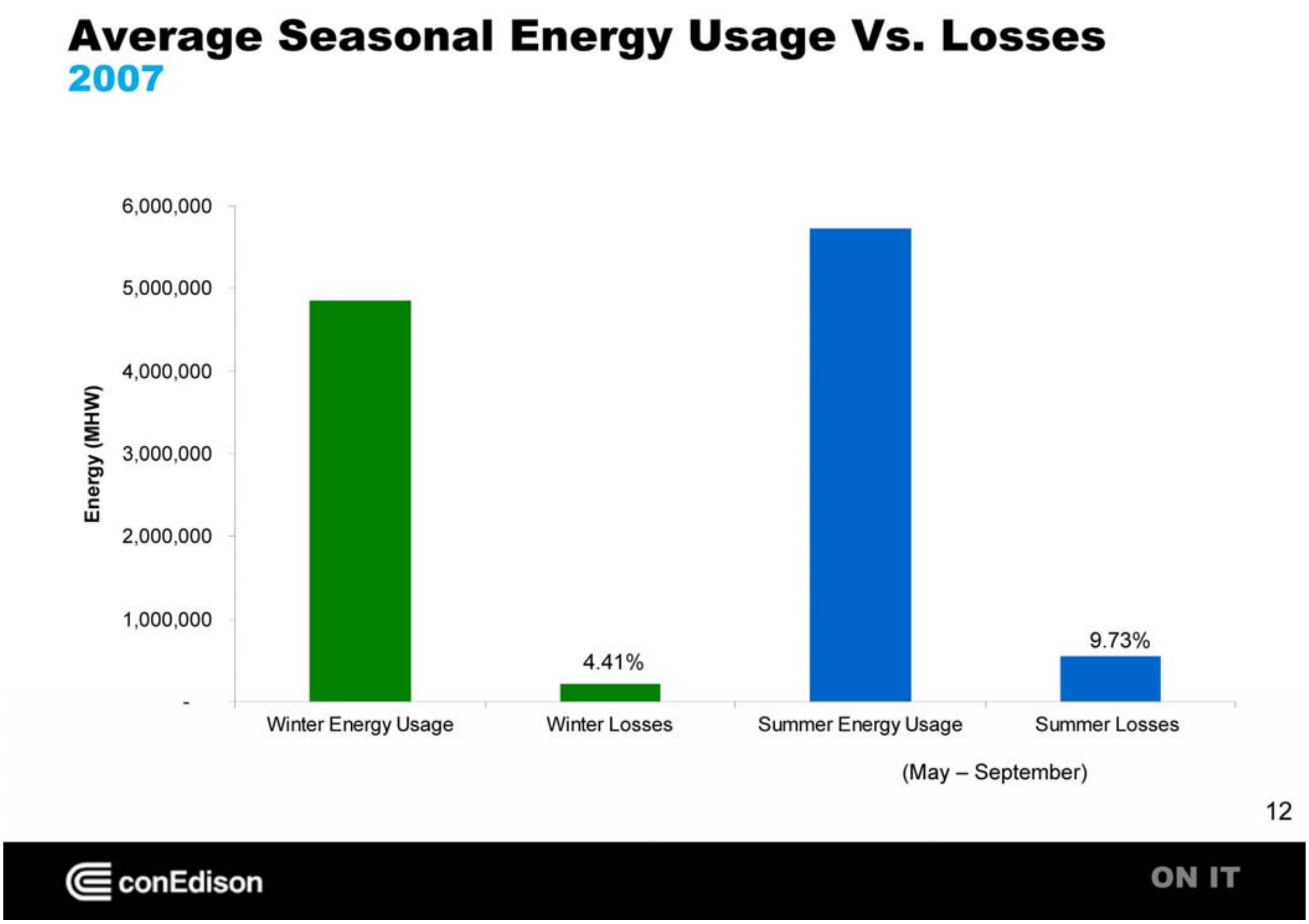

Figure 2: Excerpted from Transmission and distribution Losses. Consolidated Edison. Originally presented July 17, 2008

electrical conductors increases, their resistance increases proportionally. The equation below explains the effect of temperature on the resistance of electrical conductors.[4]

$$R = R_{ref}\,[1 + \alpha(T - T_{ref})]$$

Where,

R = Conductor resistance at temperature "T"

R_{ref} = Conductor resistance at reference temperature T_{ref}, usually 20° C, but sometimes 0° C.

α = Temperature coefficient of resistance for the conductor material.

T = Conductor temperature in degrees Celcius.

T_{ref} = Reference temperature that α is specified at for the conductor material.

For copper α= 0.004041 per degree-C. The result is that a 10 degree-C (18 deg-F) temperature rise will yield a 4% increase in the resistance of a copper conductor. As thermal losses in wires are proportional to the resistance (R), the line losses increase proportionally. Additionally, as the thermal losses increase, the conductor's temperature rises still further and the resistance continues to increase. This process continues until the conductor temperature reaches equilibrium (heat gain from all sources=heat loss to air or surrounding environment) or in the extreme case, the conductor or transformer will overheat and suffer catastrophic failure.

One possible side effect of performing power factor correction could be increased levels of harmonics. Harmonics are waveforms present on the utility system that have a frequency that is a multiple of the system frequency of 60 hertz (hz). (e.g.: 120 hz-2nd harmonic, 180 hz-3rd harmonic, 240 hz-4th harmonic, etc.). The odd numbered harmonics (180 hz, 300 hz, etc.), cannot be used by equipment on the system. They are absorbed into the components on the system and dissipated as heat. For example, harmonics that enter a transformer cause eddy currents in the magnetic core which are released as heat. Sources of harmonics on the utility system include ballasts on fluorescent lighting and switching power supplies on TV's and computers, among others. One goal of the project was to determine if there would be an increase in harmonics after installing power factor correction at the various locations.

By reducing currents only 7%, the associated thermal losses will be reduced by 14%. That reduction will be augmented as the temperatures of the conductors will be lower, resulting in a lower conductor resistance. The goal of this project was to determine the amount of loss reduction achievable through adjusting the power factor of various types of building loads, the associated cost of that process, and to see if there were any undesirable side effects, such as an increase in harmonics.

4 Temperature Coefficient of Resistance: Physics of Conductors, http://www.allaboutcircuits.com/vol_1/chpt_12/6.html

3.0 Implementation

Implementation of the Power Factor Correction Project involved several steps.

1 **Acquiring Funding**: This was provided through a NYSERDA Grant to offset the cost of equipment that would be installed on utility poles or within customer premises

2 **Coordination with the utility**: As we were attempting to determine the aggregate effect of "At Load" power factor correction, it was essential to perform measurements at the secondary (low voltage side) of the utility distribution transformer. Consolidated Edison was extremely cooperative in this regard. They provided the funding and the personnel to install the power monitors on the utility poles. After consulting with Con Ed about their requirements, we designed and built power monitors that were mounted by Con Edison personnel on the poles. After we chose a neighborhood, they also assisted with choosing transformers that would be optimal in achieving our goal.

3 **Test Sites:** We needed utility customers that would be willing to participate in a trial of this type. We were fortunate because the residents of Hilltop Terrace were very willing participants. It is a true leap of faith for homeowners with a non-technical background to let a stranger into their home to correct a reactive power "problem" that they didn't even know existed. In addition to having cooperative residents, Hilltop Terrace was ideal in that it was fairly typical of much of the housing stock in the New York area. It is a garden apartment complex that was built circa 1965. As there are 80 units in five buildings, serviced by one transformer, the data will also be fairly representative of a 40 to 200 unit dwelling without central air conditioning, scaled for the number of units. There is a mix of one, two, and three bedroom units. Air Conditioning consisted of 120 volt and 220 volt air conditioners mounted in "through-the-wall" sleeves. The first complex that we sought to use for the trial did not want to participate. It was a complex of rental units. The landlord had little incentive to participate, as they did not pay the utility bills for the apartments. In contrast, Hilltop Terrace is a cooperative where the tenants own the apartments.

4 **Power Monitors:** The essential part of any project of this type is having accurate data. We designed and built a monitor with more capability than we thought we would need. Our reasoning was that it would be far easier to ignore unneeded data than to collect extra data from a meter that didn't have the capability. As such, each monitor collects several hundred electrical parameters and three temperature parameters and transmits them to a collection

hub twice each minute. Monitored electrical data includes voltage, current, frequency, power (KW), reactive power (KVAR), apparent power (KVA), power factor, harmonic distortion, and both voltage and current harmonics to the fortieth harmonic. Data is available both in aggregate for the three phases or by individual phase. Figure 3 is a photo of the monitor installations at Hilltop. Temperatures were recorded for the transformer, the power monitor, and the ambient air temperature. In addition, we have access to the data for a nearby solar array. This allowed us to compare the instantaneous solar load with the device temperatures. Split Current Transformers were used to measure current. This sacrificed approximately 2% in accuracy, however it let us attach the monitors without interrupting service, a requirement for Con Edison.

5 **Wireless Network and Data Hubs**: To easily and efficiently collect the data from the remote locations, we added wireless capability to the power monitors. The monitors were set up as a wireless mesh, where each wireless device can act as a transmitter/receiver or a repeater. Each group of monitors feeds back to a computer hub that collects and stores the data. It will also display the measured parameters for each monitor in the group. The hubs connect back to a central computer via a hardwired data link. The data is fully analyzed and collated at the central location. Figure 4 shows the locations of the two monitors, repeaters, and data collection hub for this portion of the project.

6 D**ata Base Design**: A data base had to be designed to format the large quantities of collected data for easy retrieval. Each monitor group will generate between 15 megabytes (MB) and 30 MB of data in a 24 hour period, depending on how far apart the monitors are and how many "hops" the data has to make from monitor to data hub.

7 **Device Design** : While devices for power factor correction are readily available for large facilities, that is not the case for the smaller scale application that we are considering here. Labor and other installation costs have to be kept to a minimum in order to make this process viable. In the past, one of the reasons that small scale power factor correction has not been applied is installation cost. The bulk of that cost is in labor. After applying for the grant and prior to being approved for the grant, we designed and fabricated devices that could be installed by a non-technical person. No electrician is needed. A patent was filed on these devices, called PLIP's®, in November, 2008. PLIP® is an acronym for "Plug In Power Factor Correction". Figure 5 is a photo of a PLIP® .

Monitor 10 Monitor 11

Figure 3: Pole Monitors at Hilltop Terrace. Monitor 10 services one building at Hilltop Terrace and a second building in a different complex. Monitor 11 services five buildings at Hilltop Terrace. The transformer at Monitor 10 is a 75 KVA, 3 phase transformer. The transformer at Monitor 11 is a 150 KVA, 3 phase transformer. Both transformers date to the construction of the complex in 1965.

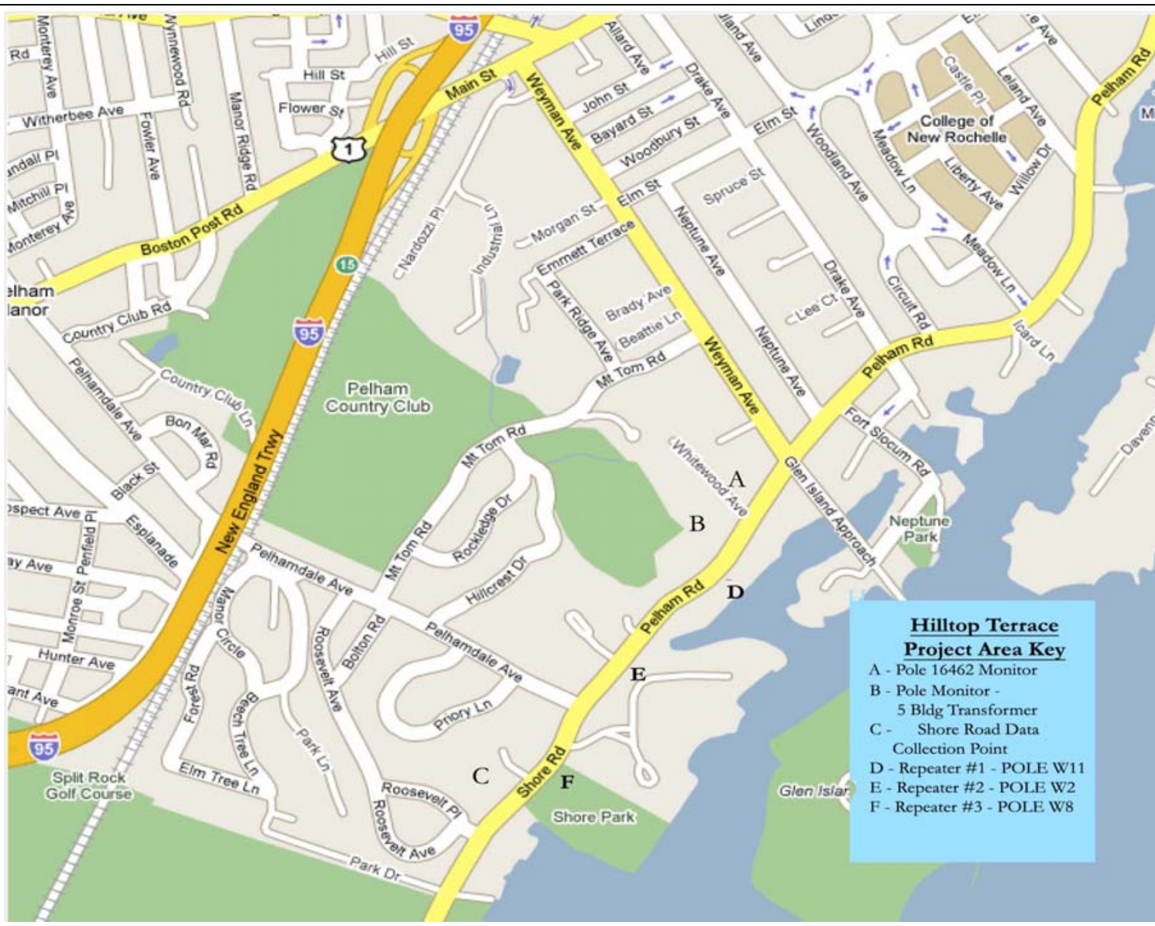

Figure 4: Hilltop Terrace Monitor, Repeater, and Hub Locations
The distance between A and C is 0.55 Miles.

Figure 5: The PLIP® Plug In Power factor correction. Power Factor Installation costs are greatly reduced. An unskilled person can install these.

4.0 Observations about customer behavior and the service area that affect energy efficiency and Related programs

While learning about the electrical characteristics of customer premise equipment, we also learned a great deal about the service area, customer behavior, and obstacles to implementing electrical efficiency programs of this type. Among things that were learned are:

1 Utility customers will not replace air conditioners until they cease to function. Many of these units are inserted through sleeves in the wall. Most of the newer, replacement air conditioners are smaller and don't fit the sleeves without some adaptation. This retrofit can be costly and time consuming. In addition, the older units are cumbersome and it is easier to leave them there until they no longer work, despite the lower operating costs of the newer units. During the course of the project, we did not encounter a single person with a new air conditioner that had purchased it before the old one ceased to function properly.

2 Rental units present a different problem as most landlords, responsible for replacing the appliances, don't pay for the electricity to operate them. In one complex that we looked at, there were over two hundred apartments with approximately four hundred fifty air conditioners. To replace all of them would have cost over $ 225,000. There were air conditioners operating there that dated to the 1960's. It was at this complex that we encountered the "What's in it for me?" syndrome. That was despite the fact that the work that we were proposing would have cost the landlord absolutely nothing except providing access.

3 In a legacy building on Central Park West in Manhattan, which only has window mounted air conditioning units at present, they have a program to insert sleeves into the walls to remove the units from the windows. Each new sleeve costs approximately $6000 without the associated air conditioner. The cost is a deterrent to participating in the project. Many residents are maintaining the status quo and keeping their old units.

4 Scheduling a convenient time to meet with the customer is one of the biggest obstacles in the process.

5 Manufacturers of newer 120 volt air conditioning units (manufactured within the past two years) have done little to nothing to correct the power factor of their appliances. Those 120 volt units operated with a power factor between 0.88 and 0.92. The newer 220 volt air conditioners operated with a power factor of 0.98 to 0.99. Older air conditioners that we measured at either voltage operated with a power factor between 0.80 and 0.92.

6 Aesthetics are important when you are going to attach an energy saving device within a utility customer's home, no matter how small the device is.

7 A load imbalance was not apparent in the data for Hilltop Terrace so it will not be discussed in the analysis. However, load imbalances were measured on other monitors that we installed. This is caused by locating too many active circuit breakers on one phase of the service and too few circuit breakers on another phase. During periods of heavy load in the summer, half of the transformer will operate near capacity, while half will be lightly loaded. If there is excess current in part of the transformer and one leg is operating near capacity, it will get warmer and operate with less than optimal efficiency. Single phase (120 V) window air conditioners and refrigerators will exacerbate this problem. Correcting this problem is as simple as rearranging circuit breakers in the service panels of a building. This measurement should be taken on a hot summer day when a building's mechanical systems will be operating at their maximum duty cycle. By balancing the loads across different phases, especially the mechanical loads, circuit heating can be reduced.

5.0 Data Analysis

Figure 6 is a graph of twenty four days of usage (July 29 to August 22) measured at the secondary of the transformer that served the eighty apartments. The magenta line is KW, the yellow line is KVA and the blue area is KVAR. The initial correction was installed in the complex on August 7. Additional correction was installed on August 11 through August 18. You will note that the KVA and the KW start to overlap, indicating a power factor approaching 1.0. Figure 7 shows the power factor for the same period (blue) and the harmonic distortion (yellow and magenta). Before the correction was installed, the power factor varied between 0.86 and 0.93. During times of peak load when the PLIP's® were operating, the power factor varied from 0.985 to 0.995. As the load dropped and the PLIP's® correction was no longer needed, the power factor dropped to approximately 0.97 to 0.975. Note that the amount of KVAR present at the transformer after correction with a 122 KVA load (August 11), is less than the amount of KVAR present before correction with a 65 KVA peak load. That day was one of very few days during the summer of 2009 to exceed 90 degrees. Also note that the harmonic levels before and after correction are the same. The harmonic spikes were occurring prior to our adding correction and are not related to our equipment. Those seem to repeat on an approximately three week interval and last for three days. We are not aware of the source of those harmonics.

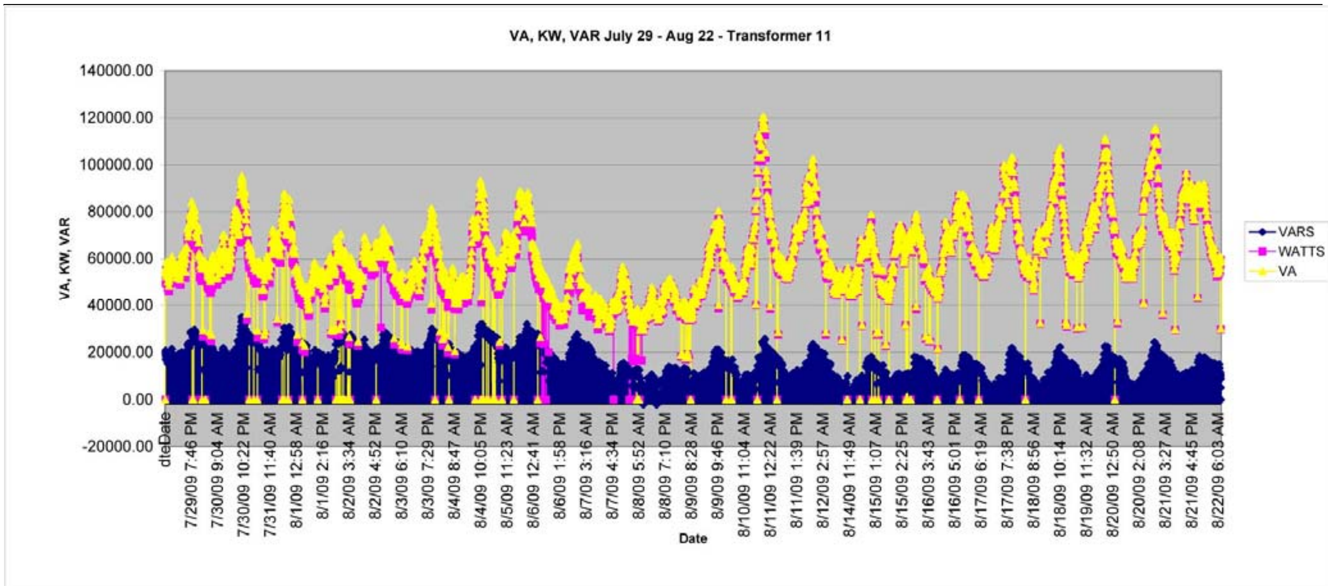

Figure 6: Transformer 11- Hilltop Terrace - Vars, Watts, VA July 29, 2009 – August 22, 2009

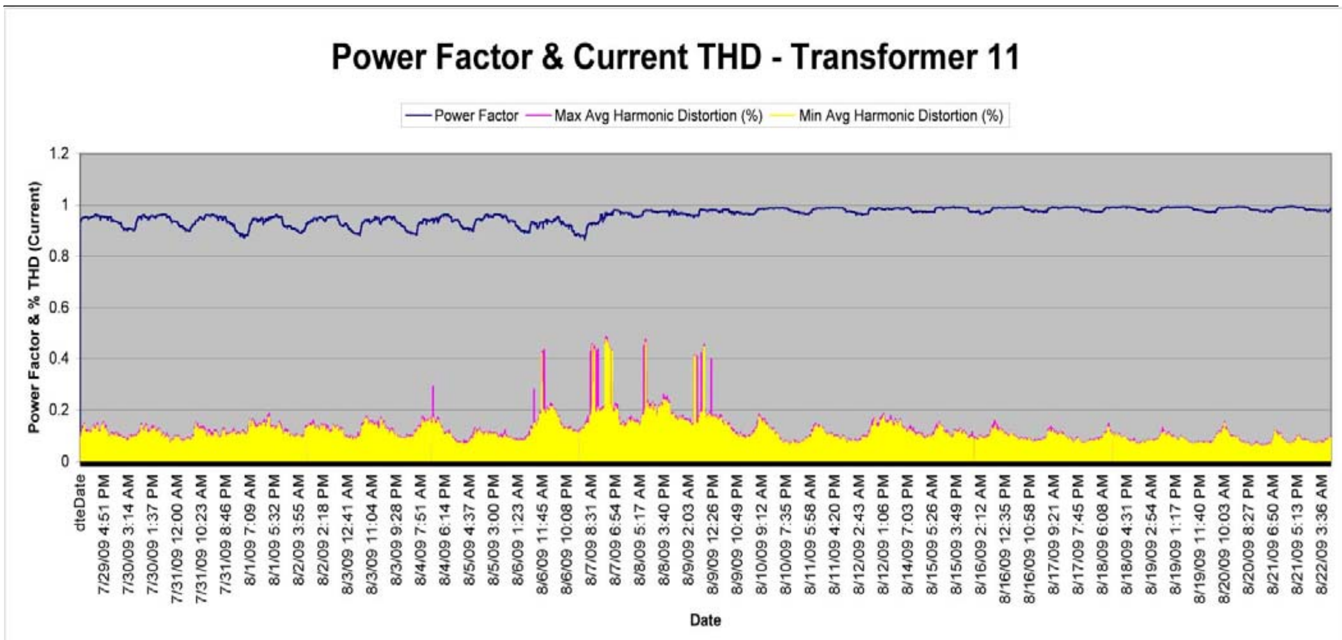

Figure 7: Transformer 11- Hilltop Terrace Power Factor and Harmonics
July 29, 2009 – August 22, 2009

The summer of 2009 was the second coolest on record in the New York area, making the execution of this project more difficult. Kilowatt output from the solar array that we are using for our solar reference is down 10% in 2009 versus 2008. Figure 8 is a graph of the transformer temperature (magenta), the monitor interior case temperature (dark blue), the monitor exterior temperature (yellow), and the solar output (light blue) for the same time period. The thermocouple that measured the transformer temperature was mounted to the surface of the unit. As the transformer had a much higher mass than the power monitor, its temperature varies much more slowly. Any rapid decreases in transformer temperature are the result of rainfall. During rainstorms, the measured temperature would drop below the transformer temperature and then rise back up to the ambient transformer temperature as soon as the storm passed. The difference in the transformer temperature from the monitor internal temperature is a function of thermal losses in the transformer resulting from inefficiencies and load. The power monitor, having a constant load and a much lower mass, more closely tracks the outdoor temperature plus the effects of solar loading. The power draw of each monitor is approximately 7 watts. 4 watts of that is for the battery charger. The light blue shows the solar array output over time. The array is located within a half mile of the apartment complex. A fine blue line indicates no cloud cover. Where the light blue area is dense, it is indicative of solar fluctuations caused by clouds passing overhead.

It can be seen that the transformer temperature and the monitor temperature are greatly affected by solar loading. There were several days where the shell of the transformer was between 130 degrees-F and 140 degrees-F. A temperature rise on the exterior of the transformer will reduce its ability to dissipate heat, resulting in a temperature increase on the interior of the unit. As mentioned earlier, that will result in a decrease in efficiency.

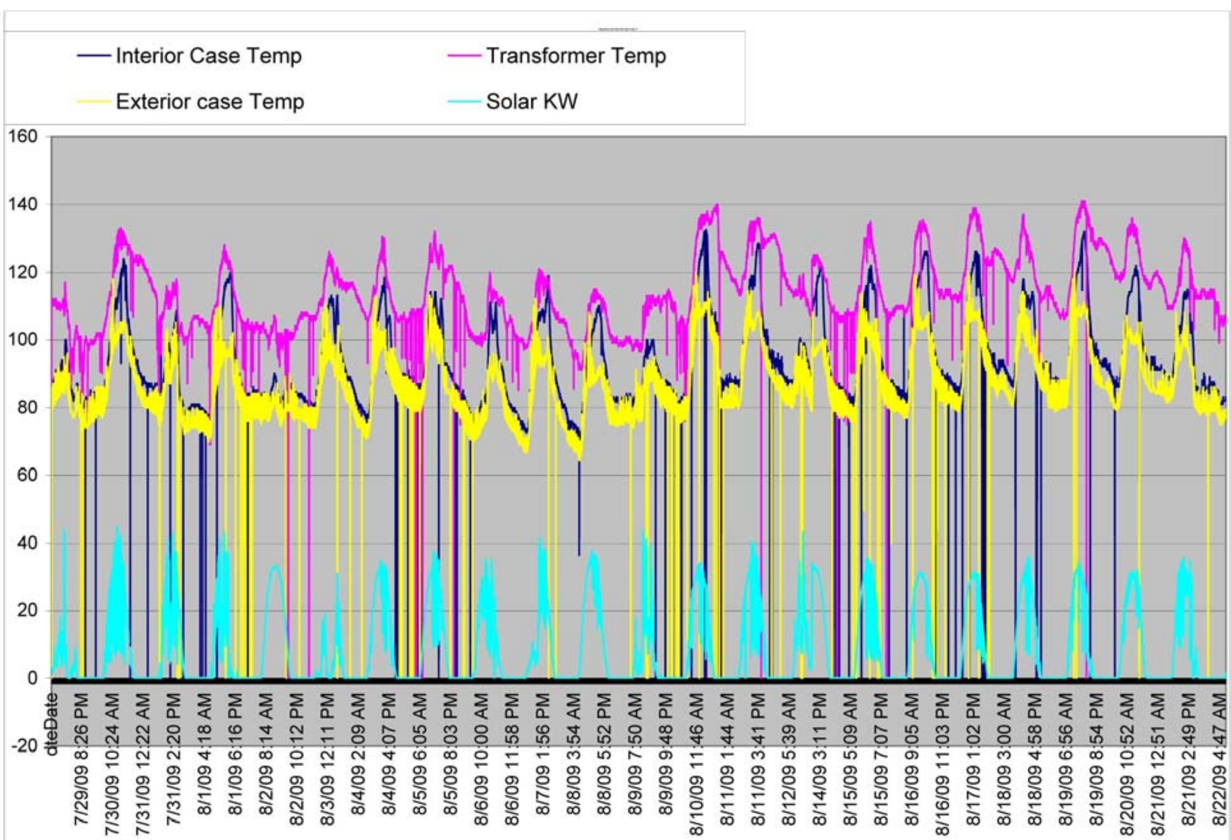

Figure 8: Transformer 11- Hilltop Terrace Temperatures July 29, 2009 – August 22, 2009
Temperatures in degrees-F, Solar output is in KW (light blue)

It can be seen from the figures above that we were able to reduce the peak load of the complex by approximately 6% when measured at the secondary of the transformer, resulting in a 12% reduction in related line losses from the point of correction back to the substation. The off peak load was reduced by approximately 9%. The period of increased load usually lasted approximately seven hours, starting at 4:30 PM to 5 PM, and continued until 11:30 PM to 12:00 midnight. The peak usually occurred between 8:30 PM and 9:30 PM, presumably as people turned on their bedroom air conditioners to cool the room before going to sleep. The minimum load usually occurred between 7:00 AM and 9:30 AM, approximately 11 hours after the peak. In the early morning, buildings will be their coolest from a lack of solar loading overnight, resulting in a lower cooling load. Also, residents will be turning off appliances at that time as they go to work.

To achieve this improvement in power factor required analyzing the base line reactive load of the facility during the cooler months. Correction was added at the buildings service entrance to correct the smaller reactive loads that are present. While this will not reduce losses after the meters, it will reduce line losses caused by the smaller loads in the 80 units from the service entrance back to the substation. Furthermore, it will work all year. A time delay relay with an "on delay" was added to the correction to ensure that it would not be active instantaneously after a blackout. The time delay is adjustable. It increases the cost of the device but as stated earlier, it is important to reduce the restart impedance in the event of a blackout. In addition, we installed 20 KVAR of correction using the PLIP's® . Based on measurements taken in June when it was still very cool outside, the peak load with no cooling for the transformer shown is approximately 40 KVA. That rises to between 80 KVA and 125 KVA on hot days during the summer. The PLIP's® were only installed on air conditioning units that were used frequently. Beyond a certain point, there is a diminishing return from adding more correction. All of the installed PLIP's® will not be operational simultaneously, as they only turn on when the associated air conditioner's compressor engages. They will not turn on if only the fan is operational. The PLIP's® achieved an energy savings before and after the meter. Based on measurements taken at individual units, we developed estimates of the savings. Figure 9 shows the waveforms for a 200 volt air conditioner, before and after correction. On that particular unit, a 15.5% current reduction was achieved, resulting in a line loss reduction of 27% related to that air conditioner. A 10% reduction in current was more common, with most improvements in the 7% to 12% range. 1 KVAR PLIP's® were used to correct the 220 volt units and ½ KVAR PLIP's® were used to correct the 120 volt air conditioners. The newer 220 volt air conditioners, when encountered, were left uncorrected. The energy savings calculations and the cost analysis appear in section 6.0.

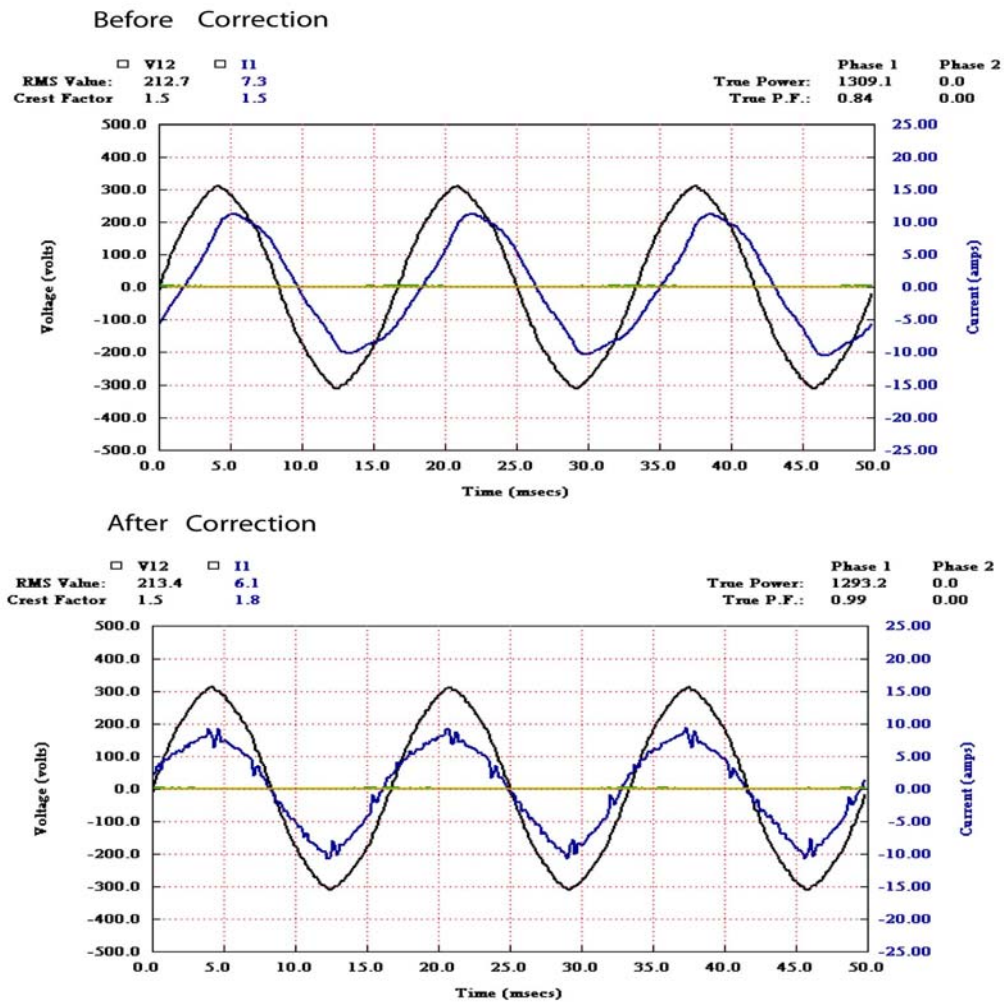

Figure 9: 220 volt window air conditioning unit before and after correction. Power Factor raised from 0.84 to 0.99. Current reduced from 7.3 amps to 6.1 amps, a 15.5% improvement.

6.0 <u>Cost Benefit Analysis</u>

Based on the techniques applied, and the increasing of the power factor at the complex, it is apparent that we achieved a reduction in losses. For the purposes of the analysis, we divided the day into two parts based on the power factor graph in Figure 7. There is the 14 hours where we achieved a power factor near unity and the 10 hour period where the power factor was near 0.97. In the calculations in Figure 10, at the end of the report, the 14 hour period is referred to as the “Peak Load” because it includes the peak period.

All calculations are based on average values measured before and after the correction was installed. The loss percentages are taken from Con Ed’s values in Figure 1 and Figure 2. Based on measurements taken on equipment and the number of units that we installed, we estimate that the savings after the meter from this process will amount to approximately 0.5% (0.005) of load. This is far lower than many published estimates of associated savings related to power factor correction, but we wanted to be conservative in our estimates. Based on our experience at Hilltop Terrace, the complex will use 3090 KWH less annually and reduce the peak load by 0.6 KW for an installation cost of approximately $4000. The return on investment (ROI) based on wholesale electricity costs and offset generation is approximately 9.3 years. As the effect of power factor correction on KW production is very predictable, the generation offset can be included. At present, new generation in the New York City area costs approximately $2000 per KW to build. That does not include the cost of the additional transmission and distribution to transfer that power. As we have no accurate way to calculate the cost of that, we did not include it in our analysis but it will reduce the 9.3 year ROI. We also did not include the savings from reduced system maintenance if this were applied over an extended area. That would also contribute to reducing the 9.3 year ROI. As these devices have a lifespan of over 20 years, they will far outlive the period for the ROI. Much of the existing equipment that these devices would be installed to correct could easily be in service for another ten years to twenty years, well beyond the period of the ROI.

To put the cost of this process into perspective, a cost comparison can be made between the cost of power factor correction and the cost of photovoltaic solar, a technology that the government has deemed worthy of public subsidies. While solar "generates" KW and power factor reduces KW, both technologies will have the same net effect on fossil fuel generation. A power meter located at the utility substation would not be able to determine if the 3090 KWH annual decrease in usage was due to the power factor correction system that we installed or a 2800 watt residential solar array at the same location (Annual KWH ≈ Array Capacity x 1.1) . At the present day cost of $ 7.50 per watt for installed photovoltaic solar, the 2800 watt array would cost $ 21,000. The power factor system that we installed would cost approximately $ 4000 for the 80 units, based on mass production costs of the devices. The net cost, when the value of offset generation is deducted, is $2800. If we add a 20% cost overrun to the total and figure that the power factor correction system would have a net cost of $3600, it would still cost 83% less than a solar array with the equivalent KW output. The public subsidy on that array would be approximately $ 8000, or over double the cost of the power factor system if it were 100% subsidized.

This is an important point because even though both systems would offset the same amount of KWH, the power factor system would have a much less visible effect on the utility customer's monthly usage bill. Where the savings would appear would be in the distribution portion of the bill in the form of reduced losses. The lack of an easily visible savings would make it difficult to induce the customer to install the system. That would mean that a large public subsidy would be needed to get these systems installed.

We are not trying to imply that photovoltaic solar is not worthy of public funding. What we are stating is that if solar is worthy of public funding, a technology that would cost less than half as much in public dollars to obtain the same net result is certainly worthwhile. In addition to the KWH reduction, power factor correction also provides a definite generation offset because the resulting energy savings are predictable and continuous, which solar does not provide. If public funding does not seem like a viable option, a one dollar monthly surcharge on each utility bill for five years would cover the entire cost. 80 apartments x $60 = $4800. It is a minimal expense to achieve a large gain.

Furthermore, if it is worthwhile to spend money to fix the problem after installation, the equipment standards should be changed to address the problem before the equipment is installed. While the ROI is 9.3 years on a retrofit, we estimate that it would be less than 3 years if the power factor correction was installed at the factory. That figure is based on the cost of energy lost across the entire system, not just after the customer's utility meter.

7.0 Conclusions

Based on our measurements and results obtained at Hilltop Terrace, we have come to the following conclusions:

- The power factor is sufficiently low in the apartment environment that improving it will result in a substantial energy savings throughout the entire utility system, when measured in KWH.

- We can cost effectively improve the power factor for existing apartment buildings in the near term.

- Standards need to be modified so that new apartment complexes are designed with a high power factor and a balanced load as part of the design criteria. Compliance should be verified prior to a Certificate of Occupancy being issued.

- Power Factor Correction in this environment does not significantly increase the amount of harmonics measured at the utility transformer.

- Power Factor Correction must be load based and must only operate when needed. Excess capacitance attached to the utility system can be as detrimental as excess inductance. Furthermore, in the event of a blackout, the excess capacitance would add extra impedance that would have to be energized, applying extra load to the system during a restart.

- Standards need to be modified so that new appliances are required to have a high power factor as part of the design criteria. This includes refrigeration and especially, air conditioners. Some of the newer 220 volt air conditioners operated with a power factor near 0.99. None of the 120 volt air conditioners encountered operated with a power factor above 0.92, including the newest units that were less than a year old. Most of the measurements were taken on hot days, so the units would have been operating as efficiently as possible.

- Standards need to be modified so that new appliances and other electrical devices to be attached to the utility have more strict limits on the amount of harmonics that they generate per watt of consumption. In particular, this will apply to computers, televisions and fluorescent lighting. Harmonics adversely effect electrical efficiency. Furthermore, harmonic mitigation can be very costly to implement.

While the last two items on the list will increase the price of appliances and other electrical devices, the accrued savings on energy will more than offset the additional cost.

8.0 Acknowledgements

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LOSS ANALYSIS - Power Factor Correction 8-29-09

Hilltop Terrace Buildings B, C, D, E, F (80 Apartments supplied by one 3 phase 150 KVA transformer)

Peak Load 1.5 KVA per Unit — Loss figures taken from Con Ed Loss Report - July 17, 2008
Min Load .4 KVA per Unit

Annual Average Distribution Losses 3.6%
Copper Losses 88% of Distribution Losses= 0.031824

Summer
Summer May-September (5 months) 9.73% loss — Resulting from higher temperatures of devices and wires (temperature coefficient of resistance)

Distribution Losses 51% of Total Loss	4.96 %
Copper Loss = 88 % of Distribution Loss	4.37 %

As a result of power factor correction

Peak Load current reduction 5% (8 AM - 10 PM 14 hours .58 Days)	Copper Loss Reduction	0.0975	**5% Power Factor improvement**
Off Peak Current Reduction 11% (10 PM - 8 AM 10 hours .42 days)	Copper Loss Reduction	0.2	**10.5 % Power Factor improvement**

							PF Saved Copper Loss	0.5% (.005)	
		={KVA/(1-copper loss)}-KVA		Total Copper Loss			<u>Before Meter</u>	<u>Saved Losses After Meter</u>	0.50%
Average Peak Period I63.8 KVA	Average Copper Loss	2.915466 KW	* 14 Hours	40.81652	KWH Daily during Peak x	0.0975	3.979611	4.466 KWH	
Average Off Peak Load 58.8 KVA	Average Copper Loss	2.686981 KW	* 10 hours	26.86981	KWH Daily during Off Peak x	0.2	5.373962	2.94 KWH	
				67.68633	Daily KWH		9.353573	7.406 Daily KWH	
Peak load savings .6 KW x $ 2000/KW = $ 1200	Power Plant Construction								
Based on 120 KVA Peak Load				16.75957	Total Daily KWH Saved				
			Total	2513.936	KWH Saved from May - September		1403.036	1110.9	

Winter

Winter October - April (7 Months)	4.41% Loss					
Distribution Losses 51% of Total Loss	2.26 %					
Copper Loss =88 % of Distribution Loss	1.99 %					
Average Load Current Reduction	7.00 %	Average Loss Reduction		14%		
Average Load 40 KVA	Average Loss	0.816327 KW	* 24 Hours =	19.59184 KWH Daily		
		={KVA/(1-copper loss)}-KVA		14% savings	2.742857 KWH/day	

576 KWH Saved from October - April

3089.936 KWH Saved Annually $ .08/KWH

$247.19 Annual Dollar Savings for electricty at wholesale prices

Approx ROI 9.30 years based on wholesale electricity costs and offset generation only

Annual Energy Savings is approximately the same as for the KWH generated
by a 2800 watt residential solar array. Array cost approx. $ 21,000 . ($7.50/watt)

Installed cost of Power Factor Correction: Approx $ 4000 including engineering.
20% of the cost of a solar array for an equivalent amount of energy savings.

Excludes some savings on the transmission system - Existing Substation correction equipment can be used to improve the PF on the Transmission System
Does not consider Greenhouse Gas Reductions
Does not consider deferral of investment on distribution system
Does not consider deferral of investment on correction at substations

40% NYSERDA subsidy of Solar costs $ 8000. 100% Subsidy of PF Correction costs $ 4000 or less for the same amount of energy

For a 40 unit building, energy savings would be one half, cost would be approximately two-thirds.
40% NYSERDA subsidy of Solar costs $ 4000. 100% Subsidy of PF Correction costs $ 2700 or less for the same amount of energy

Figure 10: Loss Calculations, Energy Saved, and Return on Investment (ROI)