METERING
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AMERICA

At Load Power Factor Correction

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

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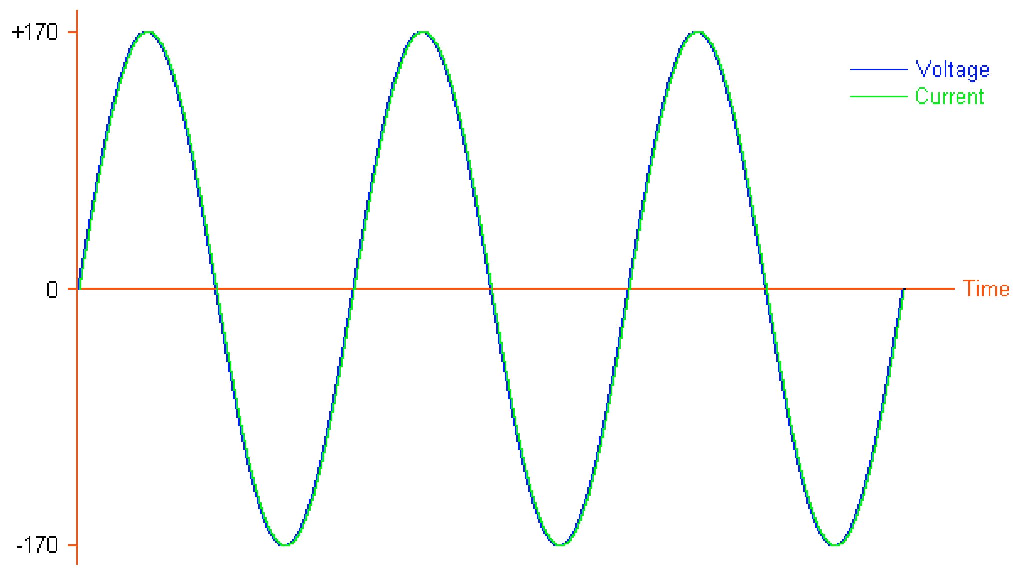
Power Factor Correction, LLC
"Bringing The World Back Into Phase, One Step At A Time"

NYSERDA New York State Energy Research and Development Authority

What are <u>Reactive Power</u> and <u>Power Factor</u>?

- **Power = Current (I) x Voltage (V)**
  - **Current & Voltage are in phase (Power Factor =1.0)**
  - **Devices on System can do maximum amount of work with the minimum amount of current.**

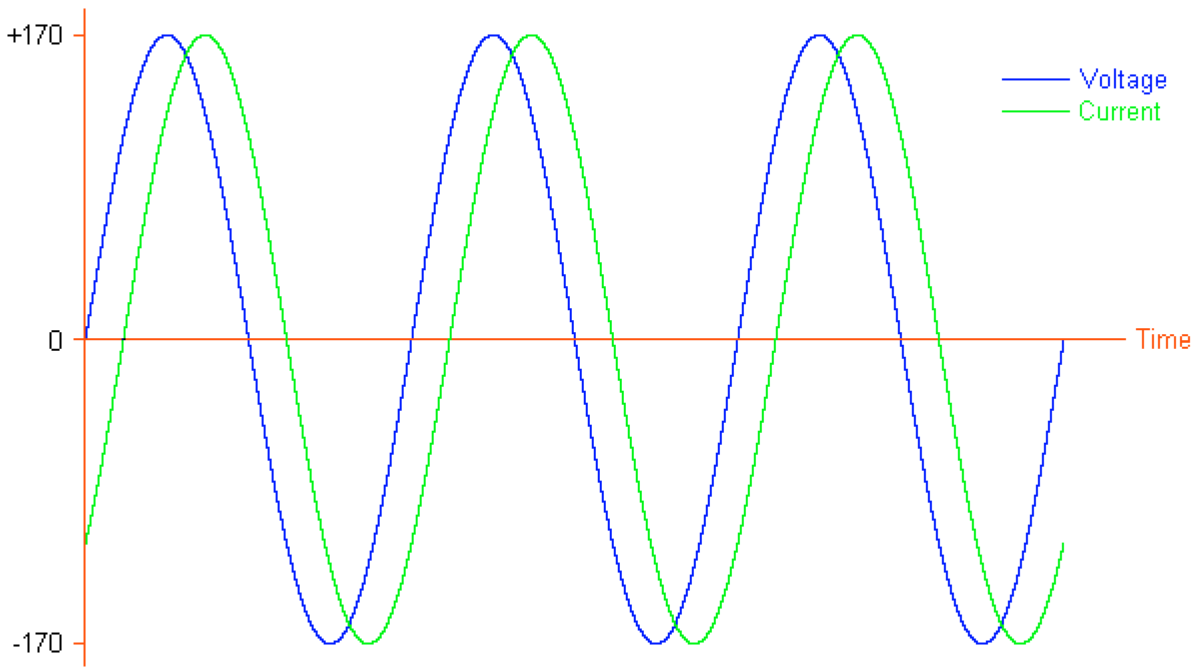


What happens when motors and transformers (Inductive Loads) are introduced into a circuit ?

- **The inductive loads discharge reactive power onto the system**
- **Current waveform starts to lag behind the voltage waveform because of the inductance of the magnetic devices.**
- **Higher Currents (I) are present on the system for the same amount of power being delivered to the customer.**
- **The higher currents result in higher I^2R (Thermal) losses in the conductors and transformers on the system.**

Voltage and current 45 degrees out of phase

- **Power Factor=0.7** **(lagging– current lags the voltage)**



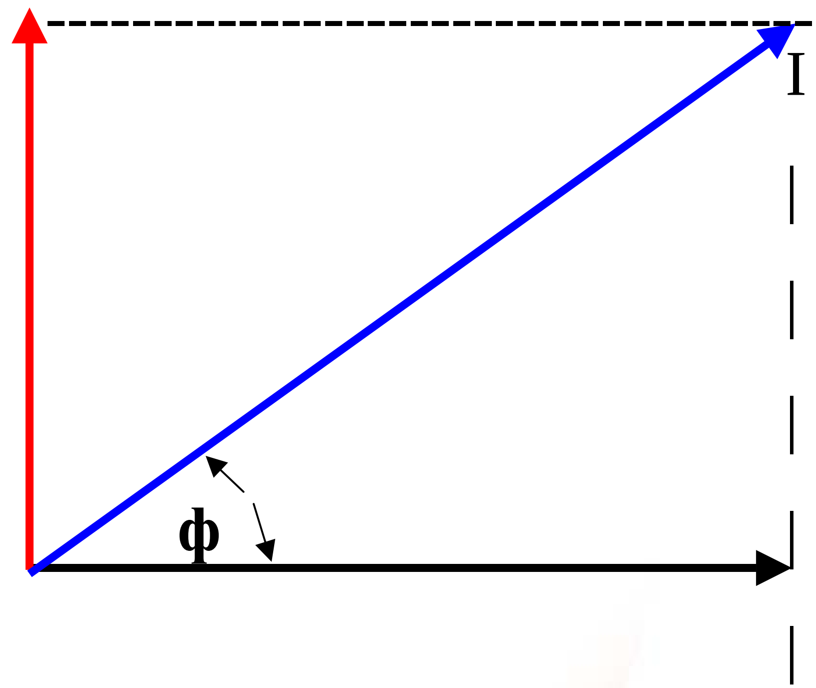
What is Reactive Power ?

It is the component of Apparent Power that is 90 degrees out of phase with the Real Power.

Reactive Power = 60 KVAR (Lagging)

Apparent Power = 85 KVA

I_{AVG}= 227 Amperes



Actual current of system

Real Power = 60 KW

I_{AVG} = 157 Amperes if PF=1.0

Building PF= .7

ϕ = 45 degrees

Power Factor=cosine ϕ = Real Power / Apparent power

HOW DOES THE PRESENCE OF REACTIVE POWER AFFECT DISTRIBUTED GENERATION AND THE UTILITY?

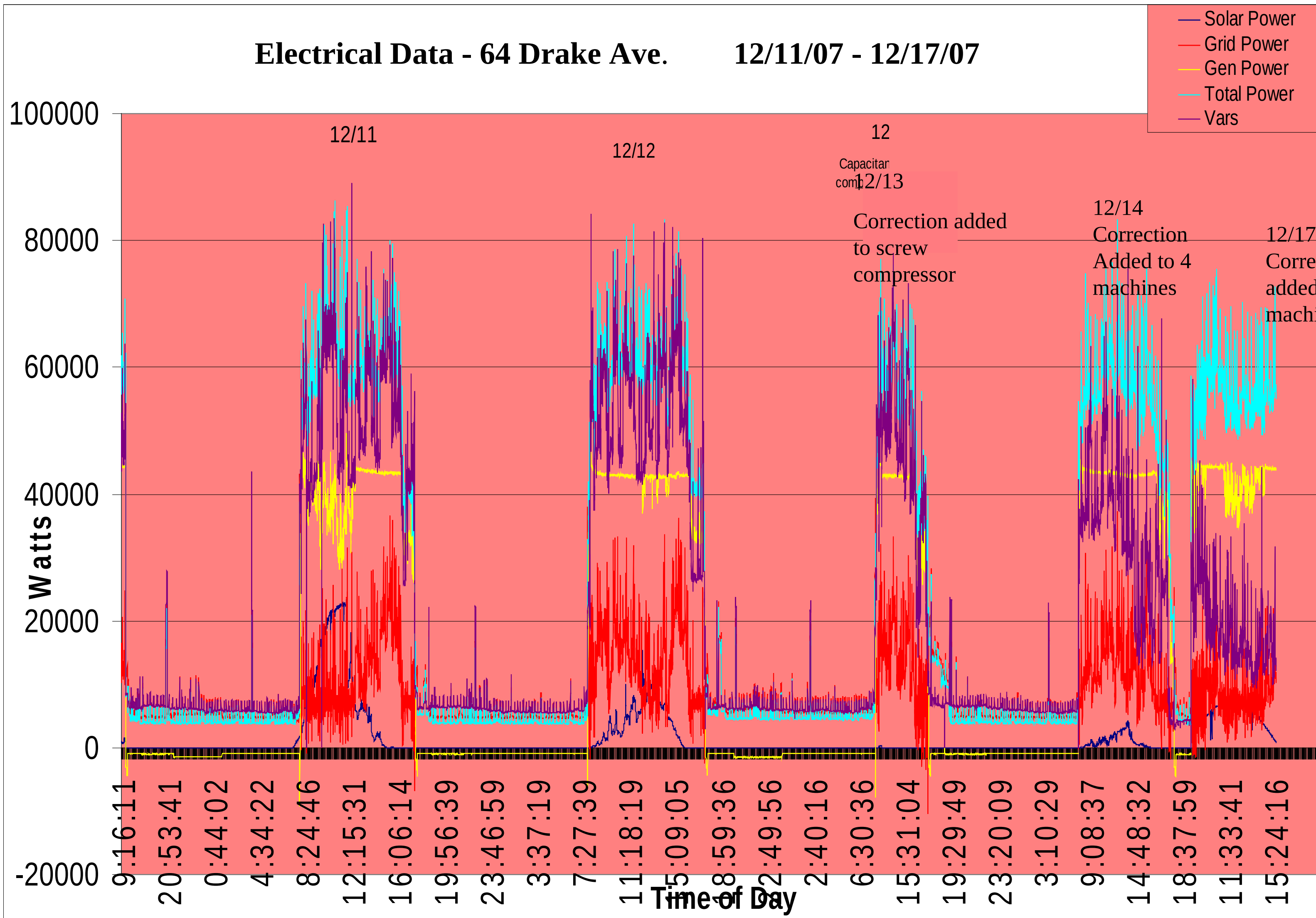
CHP system (Micro-turbines)

INSTALLED 2003

Photo-voltaic Solar Array

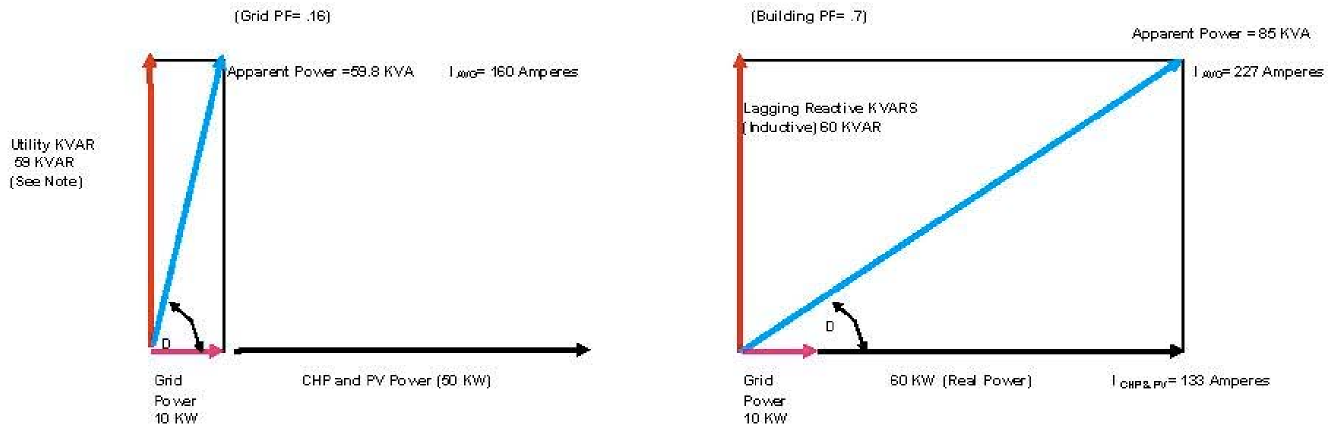
INSTALLED 2007

During Power Factor Correction



What effect does this have on the utility system and on the customer’s utility bill ?

Before Power Factor Correction

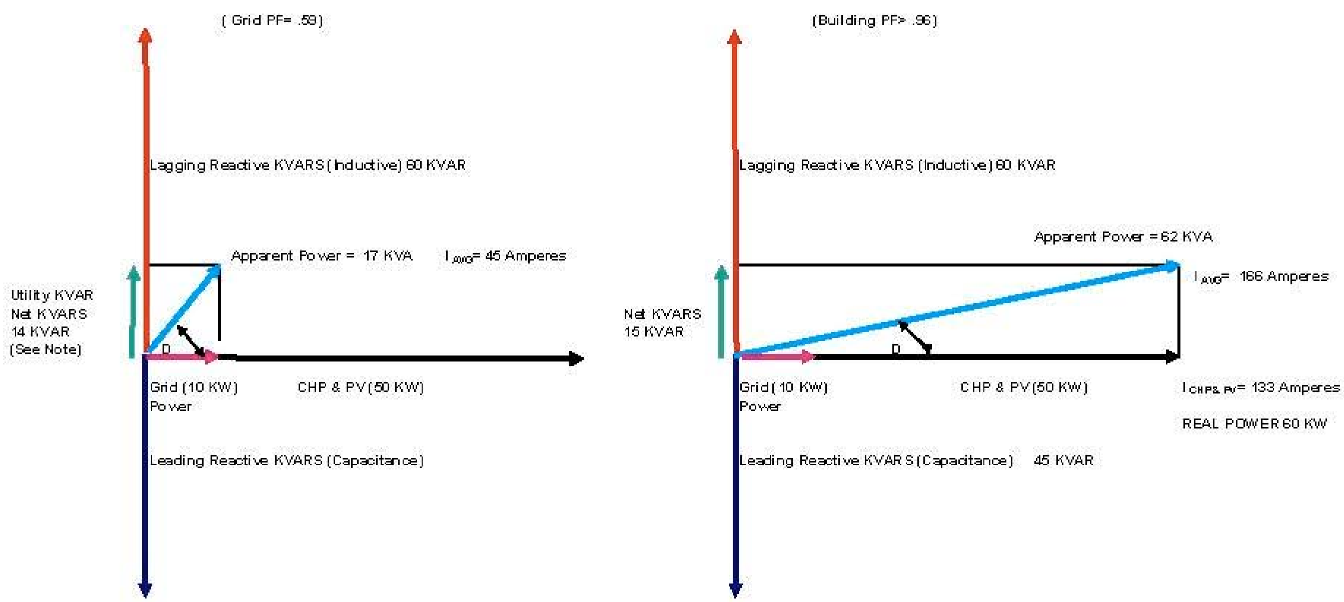


I AVG is the average current per phase in the 3 phase system

AT LOAD CORRECTION ONLY

After Power Factor Correction

Capacitance Added



PF=cosine = Real Power (KW) / Apparent Power (KVA)

AT LOAD CORRECTION AND SERVICE ENTRANCE CORRECTION

BEFORE

Utility Current

I_{AVG}=89.4

TIME - 11:27:36 2/4/8

SOURCE	GRID	SOLAR	CAPSTONES
PHASE 1 VOLTS	125.64996	125.57495	125.64996
PHASE 1 AMPS	96.67998	10.42000	117.39997
PHASE 2 VOLTS	125.19996	125.22496	125.24996
PHASE 2 AMPS	99.83997	10.48000	121.31996
PHASE 3 VOLTS	125.27494	125.19996	125.27494
PHASE 3 AMPS	71.59999	7.54000	118.99998
POWER FACTOR	.69750	.86600	.99160
VARS	22649.99218	.00000	.00000
CALCULATED VARS	24717.45703		
KWATTS	24059.99218	3089.99902	44489.99218
FREQUENCY	60.01999	60.02699	60.03099

		Capacitance
TOTAL BUILDING POWER DEMAND	:71639.97656	.00000
TOTAL BUILDING POWER FACTOR	:.94532	10000.00000
TOTAL BUILDING KVARS	:49717.45703	10000.00000
BUILDING KVAR ADJUSTMENT	:25000.00000	5000.00000

AFTER

Utility Current

I_{AVG}=73.3

Down 18%

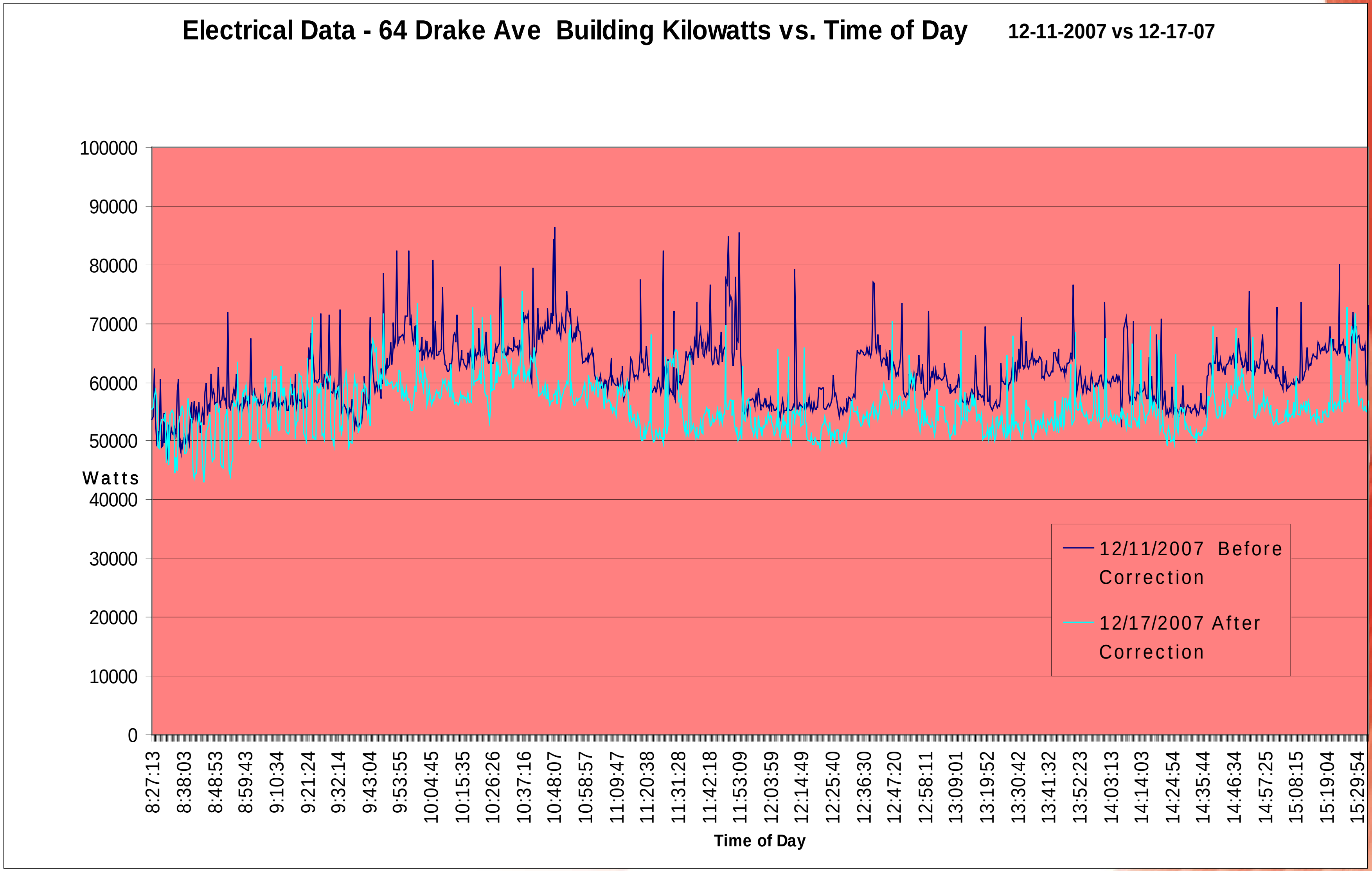
5% Reduction in Building Current

TIME - 11:30:23 2/4/8

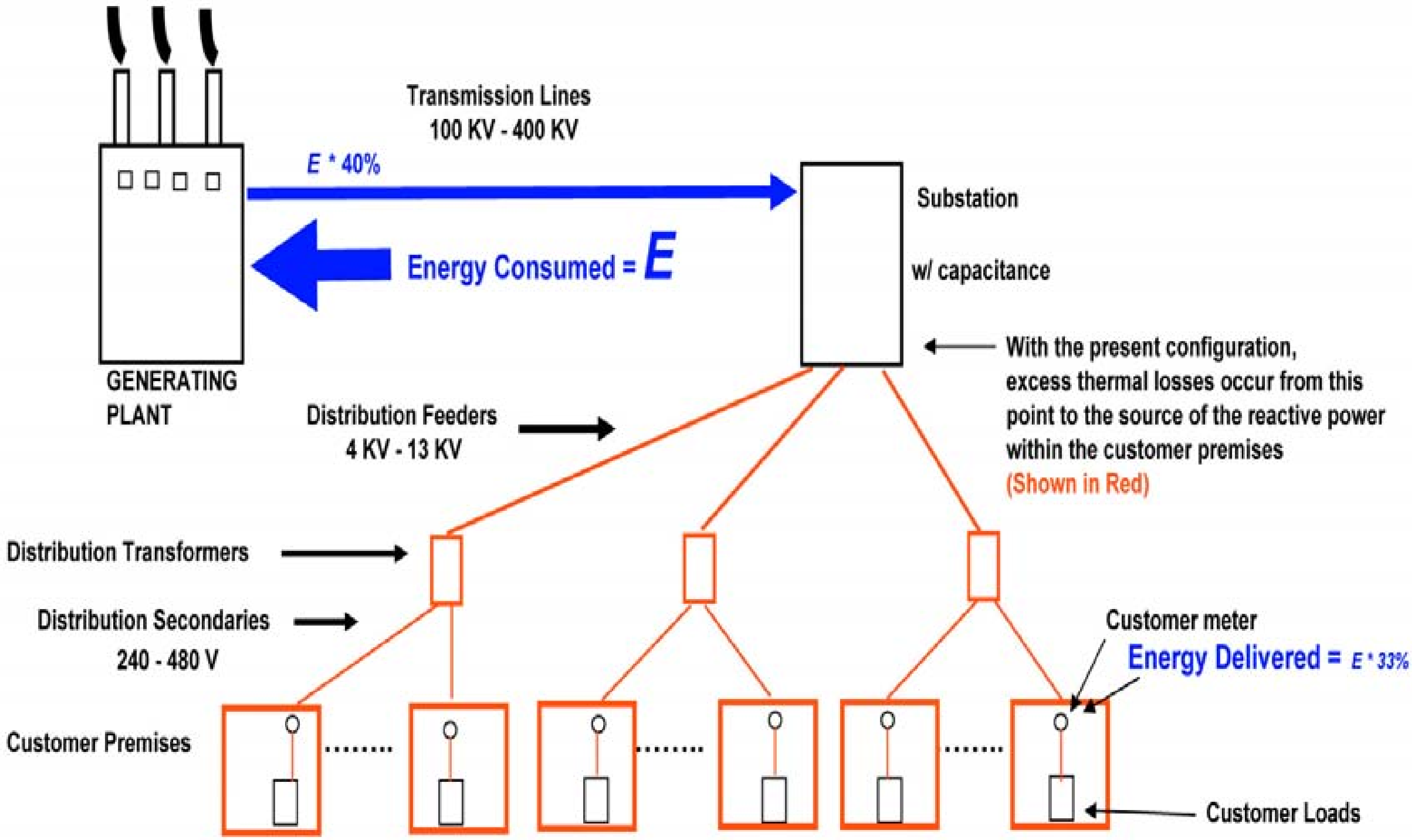
SOURCE	GRID	SOLAR	CAPSTONES
PHASE 1 VOLTS	125.67495	125.69999	125.77497
PHASE 1 AMPS	86.83997	10.22000	117.51997
PHASE 2 VOLTS	125.37496	125.47496	125.39994
PHASE 2 AMPS	86.39998	10.30000	120.11997
PHASE 3 VOLTS	125.59994	125.62496	125.57495
PHASE 3 AMPS	46.75999	7.14000	118.79997
POWER FACTOR	.86740	.86390	.99190
VARS	3989.99902	.00000	.00000
CALCULATED VARS	14111.33789		
KWATTS	24599.99609	2999.99951	44399.98437
FREQUENCY	60.01198	59.96500	60.01599

		Capacitance
TOTAL BUILDING POWER DEMAND	:71999.96875	20000.00000
TOTAL BUILDING POWER FACTOR	:.98133	10000.00000
TOTAL BUILDING KVARS	: 59111.33593	10000.00000
BUILDING KVAR ADJUSTMENT	:45000.00000	5000.00000

KVAR CORRECTION REDUCES KW CONSUMPTION



ELECTRIC POWER TRANSMISSION

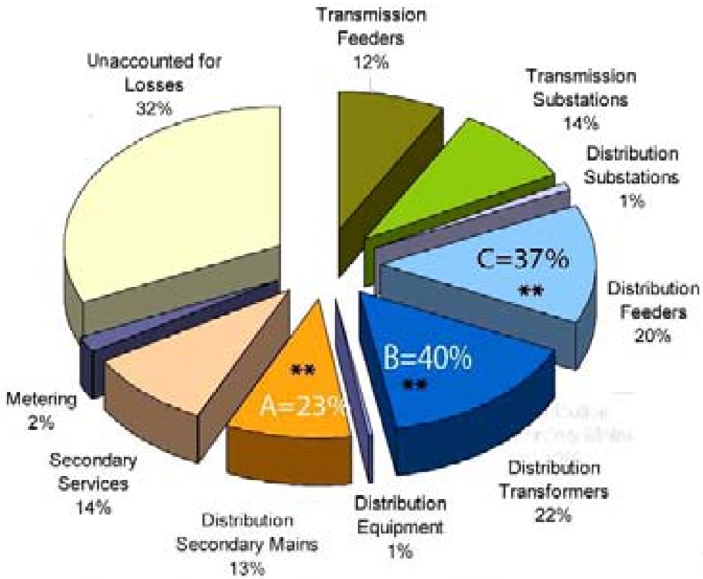


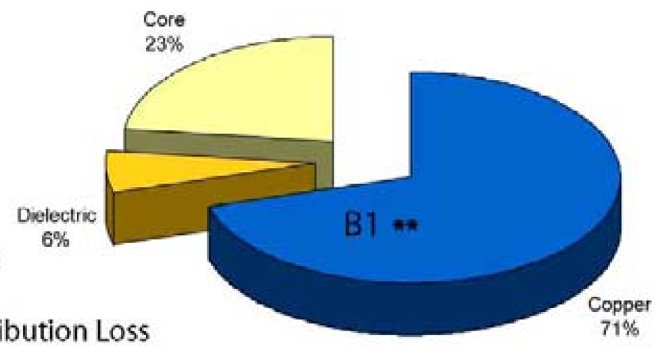
From Con Ed Presentation to PSC July 17, 2008
Notations Added 9/2009 marked by " ** "

Transmission & Distribution Losses

Con Edison

- 1.2% Transmission Losses
- 3.6% Distribution Losses
- 2.2% Other Losses





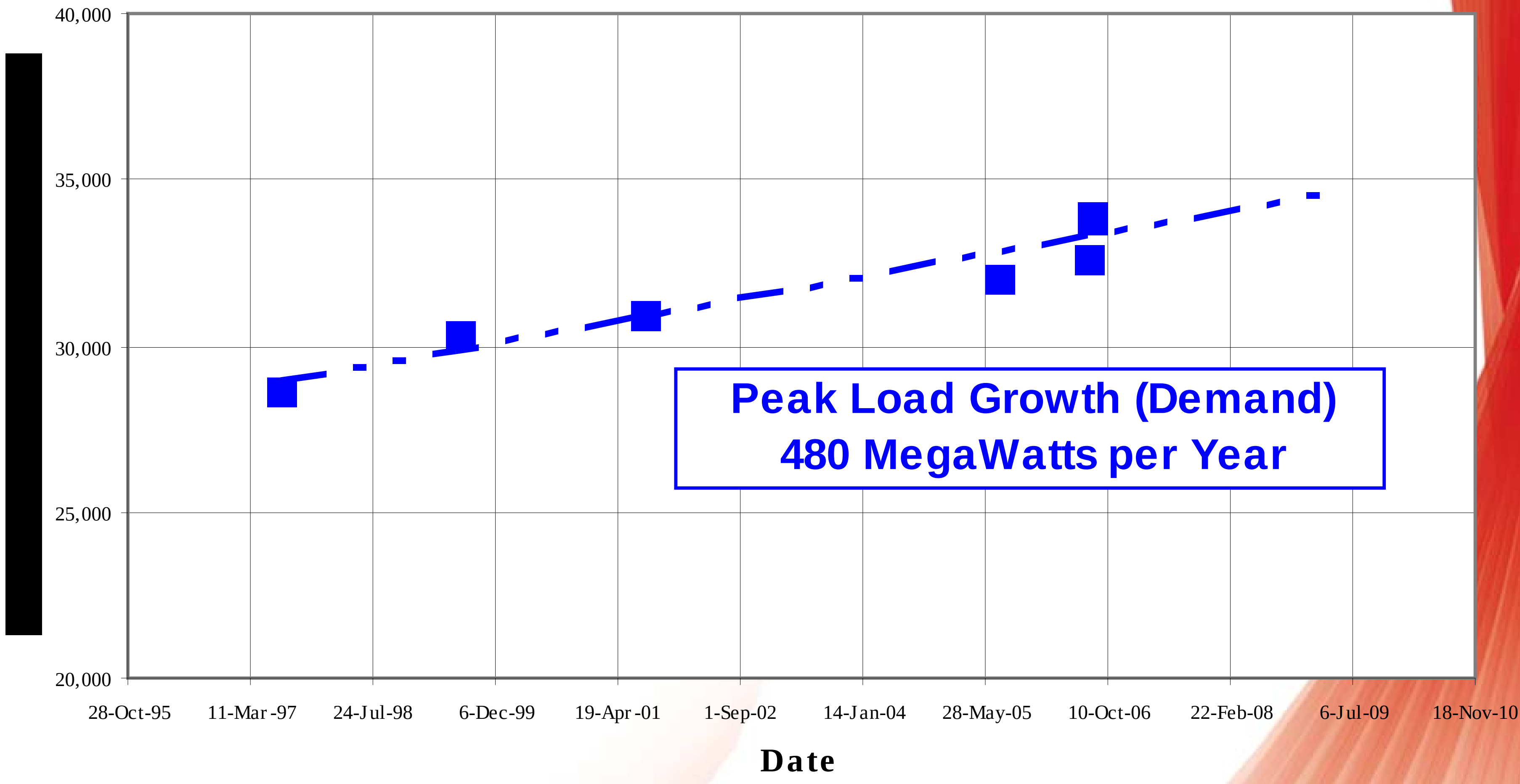
** A+B+C=.100% of Distribution Loss
B1=Transformer Copper Loss
Copper Loss={(.71 x .4) + .23 + .37} x .Distribution Loss
=.88 x Distribution Loss

3.2% of all losses are from copper loss on the distribution system

Power Consumption is Rapidly Increasing

Breaking Records: New York State Peak Load Records, 1997 to 2006

Courtesy of NYSERDA - J. Borowiec



Correction Parameters

- **Correction Devices should be located as close to the load as possible**

- **Devices should only operate when needed. Too much correction is as detrimental as too little.**

What will it cost to correct the power factor on a system wide basis ?

- **Material**

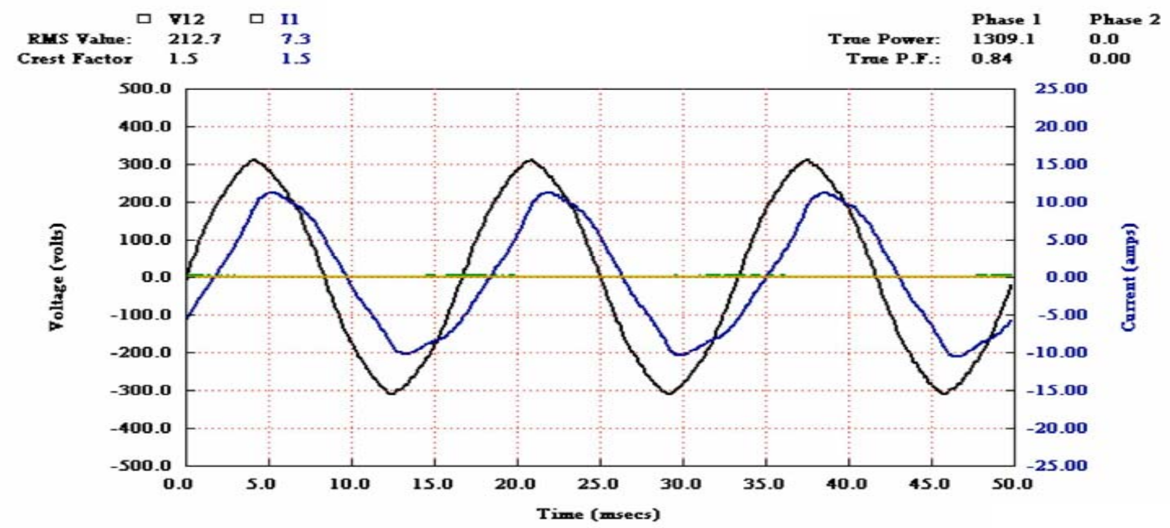
  (Correction Capacitors, Harmonic Filters)

- **Labor for installation**

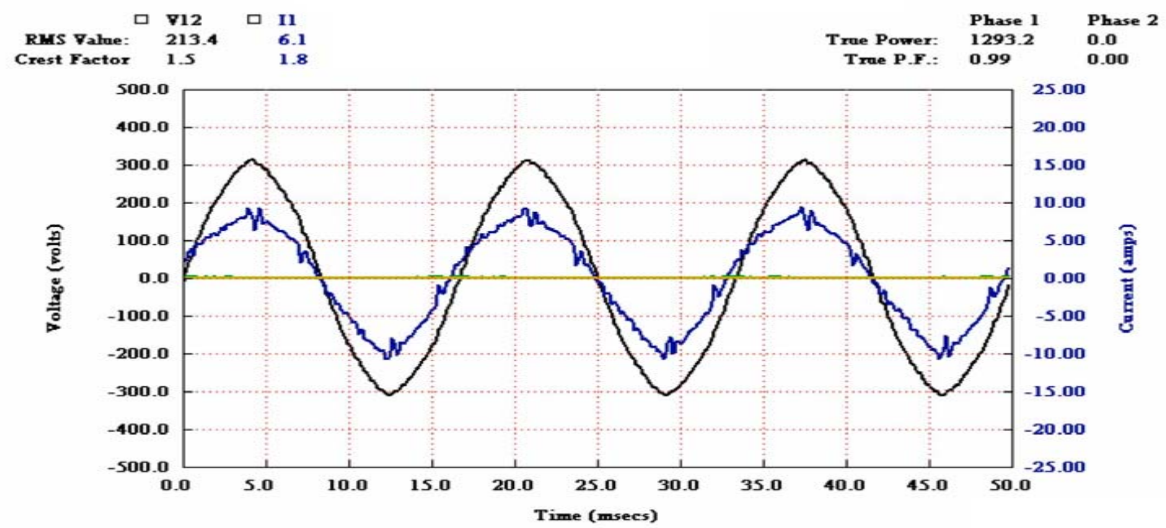
  Conventional wisdom indicates that the labor costs are too high if the load is too small

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

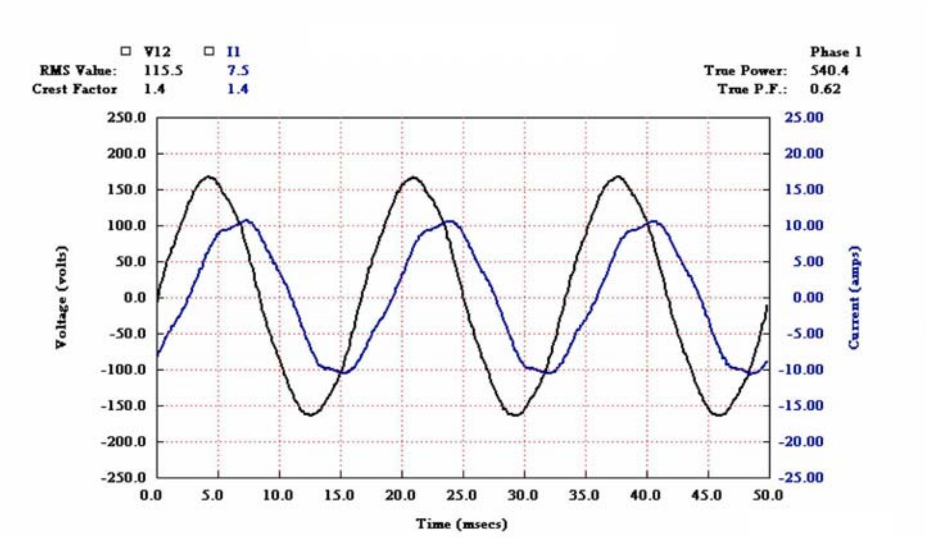
Before Correction



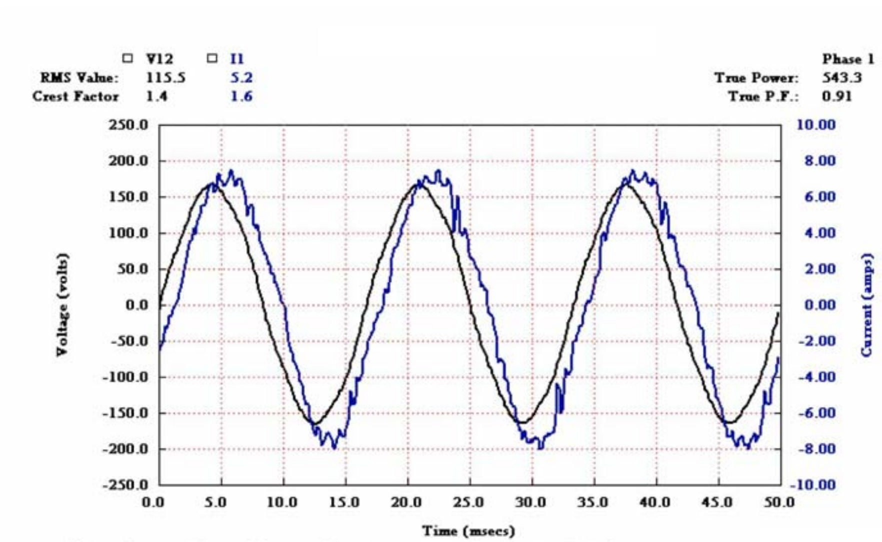
After Correction



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.



Before Correction - Power Factor =.62, Current=7.5 Amperes

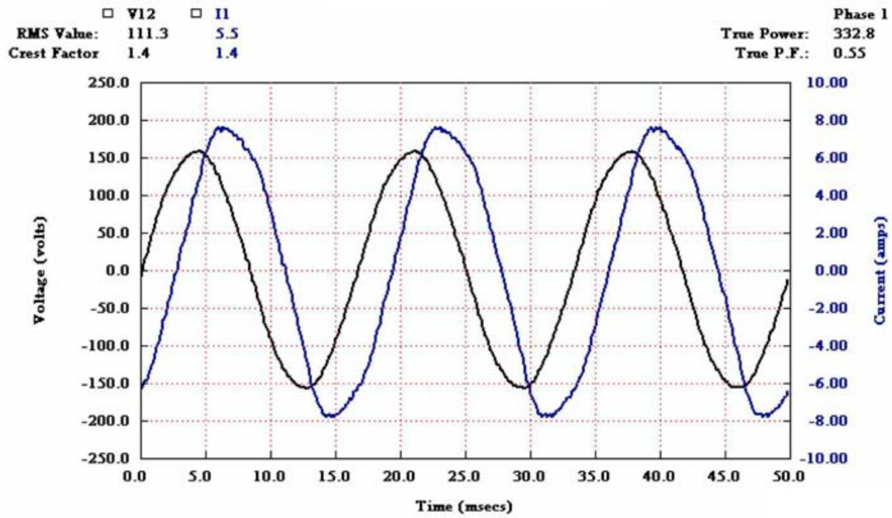


After Correction - Power Factor = .91, Current =5.2 Amperes
31% Current Reduction, 51% reduction in associated line losses

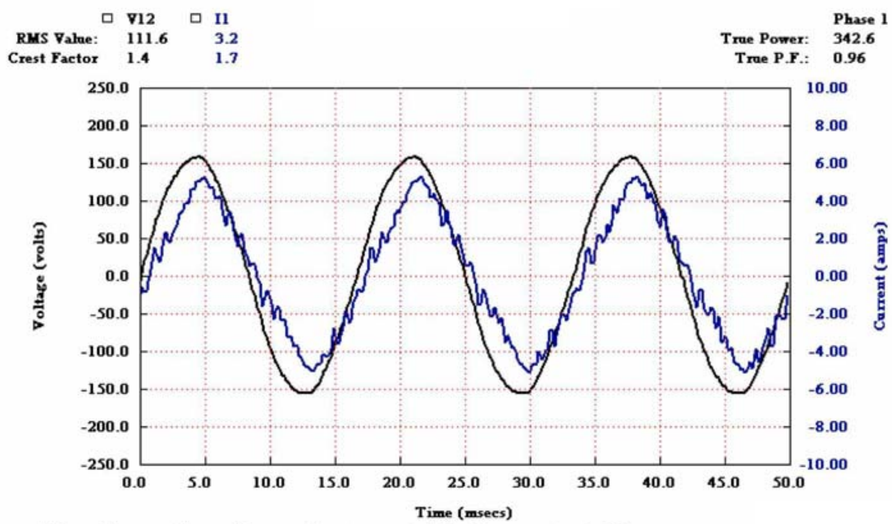
Before and after waveforms from a Dixie-Narco vending machine.

A 2.3 ampere (31%) current reduction was achieved through the use of power factor correction.

51% Reduction in associated line losses



Before Correction - Power Factor =0.55, Current = 5.5 Amperes

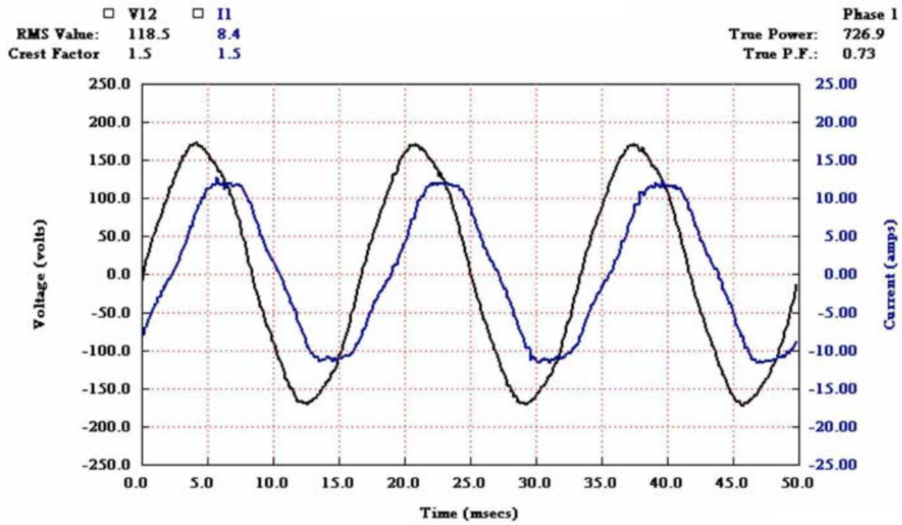


After Correction - Power Factor =0.96, Current =3.2Amperes
42% current reduction , 66% reduction in associated line losses

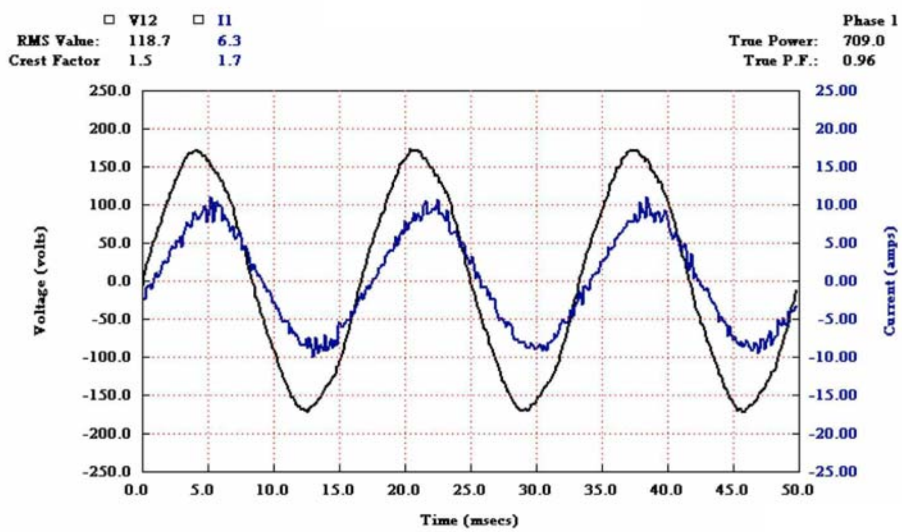
Before and after waveforms from a Pepsi® High Visibility vending machine.

A 2.3 ampere (42%) current reduction was achieved through the use of power factor correction.

66% Reduction in associated line losses



Before Correction - Power Factor = .73, Current=8.4 Amperes



After Correction - Power Factor=.96, Current=6.3 Amperes
25% Current Reduction , 43% Reduction in associated line losses

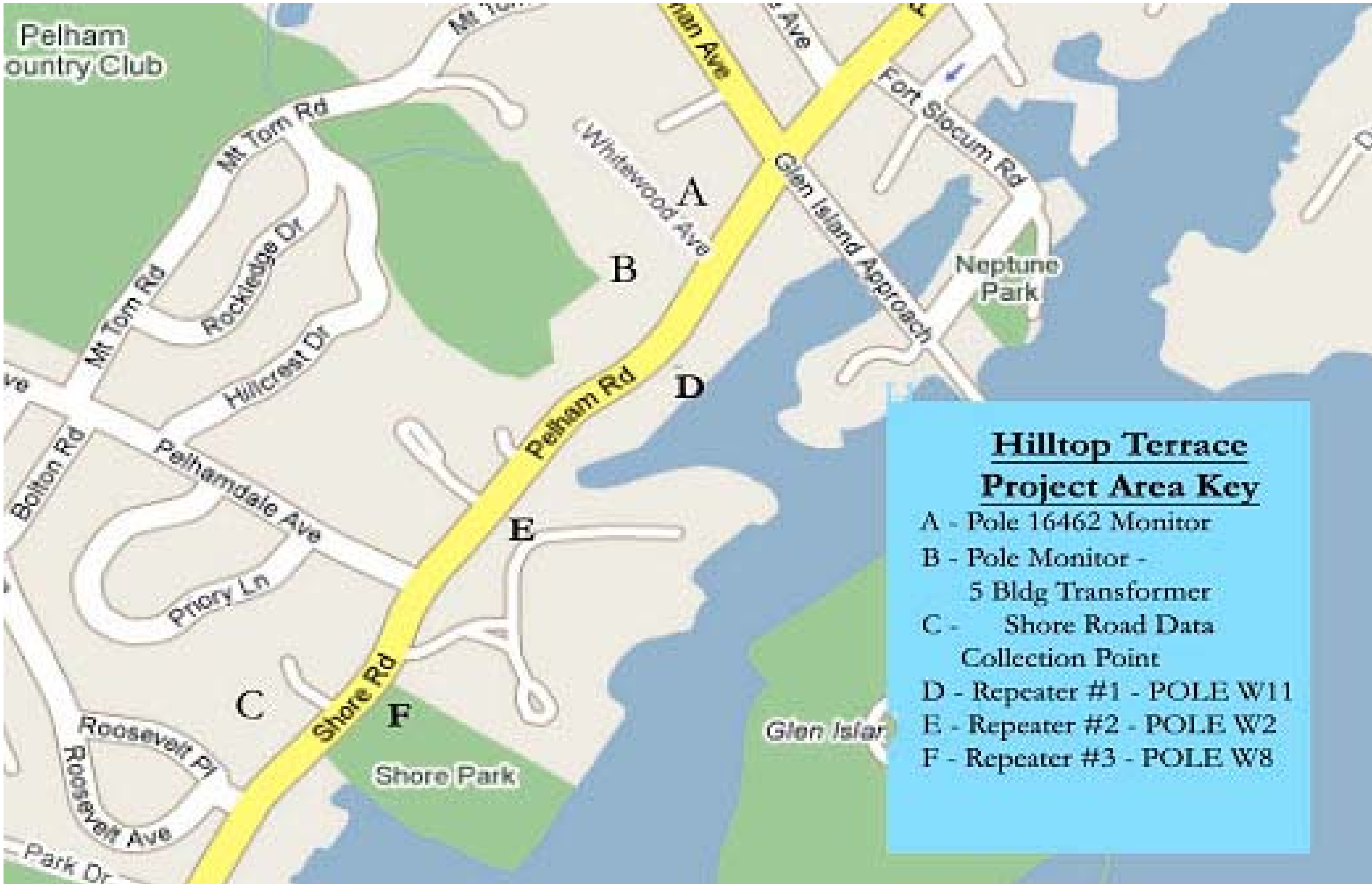
Before and after waveforms from a Dixie-Narco vending machine.

A 2.1 ampere (25%) current reduction was achieved through the use of power factor correction.

43% Reduction in associated line losses

What is the net effect of power factor correction on a system wide basis ?

Hilltop Project Area



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.

Reduced Thermal Losses

- **Lower KVA Load results in lower currents**
- **Lower Currents result in less heating and lower KW losses in the wires within customer premises**
- **The same is true of the conductors and transformers on the utility's Distribution System**
- **Lower heating of the conductors further reduces their resistance and associated heat loss (I^2R) because of the temperature coefficient of resistance. The losses are cumulative from all of the reactive sources.**

Locations of Circuit Resistance (R) and the Resulting Thermal Losses

- **Wire Resistance** **(#14 wire .003 ohms/ft)**
- **Wire Interfaces *****
- **Receptacles *****
- **Switches *****
- **Circuit breakers *****

*** **Subject to Oxidation**

Temperature Coefficient of Resistance

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

Where,

$R =$ Conductor resistance at temperature "T"

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

$\alpha =$ Temperature coefficient of resistance for the conductor material.

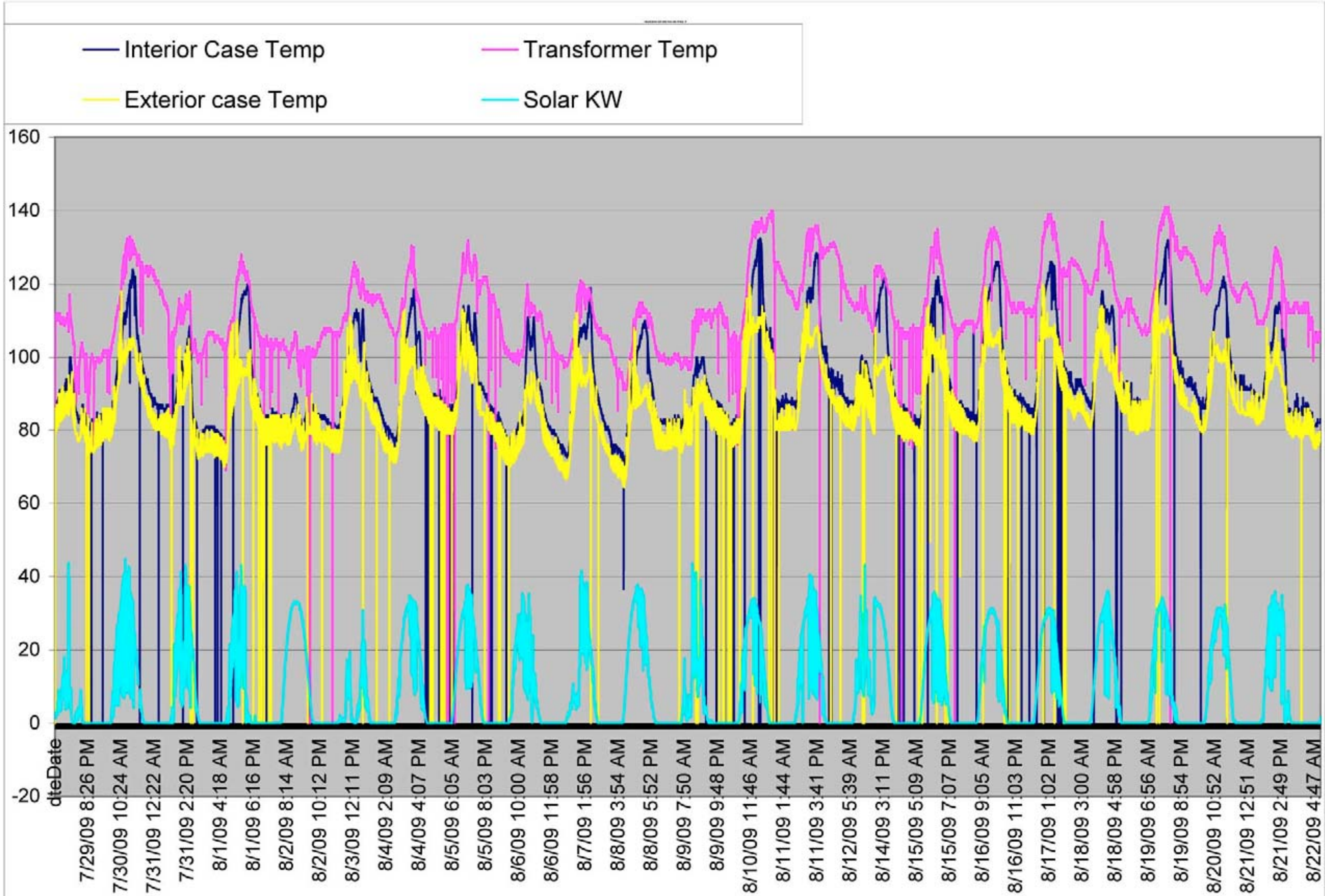
$T =$ Conductor temperature in degrees Celcius.

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

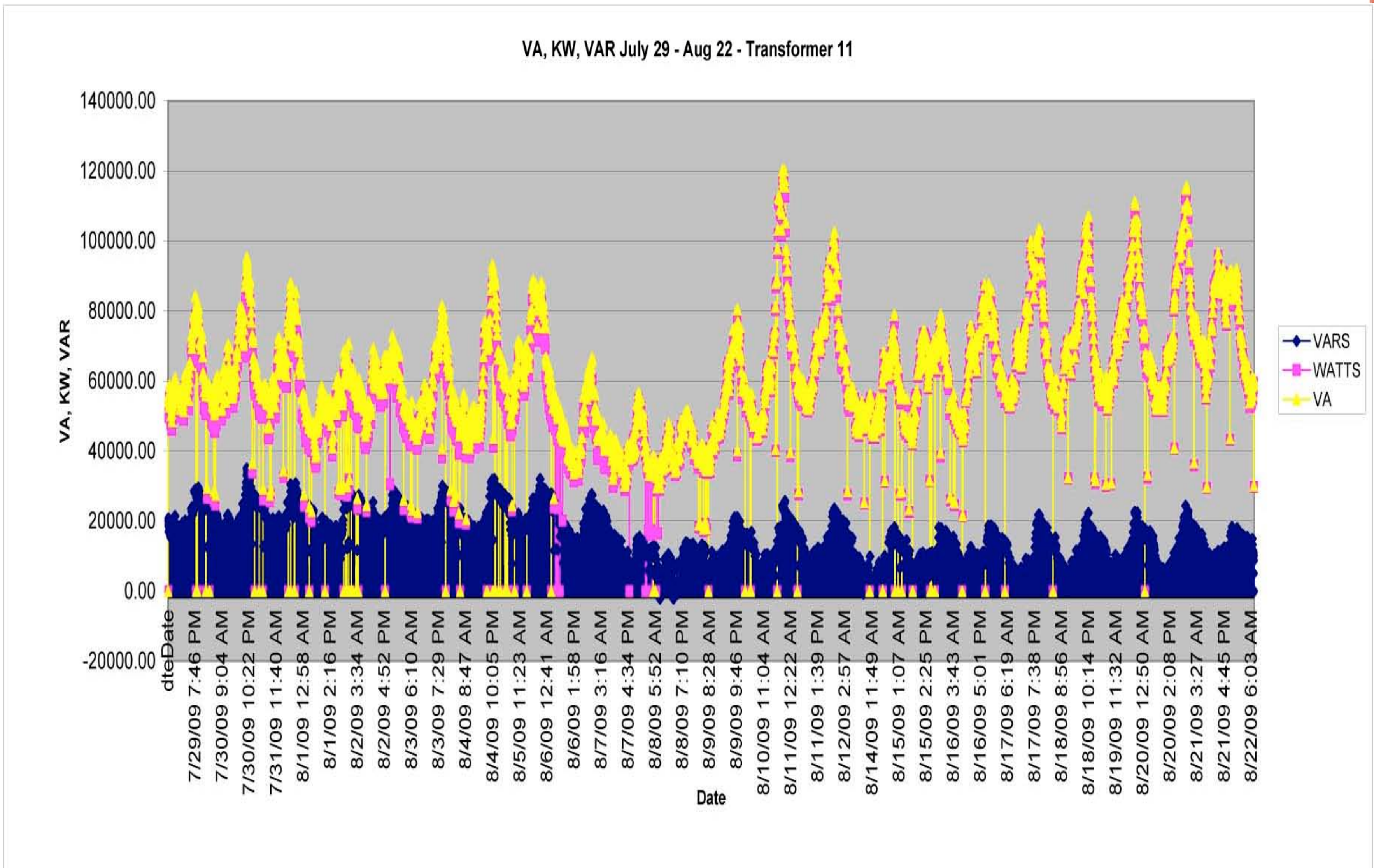
For Copper, α= 0.004041

10 degree C (18 degree F) rise in conductor temperature results in a 4% rise in resistance and a 4% increase in line losses

Conductor Temperatures can increase by 40 deg-F (22 deg-C) on Sunny Days. R increases by 8.8%



Hilltop Transformer 11 July 29 - August 22, 2009

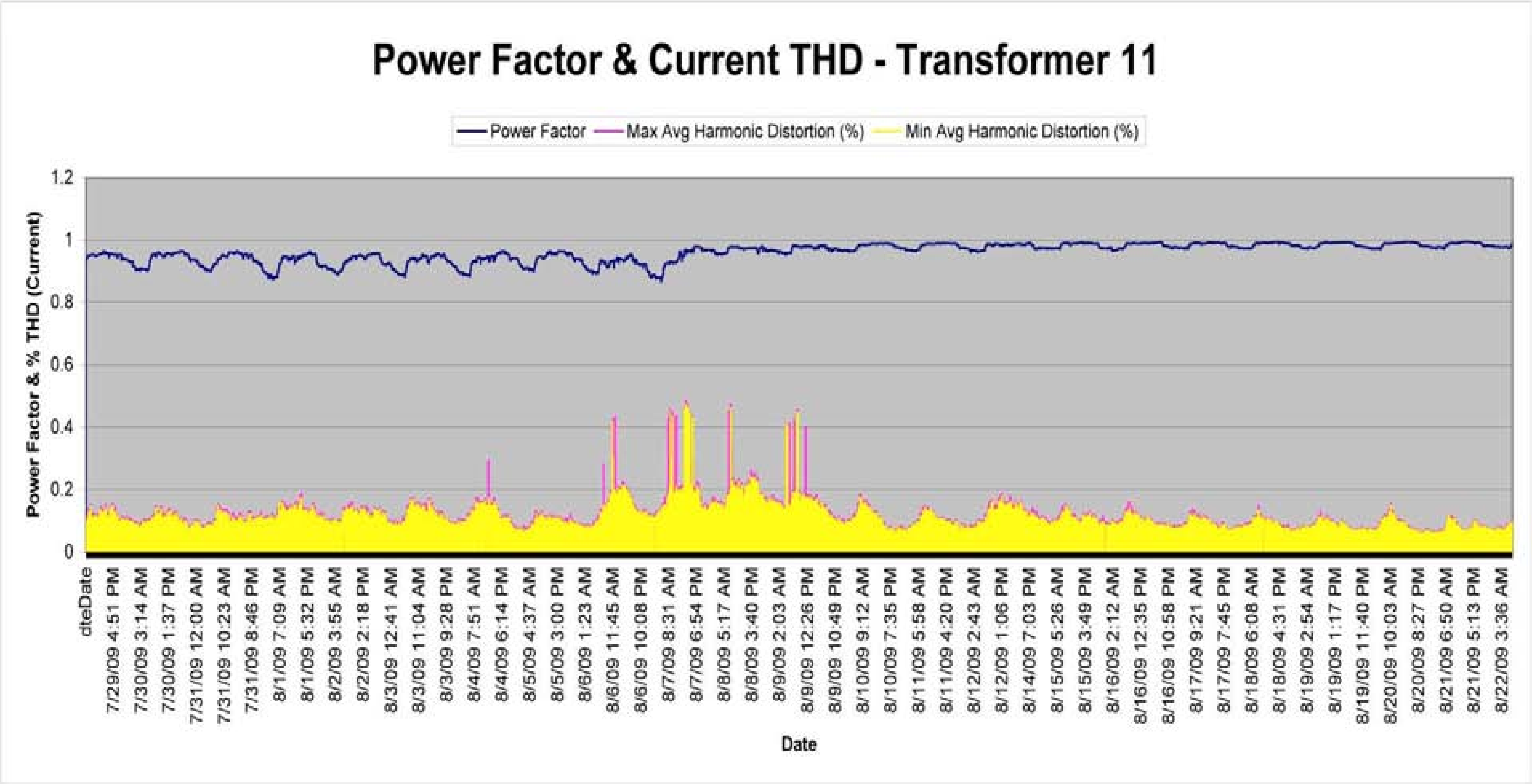


Before August 7 - PF Varied between 0.86 and 0.93

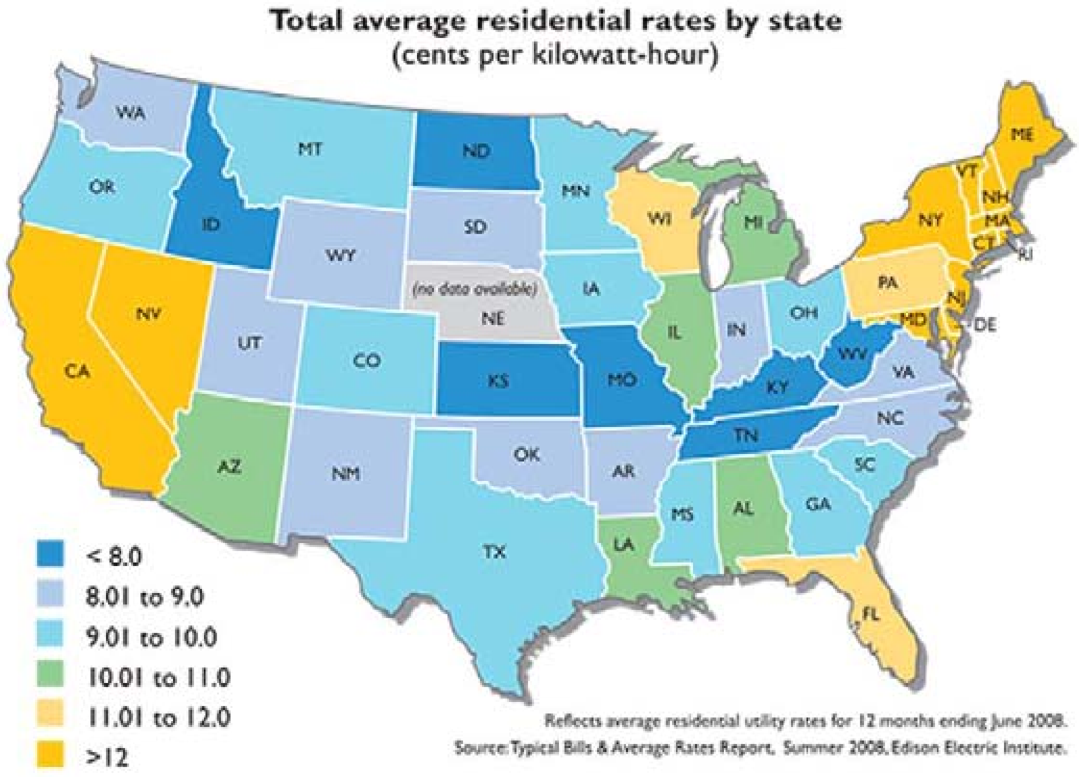
After August 7 - PF Varied between 0.97 and 0.99

Annual Savings : Approximately 3090 KWH

Peak KW Reduction : 0.6 KW



Cost Per KWH Varies Nationwide



- **Dollar Savings are dependent on KWH costs**
- **KWH costs tend to be higher in the population centers**
- **In a multi-family dwelling, power factor correction will cost 75% less to implement than a solar array of equivalent annual KWH capacity**
- **Unlike most “Green” energy sources, Power Factor Correction provides a generation offset because its effect is predictable. It also replaces some equipment investment at the substation. This increases the cost effectiveness of the process**
- **When used with refrigerated vending machines, the ROI is between 3 and 4 years based on after the meter savings to the customer. There is an equivalent KW and KWH savings on the distribution system.**

Conclusions

- **There are large KW and KWH savings to be gained within customer premises and on the utility distribution system by improving power factor**
- **Power Factor Correction can be cost effective to implement on the small scale.**
- **Equipment Standards must be modified to mandate a high power factor. It is less expensive to fix the problem at the factory than in the field.**
- **Power Factor correction has to be viewed from the perspective of a Public / Private (Utility/ Customer) partnership, as both parties have much to gain from its implementation.**
- **Reduced losses=Lower Rates**