Power Quality

How It Affects All of Us and How to Improve It

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Water Quality

- We are all concerned about the quality of our water
- We don't think twice about the quality of our electricity
- Indirectly, less than optimal power quality may be harming us as much as poor water quality would.   It results in large amounts of wasted energy and the associated greenhouse gas and pollutant emissions

What are the Costs of Poor Power Quality & Low Efficiency ?

Figures are for the Con Ed service area, alone !!

- **Utility Equipment failures resulting in localized blackouts**
- **Up to $ 500 million in additional annual fuel consumption needed to make electricity**
- **Up to 700,000 tons of additional annual CO_2 Emissions**

What can the Public Do ?

Businesses, Schools & Residences

- Help to improve Power Quality
  - Install equipment to improve Power Quality
  - Write to your legislators in support of efficiency improvements and net metering for larger solar and cogeneration projects

- Install Distributed Generation
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Some Basics of Alternating Current (AC) Electrical Distribution

- Voltage is a measure of how much energy each electron is carrying
- Current is a measure of how many electrons are flowing through the wire
- Current and Voltage Oscillate 60 times per second as a sinusoid (sine wave) - 60 cycles or 60 Hertz (Hz)
  - The frequency of the oscillation is controlled by the generating plant

More Basics of Alternating Current (AC) Electrical Distribution

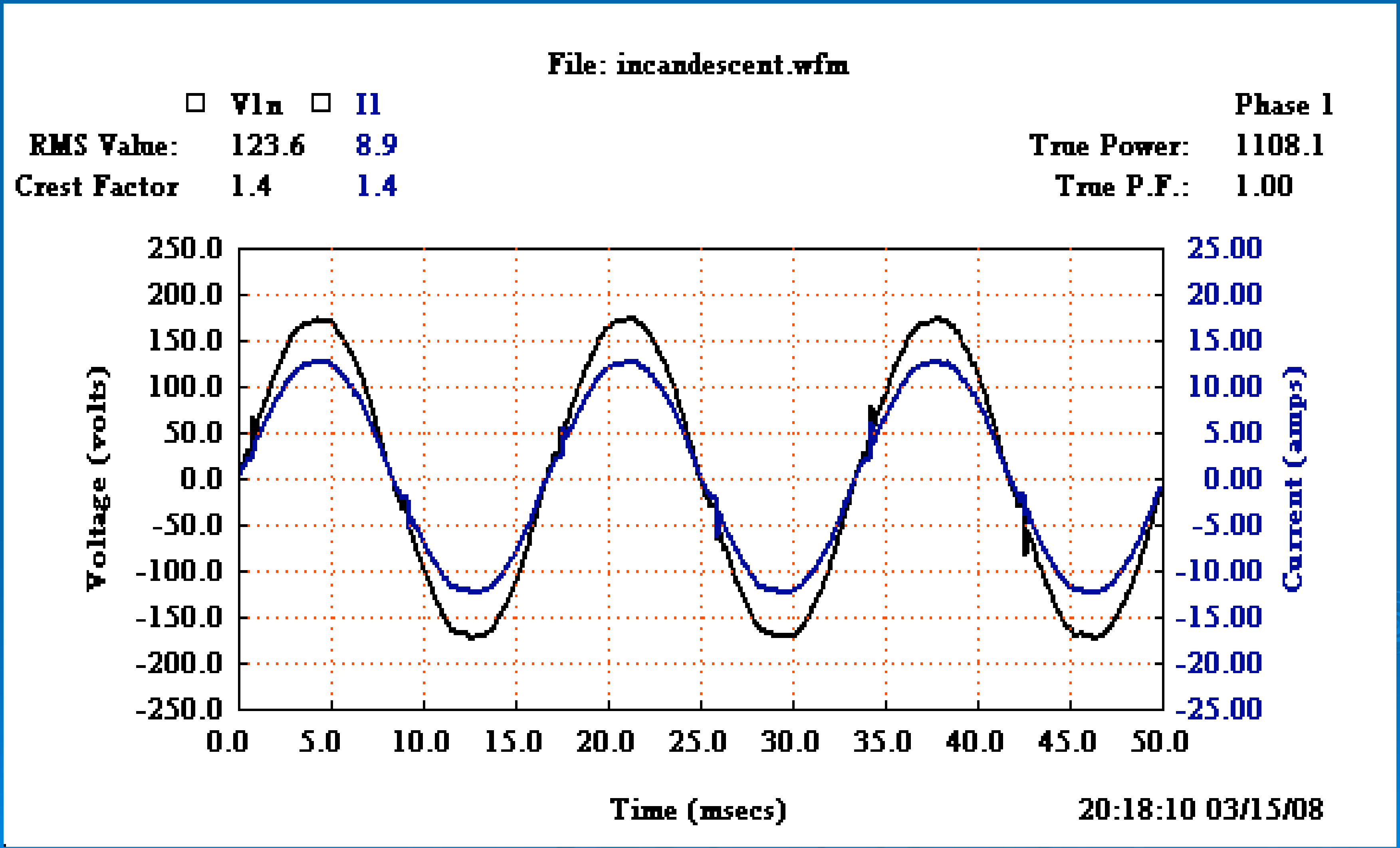
- Power Delivered= Current (I) x Voltage (V)
  - Voltage is set by the generating plant
  - Current varies according to customer demand – measured in amperes (amps)
  - Example : 60 watt light bulb = 120 volts x .5 amps

- **Electrical resistance** is a measure of the degree to which an object opposes an electric current through it – measured in ohms

- Power Consumed=Current^2 (I^2) x Resistance (R)
  - Everything on the network has a resistance – even the wires (example: an overloaded extension cord gets very warm)

- Power on the utility network is measured in Volt-Amps (VA) or 1,000 Volt-Amps (KVA), not Watts

Waveform for twenty 60 watt incandescent bulbs



What is a Transformer ?

- The transformer converts high voltage and low current on the generating plant side (primary side) to lower voltage and higher current on the customer side (secondary side)

- Power (I x V) on both sides of the transformer is equal – less thermal losses in the transformer
  - Example – 4000 volts x 110 Amps on primary is converted to 220 volts x 2000 amps on secondary
  - Both sides have 440,000 VA or 440 KVA
  - Approximately 1% of energy is lost as heat in the transformer
  - On the secondary side (customer side) of the transformer, the voltages (V) are lower and the currents (I) are higher.
  - Losses are approximately 40,000 times larger on the secondary side of the transformer

Efficiency of the Electrical Distribution System

- The average Natural Gas generating Plant is approximately 38% to 40% efficient
  - 60% of the energy goes up in smoke

- 8% of the electricity that leaves the generating plant gets dissipated as thermal losses on the wires and cables before it reaches the customer

- The Result is that only one third of the energy from the fuel reaches the consumer as electricity

How can we Improve Efficiency ?

- Locate Power Plants near the customer
  - Not viable because of the population density of our area
- Improve the Efficiency of the Power Plants
  - Newer Combined Cycle Gas Generating Plants Operate with an efficiency of 55%
- Improve the Efficiency of the Distribution Network
  - Improve Power Quality
- Distributed Generation
  - Power is generated close to the consumer
  - Fewer Transmission Losses

Improve the Efficiency of the Distribution Network

- What causes poor power quality ?
  - Equipment within the Customer Premises
    - Motors (Air Conditioning, Refrigerators, Pumps, etc.)
    - Computer Power Supplies
    - All Transformer based lighting
      - CFLS
      - Metal Halide
      - Fluorescent

What happens when these devices are introduced into the system ?

- The devices discharge Reactive Power onto the network

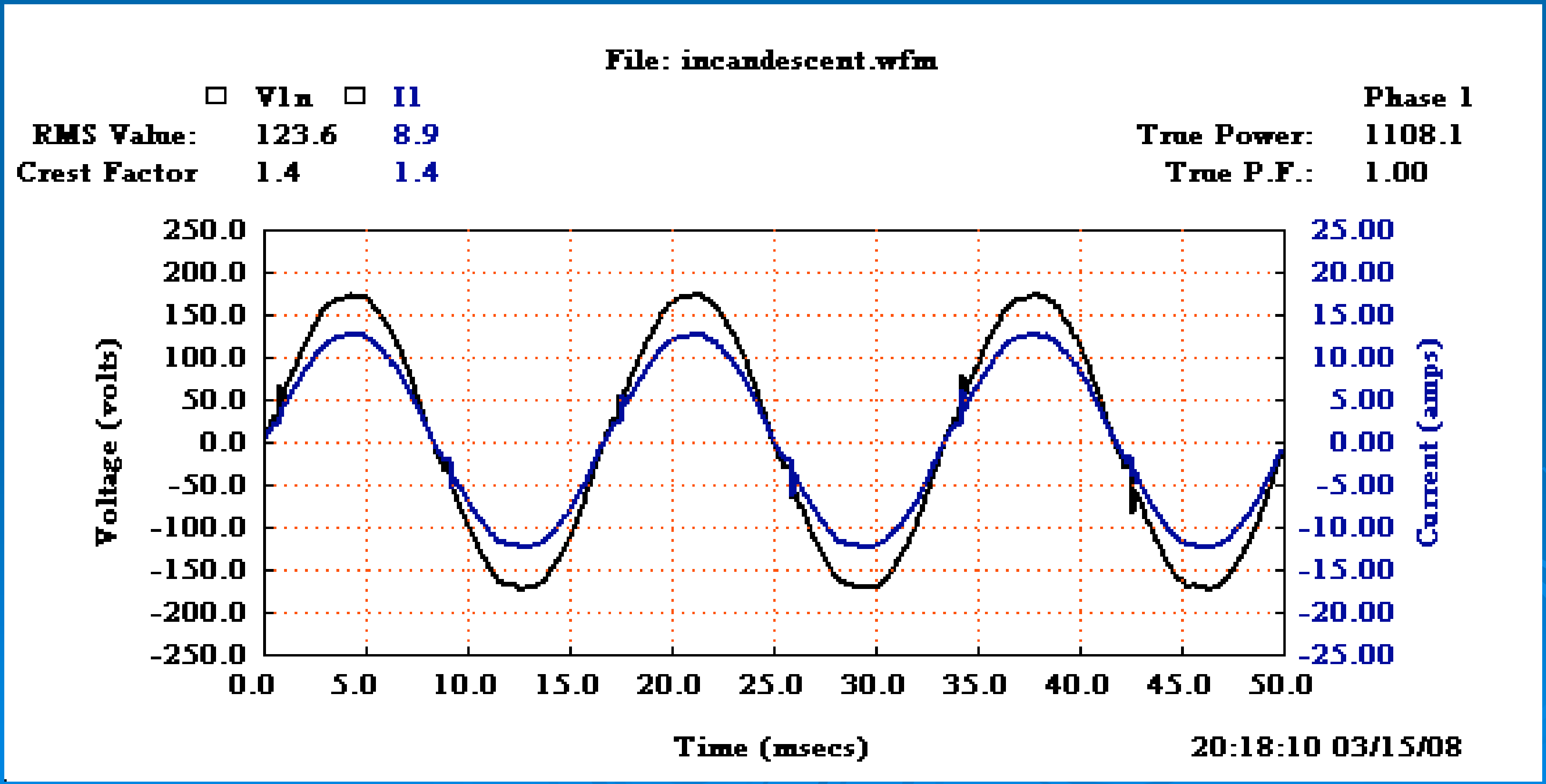
- Resulting in:

  - The current waveform starts to lag behind the voltage waveform

  - Power at the load drops because voltage is at maximum when current is not

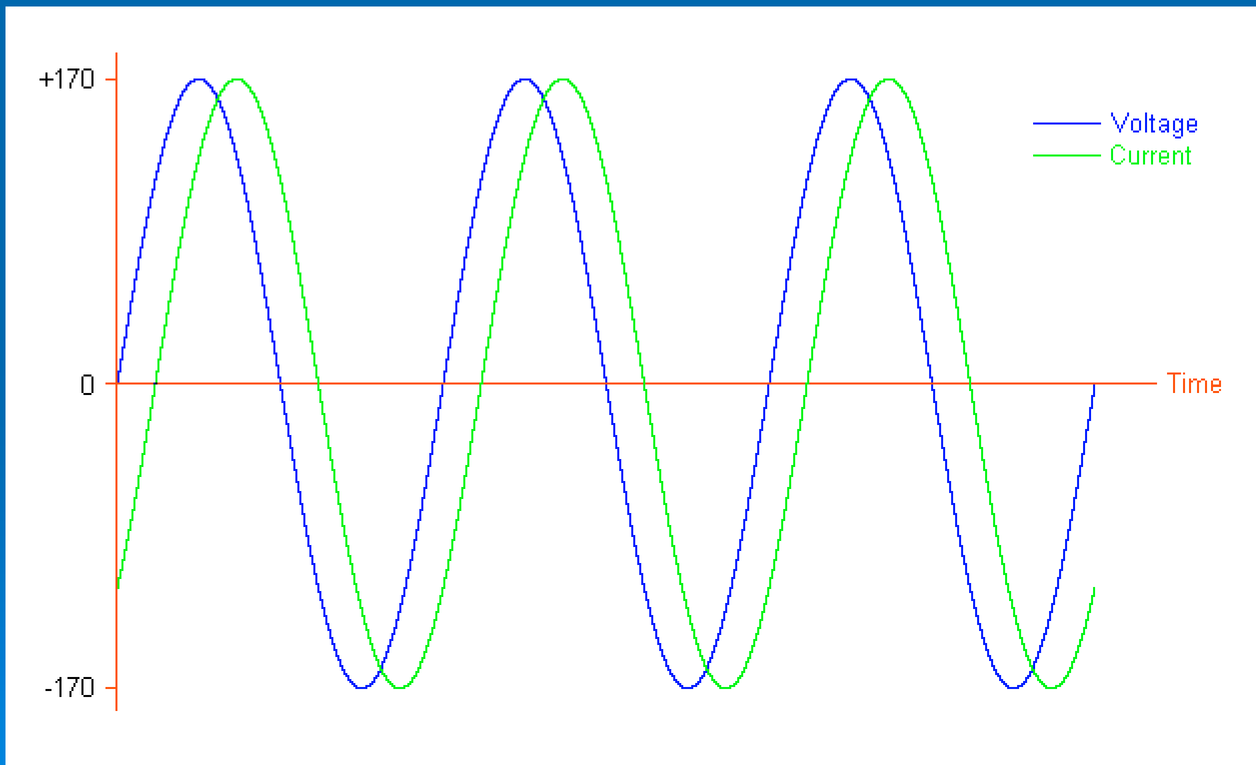
What are Reactive Power and Power Factor?

- **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 least amount of current (amps)



If the Voltage and current are 45 degrees out of phase

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



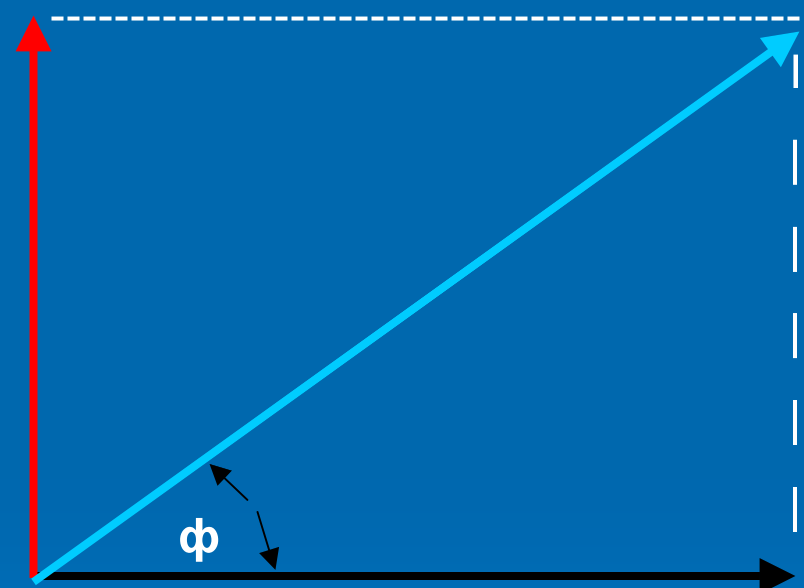
What is Reactive Power ?

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

Reactive Power = 60 KVAR

Apparent Power = 85 KVA

I_{AVG}= 227 Amperes



Actual current of system

70% increase in current <u>TRIPLES</u> the thermal losses in the system

Real Power = 60 KW

I_{AVG} = 133 Amperes if PF=1.0

Building PF= .7 ? = 45 degrees

Power Factor=cosine ? = Real Power / Apparent power

What is the result of the current and voltage being out of phase ?

- Motors and transformers attempt to do the work that they are physically designed to do based on their rated values. (e.g., RPM, Frequency & Horsepower for motors)
- As voltage is constant, they draw more current to produce their rated power output. $(P = I * V)$
- Currents rise throughout the system
- As currents rise, the thermal losses in all parts of the system increase. System loses efficiency.
- Power $P = I^2 \times R$ **(R is the resistance of the wires and motors, etc.)**

What is Distributed Generation ?

- Wind
- Tidal
- Solar
- Cogeneration

Photo-voltaic Solar Array

Co-generation – Combined Heat & Power CHP system (Micro-turbines)

What does Distributed Generation Do ?

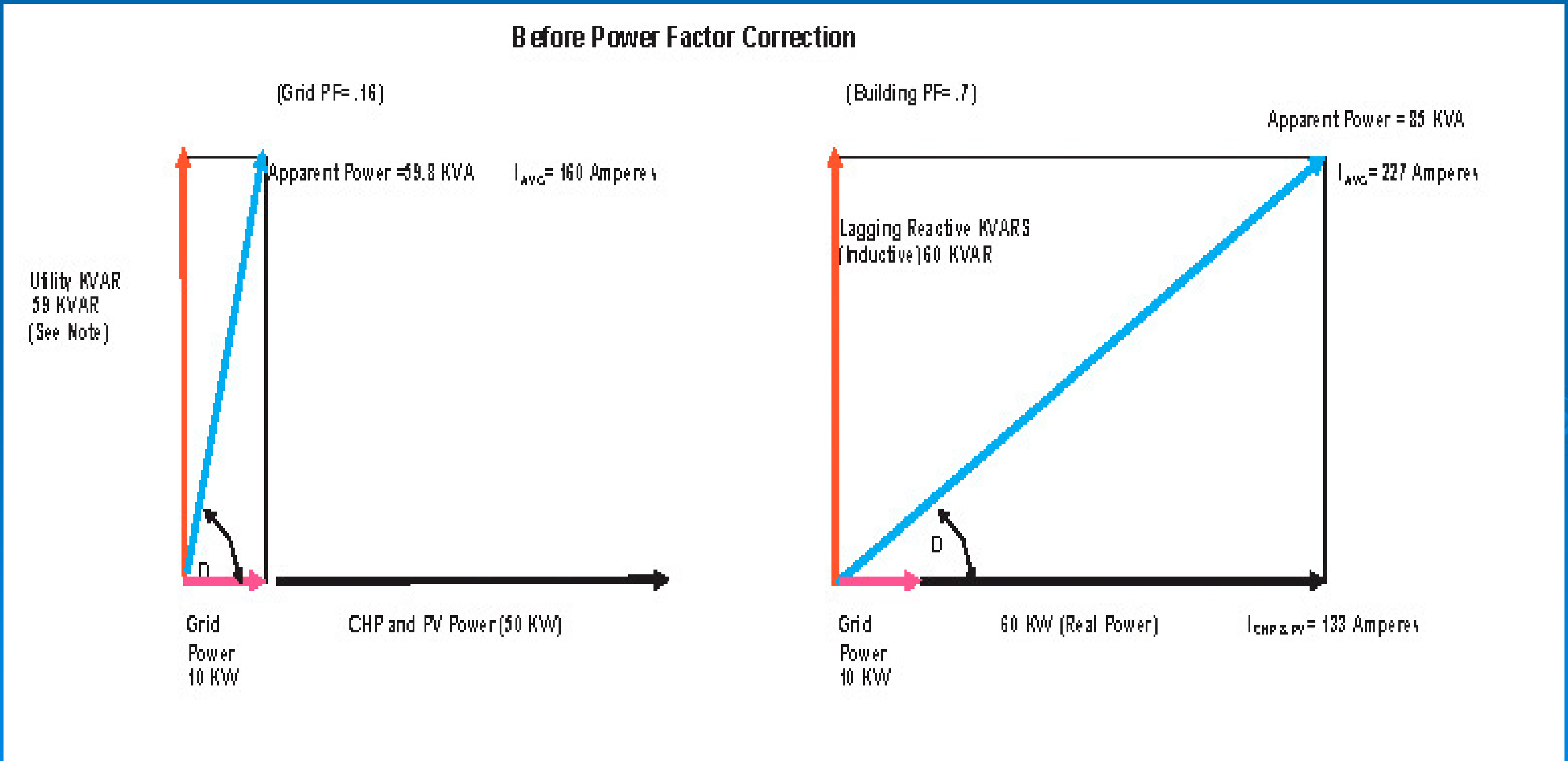
- Most Produce Power by using inverters to create the AC waveform
- Inverters allow precise alignment of the DG waveform with the utility waveform
- Produce power with a very high PF (>0.98)
- Localized Power Production reduces transmission losses and maximizes energy efficiency
- CHP Offsets building loads to reduce peak demand
  - Operates with > 70% Energy Efficiency
- PV provides power with no use of fossil fuel
- Reduces Real Power Demand from the Utility

So, what's the problem ?

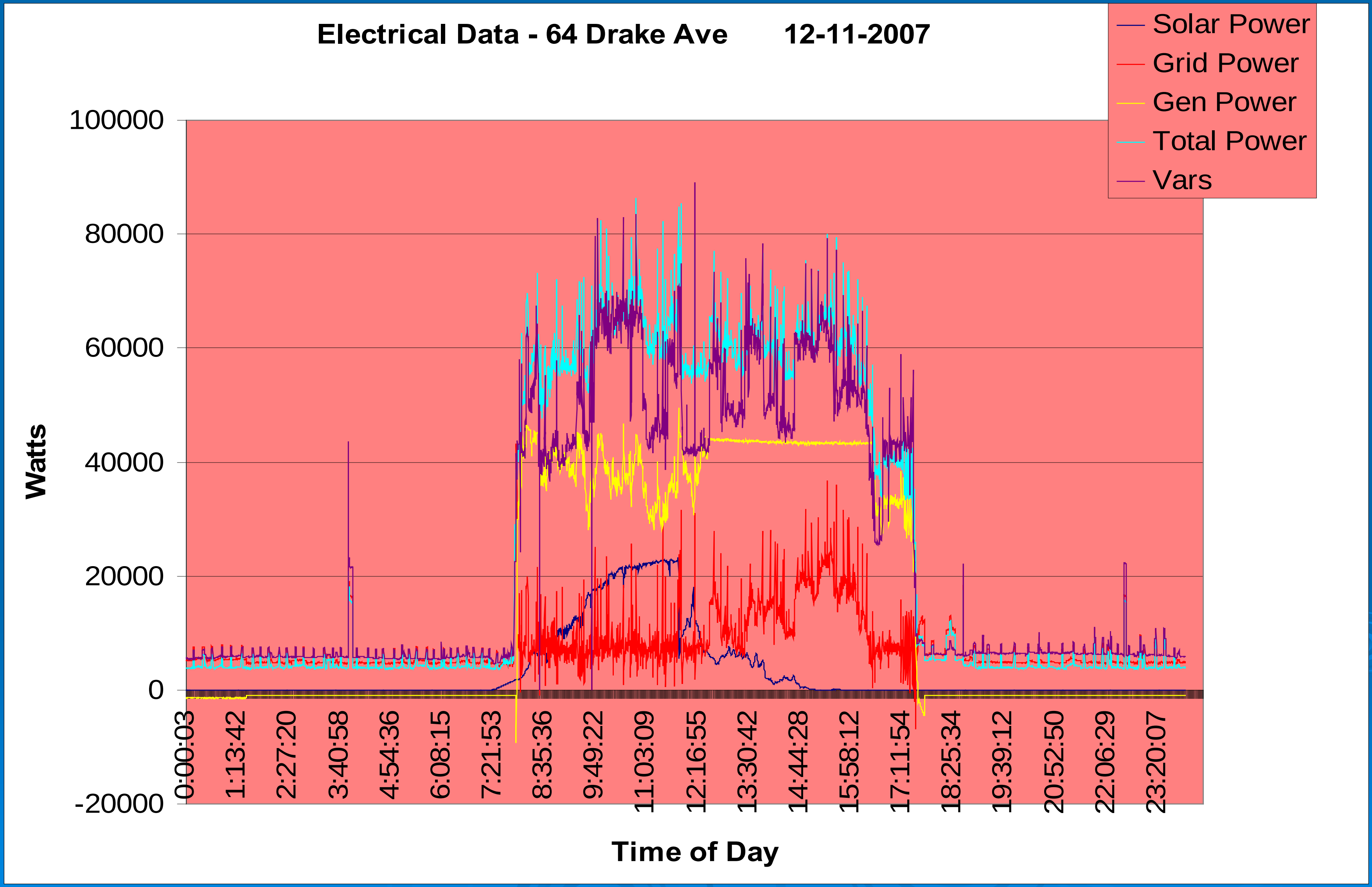
- Reactive Power of the facility remains Constant
- Real Power provided by the Utility decreases
- Phase angle at Service Entrance increases.
- Power Factor Drops to between 0.1 and 0.2
- Currents and voltages at Utility Interface approach 90 degrees out of phase
- Currents Rise entering building from the Utility
- Power Losses on the Utility Network Rise

What Happens to the Utility Power Factor When DG is Installed ?

- Phase angle opens as real power decreases
- Only achieve 30% decrease in apparent power with an 84% decrease in Real Power



Before Power Factor Correction



What are the effects of a Large amount of Reactive Power and a Low Power Factor on the Utility Network?

- Greater power losses occur in all components caused by higher currents. These losses manifest as heat. ($P=I^2 \times R$)
- Burning wires and cables (Queens-2006)
- Burning transformers
- Increased generation required to compensate for losses
- Wasted Energy
- Increased Greenhouse Gas Emissions from extra power production

Even Bigger Problems as more DG comes on-line

- Very Low Power Factor Threatens Grid Stability

- Problem will occur with all High PF, Inverter based DG installed within a service area.

- The higher the power output of the DG, the bigger the potential problem.

Can the problem be fixed ?

- **Yes. By adding Power Factor Correction to the service.**

What is Power Factor Correction?

- Power Factor Correction re-aligns the voltage and current waveforms so that they are in phase.

- Power Factor Correction Capacitors are sized for each inductive load on the system and wired in parallel with the inductive load.

What do we gain by installing Power Factor Correction ?

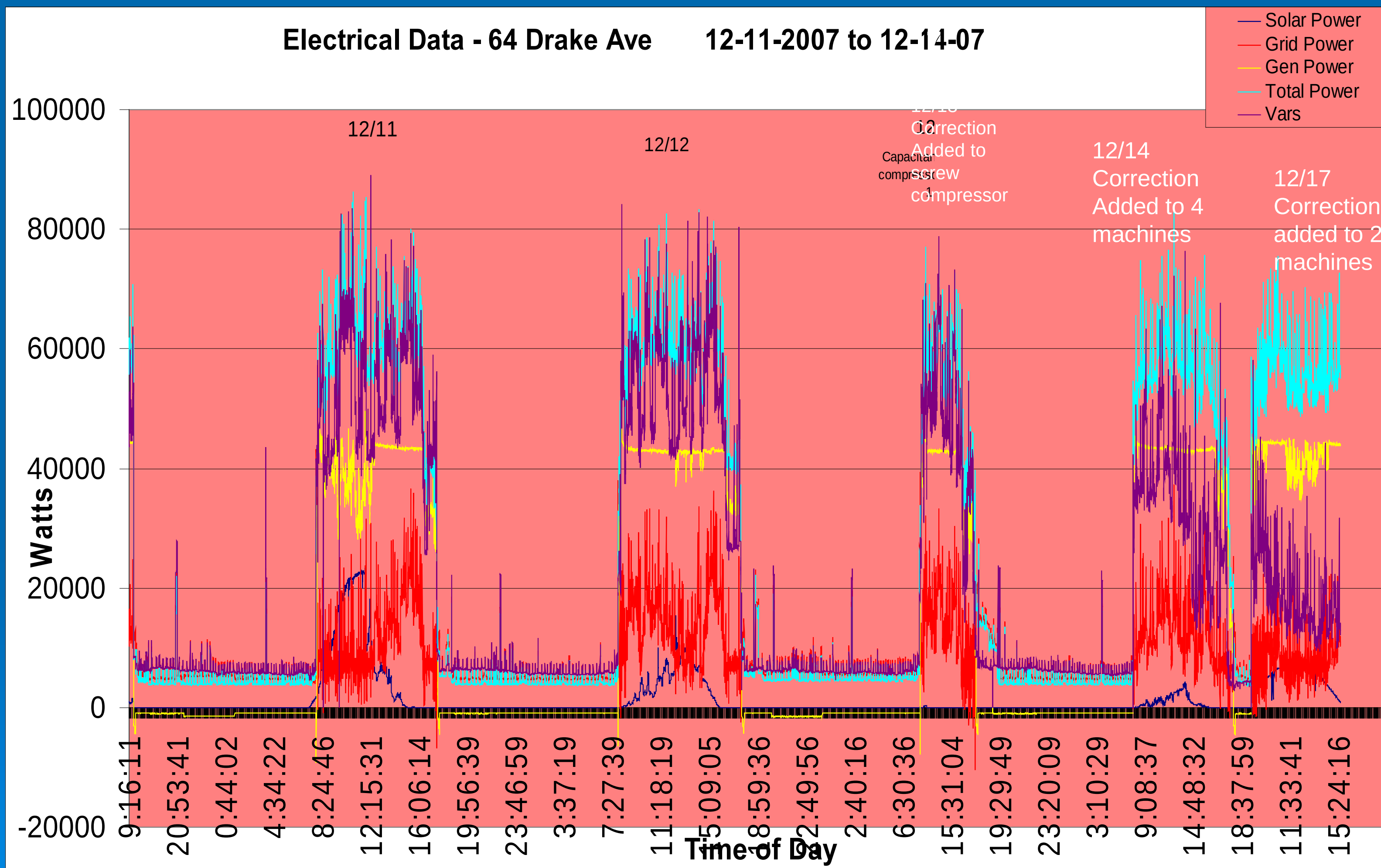
- Improves Utility Power Factor. Even greater reduction of grid losses by reducing KVAR and KW.
- Reduces building losses and lowers the utility bill by about 4%.
- Reduces thermal degradation of facility electrical devices and associated maintenance.
- Pays for itself.

Installation of Power Factor Correction

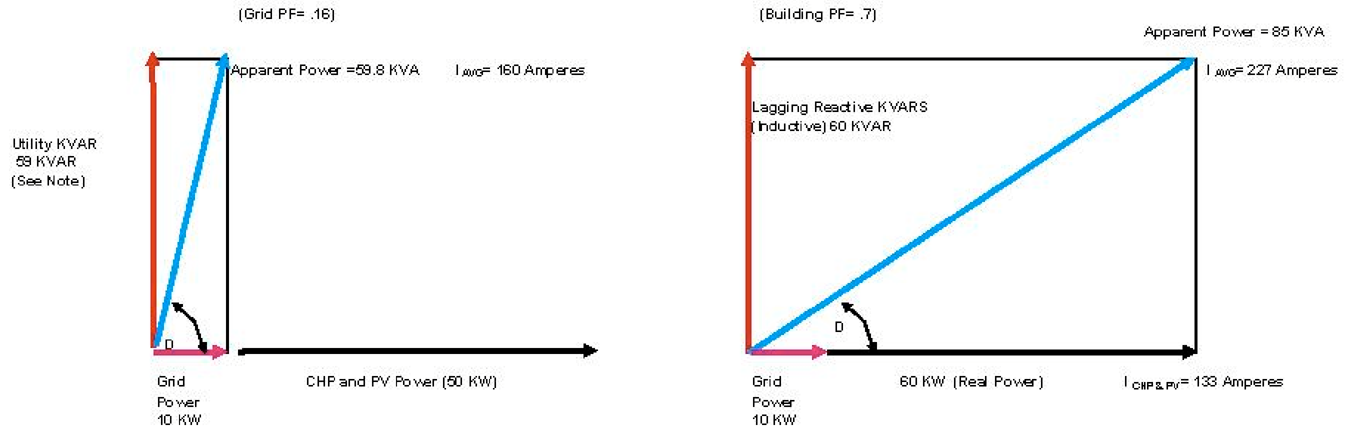
7.5 KVAR Located at the load

45 KVAR Located at Service Entrance

During Power Factor Correction



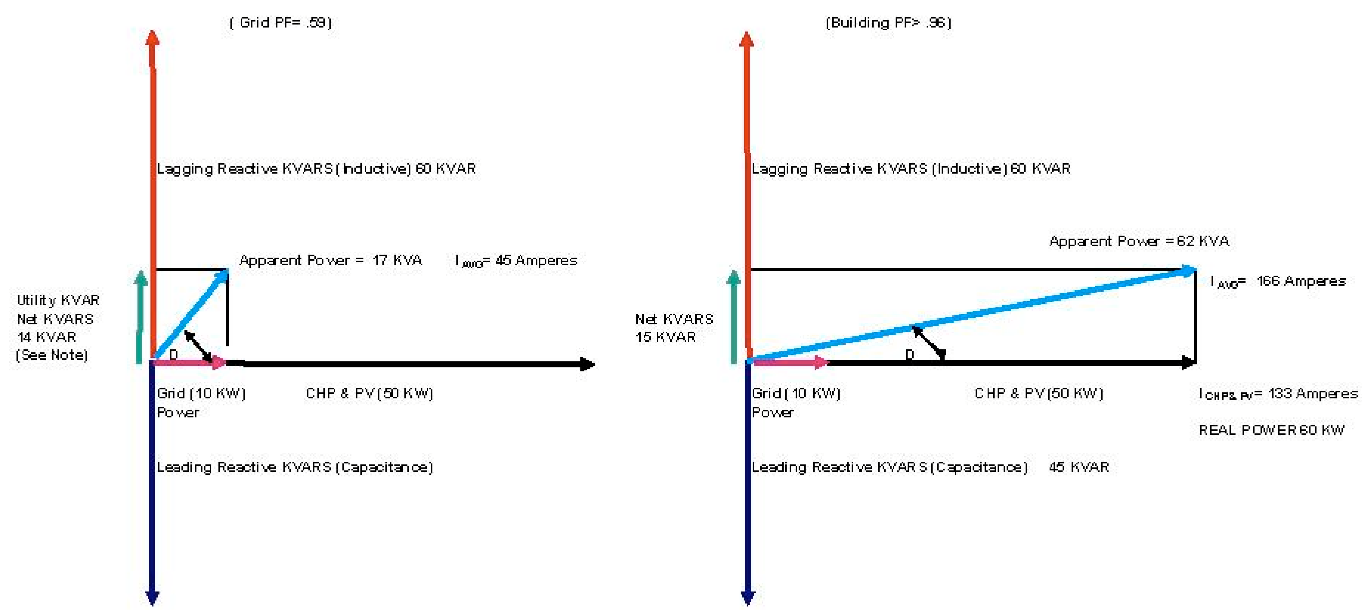
Before Power Factor Correction



I_{AVG} is the average current per phase in the 3 phase system

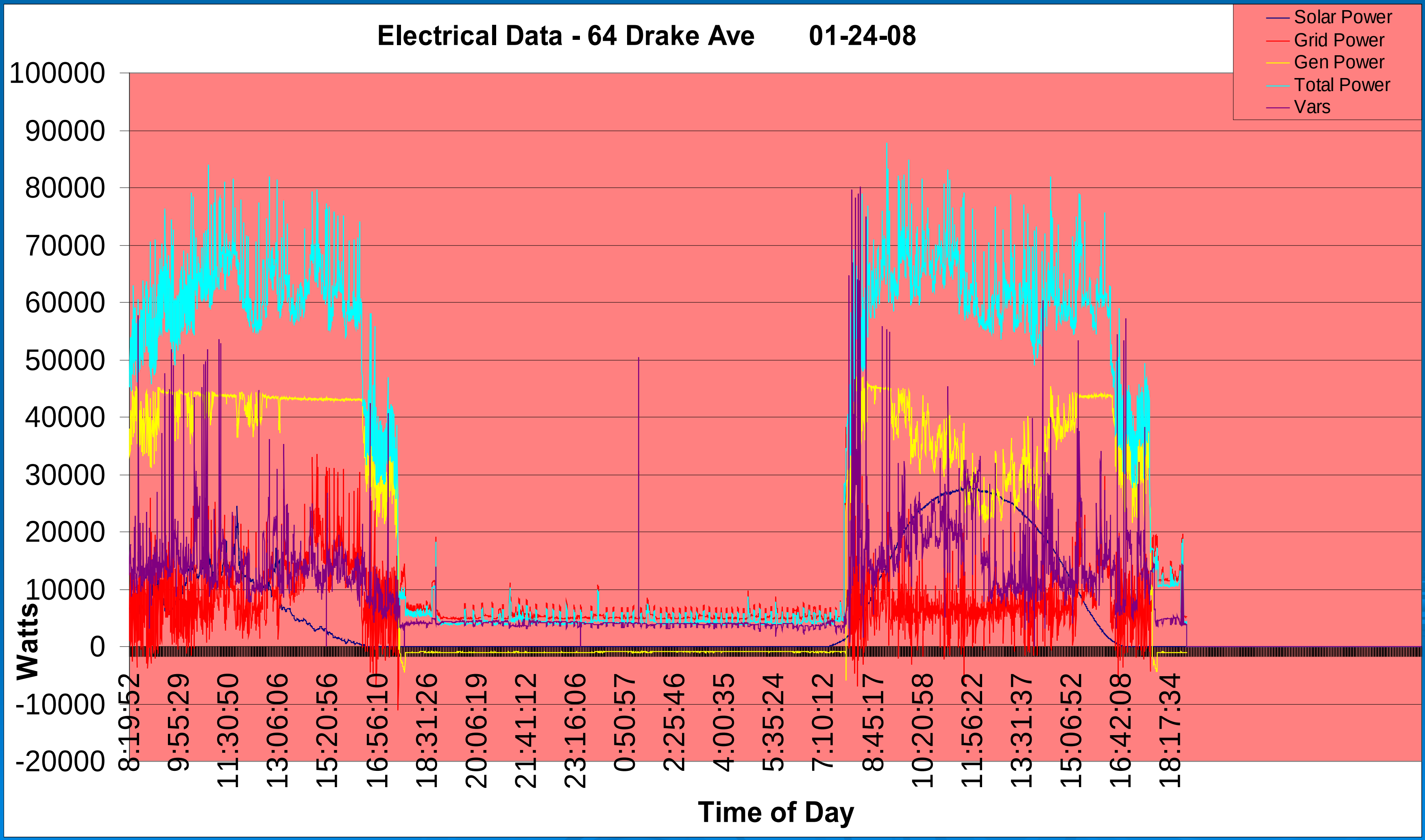
After Power Factor Correction

Capacitance Added

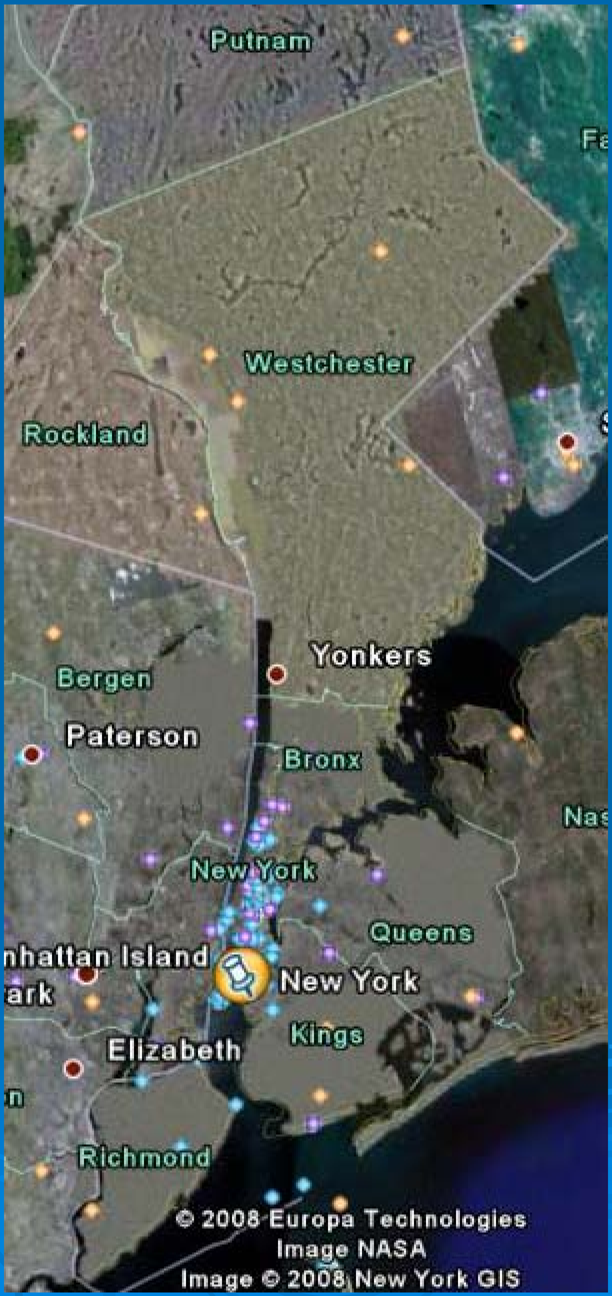


PF=cosine = Real Power (KW) / Apparent Power (KVA)

After Power Factor Correction



The Bigger Picture



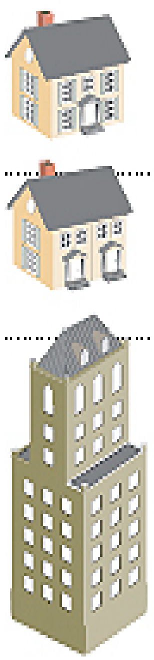
Increase in Electric Load

- Increase in Air Conditioning Load
  - 56% of Residences had Air Conditioning in 1978
  - 77% had Air Conditioning in 2001 (Source: NY Times August 2, 2006)
- Every Desktop computer has a 200 - 300 watt power supply that is a relatively large source of reactive power
- Widespread use of Metal Halide and other transformer based lighting w/ “poor” PF
- The new CFL’s that are replacing incandescent bulbs, while reducing KW load are increasing KVAR load. The effect on apparent power is not as great as on the real power. Some have a PF=.54 and 125% harmonic distortion.

Newer, Larger Homes are Using More Energy

Greener Pastures? Studies have shown that suburbanites use more energy and produce more carbon dioxide than city-dwellers.

Energy use of the average household — based on family size, income and other factors — in three types of housing in the Atlanta metropolitan area.



	AVERAGE AREA (SQ. FT.)	ESTIMATED RESIDENTIAL ENERGY USE PER YEAR, IN MILLIONS OF B.T.U.'s: HEATING	COOLING	OTHER	TOTAL
Single-family detached	2,368	45.7	8.0	44.0	97.7
Single-family attached	1,121	36.6	6.1	36.7	79.4
Multifamily	1,087	24.5	5.4	28.3	58.2

Sources: *Prof. Reid Ewing, National Center for Smart Growth Research & Education, University of Maryland; Dr. Lawrence Frank and James Chapman, The Atlanta SMARTRAQ Study: Final Report, 2004.*

Average weekday carbon dioxide emissions per person in the 13-county Atlanta metropolitan area.

31.1 pounds

23.5 pounds

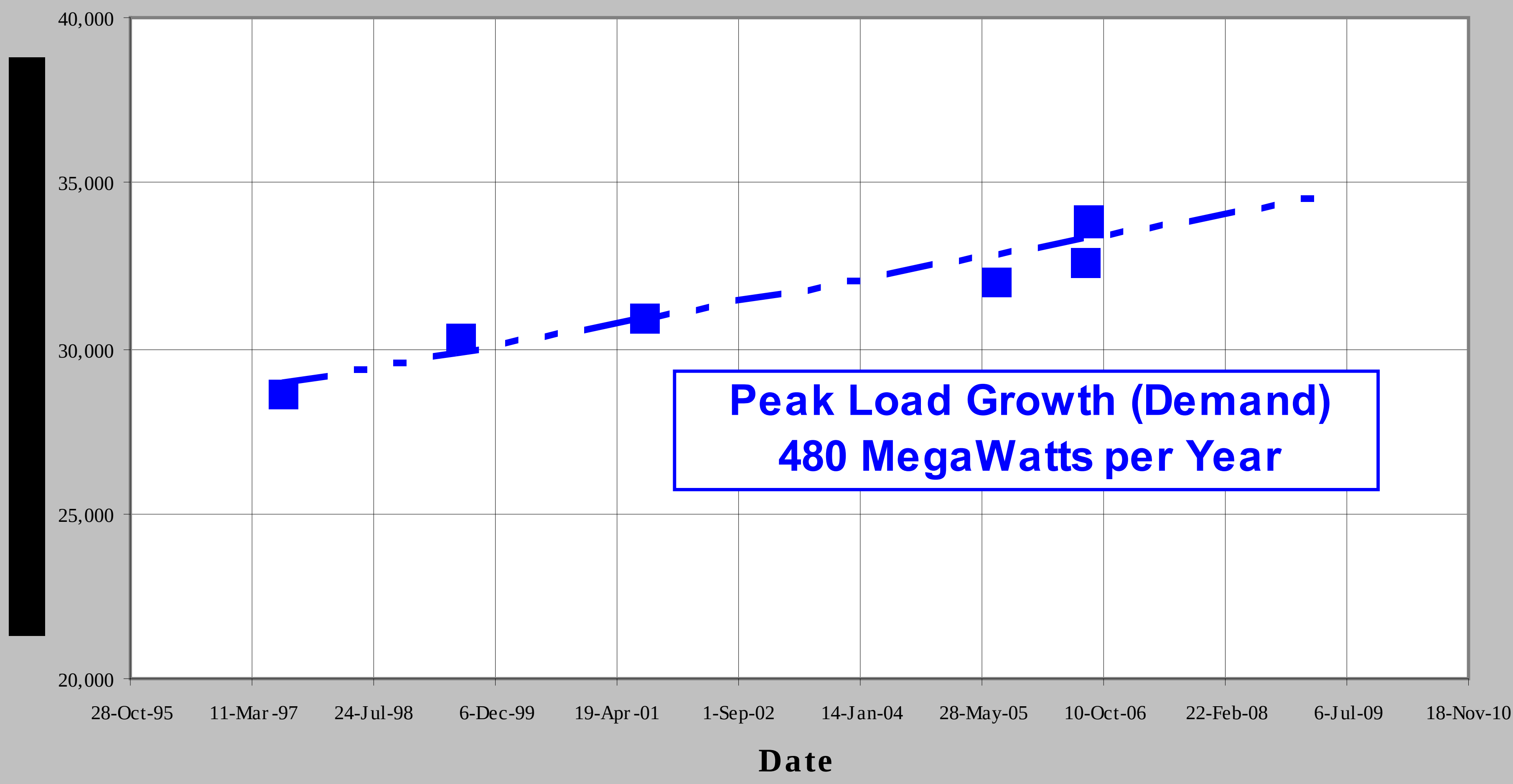
THE NEW YORK TIMES

NY Times 2/10/08

Power Consumption is Rapidly Increasing

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

Courtesy of NYSERDA - J. Borowiec



Apply Power Factor Correction Across the Entire Service Area

- Precedent set with water distribution
- Backflow Preventers are required to prevent Customer Premise “contaminants” from entering utility’s distribution network
- Apply concept to Electric Distribution

Can Network Wide Power Factor Correction be Applied Cost Effectively to Smaller Businesses and Residences

- A study Done in Whitby, Ontario in a Residential Subdivision during 2005 documented large potential savings

- In Whitby, only service entrance was corrected. Resulted in a leading PF at times.

- Our analysis of a residence indicates that a home w/ two Air Conditioning Compressors could be corrected with three PF devices for approximately $ 600 in equipment, plus 3 hours labor

$$ Savings Resulting from Network Wide Power Factor Correction

- **Reduced Cost of Equipment because of fewer failures**
- **Lower residual costs related to power failures**
  (e.g. Spoiled Food, Lost Business, etc.)
- **Reduced Labor Costs - Labor can be used to improve the network instead of maintaining the status quo.**
- **Eliminates need for Large Power Plant Construction**
- **Lower customer electric bills**
- **$ 350 Million to $ 500 million of Fuel Annually**
  (at $ 11.00 per 1000 CF)

Energy Savings Resulting from Network Wide Power Factor Correction

- **Reduce Transmission Losses by 125 Megawatts (MW)**

- **Reduce Customer Premise Losses by up to 4%**
  - **(500 Megawatts)**

- **Reduce Energy Usage by 930 MW to 1600 MW**
  (40% Generation efficiency, 92% Distribution Efficiency)

- **Reduce Natural Gas Consumption by 32,000 to 53,000 Therms per Hour (3 million to 5 million Cubic Feet per Hour)**
  - **27 billion to 45 billion cubic feet of natural gas annually**

- **Reduce Annual CO_2 Emissions by 420,000 tons to 700,000 tons**

Environment needed to achieve Network Wide Power Factor Correction

- **Regulatory Support -**
  - KVAR charges commensurate with their actual cost
  - Modification of Electrical Codes to Require High PF
  - Requirements that new equipment has PF correction installed at the factory (e.g. Air Conditioning)
- **Financial Support -**
  - NYSERDA Smart Loans to defer cost over time. This will allow the real savings to pay for the debt and minimize resistance to the project from the customer side.
- **Utility Support -**
  - Staff and data will be needed to provide feedback on the condition of the utility network where correction is being implemented and to confirm that the installation is working

Conclusions

- DG can help to greatly reduce demand on the utility network
- Power Factor Correction must be included in all high PF, inverter based DG installations and depending on the size of the DG plant, in the surrounding area as well
- Power Factor Correction in all customer premises will improve energy efficiency and service while reducing costs and pollution
- Power Factor Correction is both economically and logistically feasible
- Power Factor Correction is an environmental necessity