Power & Energy Monitoring in the Era of Green Energy



Weschler Instruments

Agenda

- Energy Trends
- Consumer Load Monitoring
- Commercial & Industrial Applications
- Industrial Products
- Test Equipment

Distributed Generation

- Solar
- Wind
- Geothermal
- Hydroelectric

Off-Grid Operation

- Mobile Applications
- Temporary Applications
- Isolated Sites
- Innovators

Smart Meters

- Automated Reading (AMR)
- Outage Notification
- Real Time Load Monitoring
- Variable Rate Billing
- Remote Load Shedding

Time of Day Rates

- Reduce Demand Peaks
- Defer Power Plant Construction
- Better Utilize Existing Transmission Lines
- Encourage Conservation

Real Time Load Management

- By Utility or Customer
- Prevent Overloads, Brownouts & Blackouts
- Avoid Power Plant Construction
- Defer New Transmission Lines

Cogeneration

- Combined Heat & Power
- Supply Local Electrical Need
- Sell Excess Power to Utility

- Standby Power

Higher Energy Costs

- Fuel Prices
- Emission Controls
- Delivery Fees
- Carbon Tax
- Escalating Rate Brackets

Mandatory Conservation

- Energy Independence & Security Act (2007)
- Executive Order 13423 (2007)
- Energy Policy Act of 2005
- DOD Instruction 4170.11 (2005)
- LEED Certification
  (Green Building Initiative)
- Utility Demand Response programs

Energy Trends

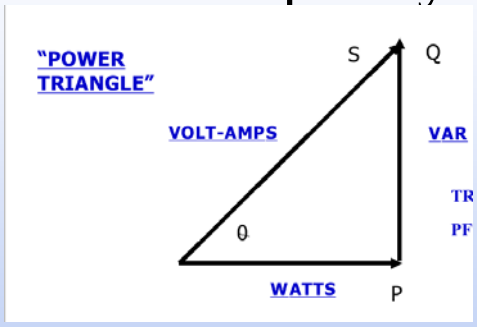
- Distributed Generation
- Off-Grid Operation
- Smart Meters
- Variable (Time of Day) Rates
- Remote Load Management
- Higher Energy Costs
- Mandatory Conservation

Goal – Conserve energy & reduce fossil fuel use

Where & How Much $\Rightarrow$ Need to Measure

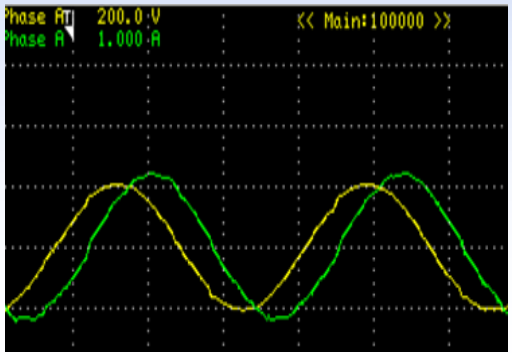
Key Terms

Active Power	W = VA (DC source) W = VA·PF (AC source)
Apparent Power	S = VA
Reactive Power	Q = VAr
Power Factor	PF = W/VA λ
Active Energy	kWh
Demand (kW)	Average power for time interval
Fundamental	Mains frequency
Harmonic Order	Multiple of mains frequency

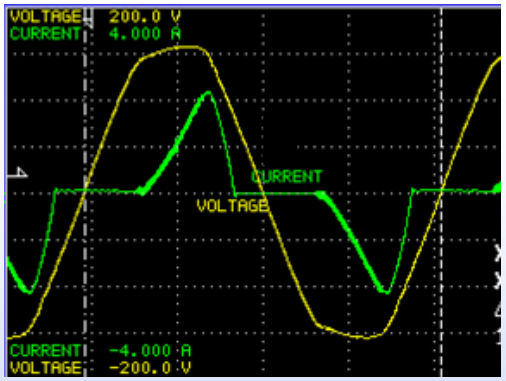


Waveforms

Motor Load



Switching Power Supply



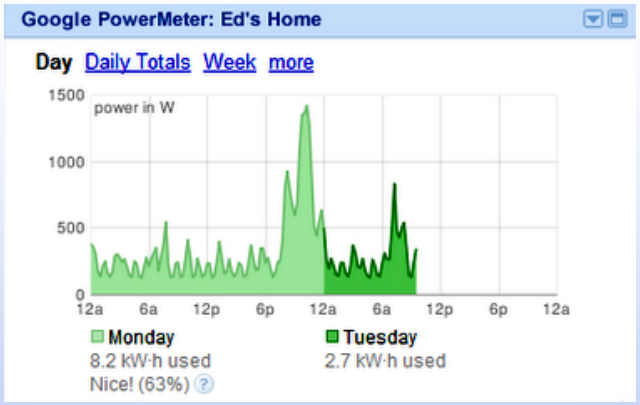
Power Measurement ICs

- RMS Voltage, RMS Current
- Line Frequency
- Neutral Line Current
- Power Factor(s)
- Voltage Phase Angles
- Active/Reactive/Apparent Power
- Active/Reactive/Apparent Energy
- Fundamental/Harmonic Power
- Bi-Directional

Load Monitoring

Consumer Products

- Single Device
- Entire House
- Web Enabled



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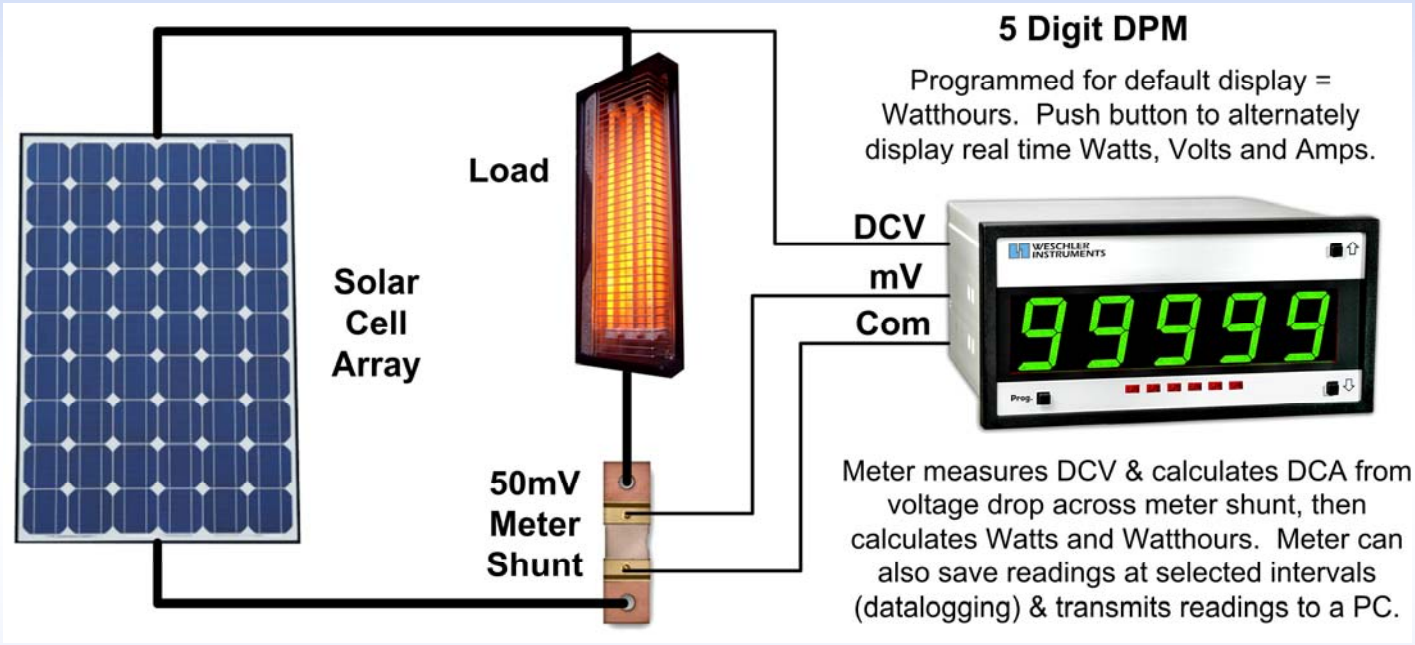
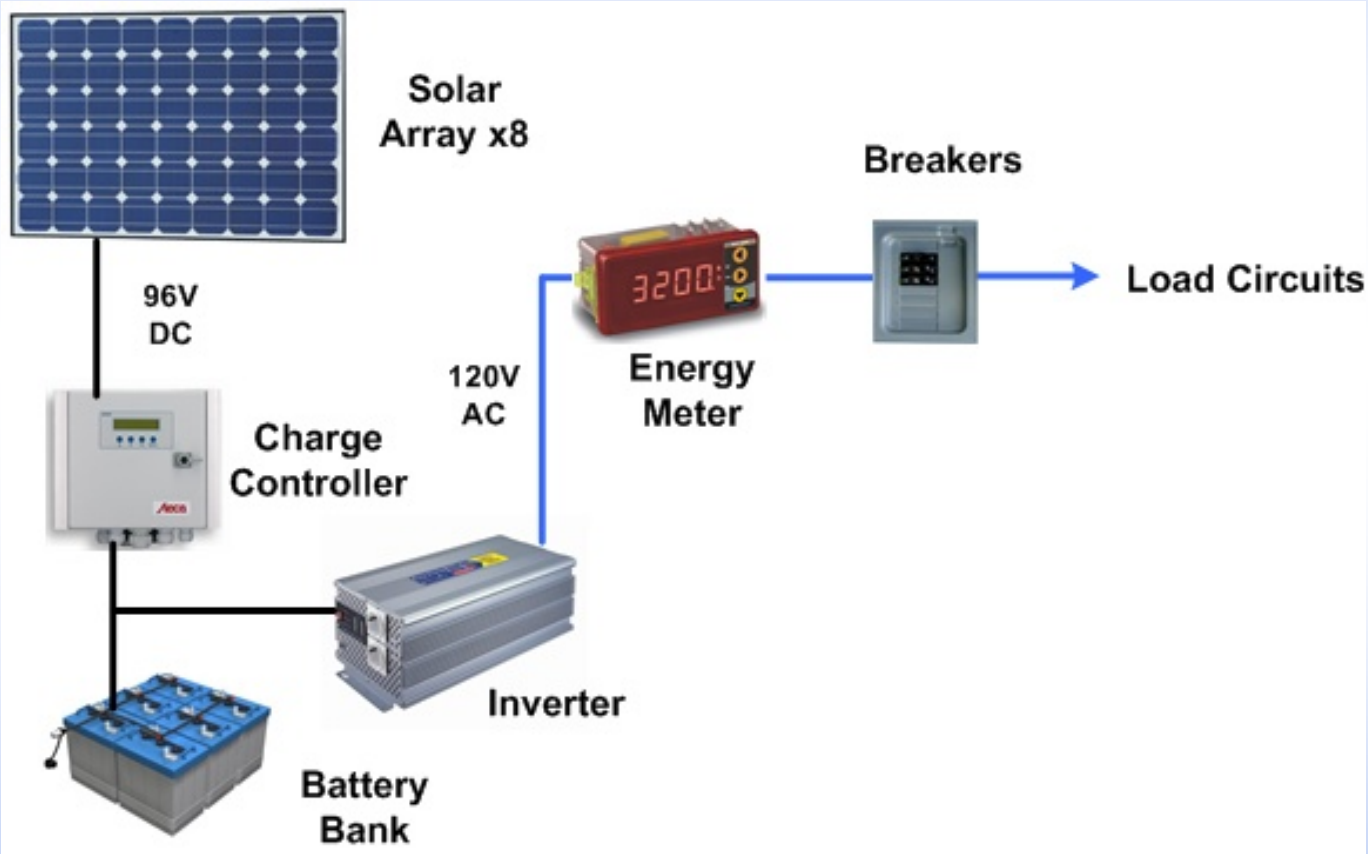
Commercial Applications

- Generation
- Load Monitoring
- Demand Management

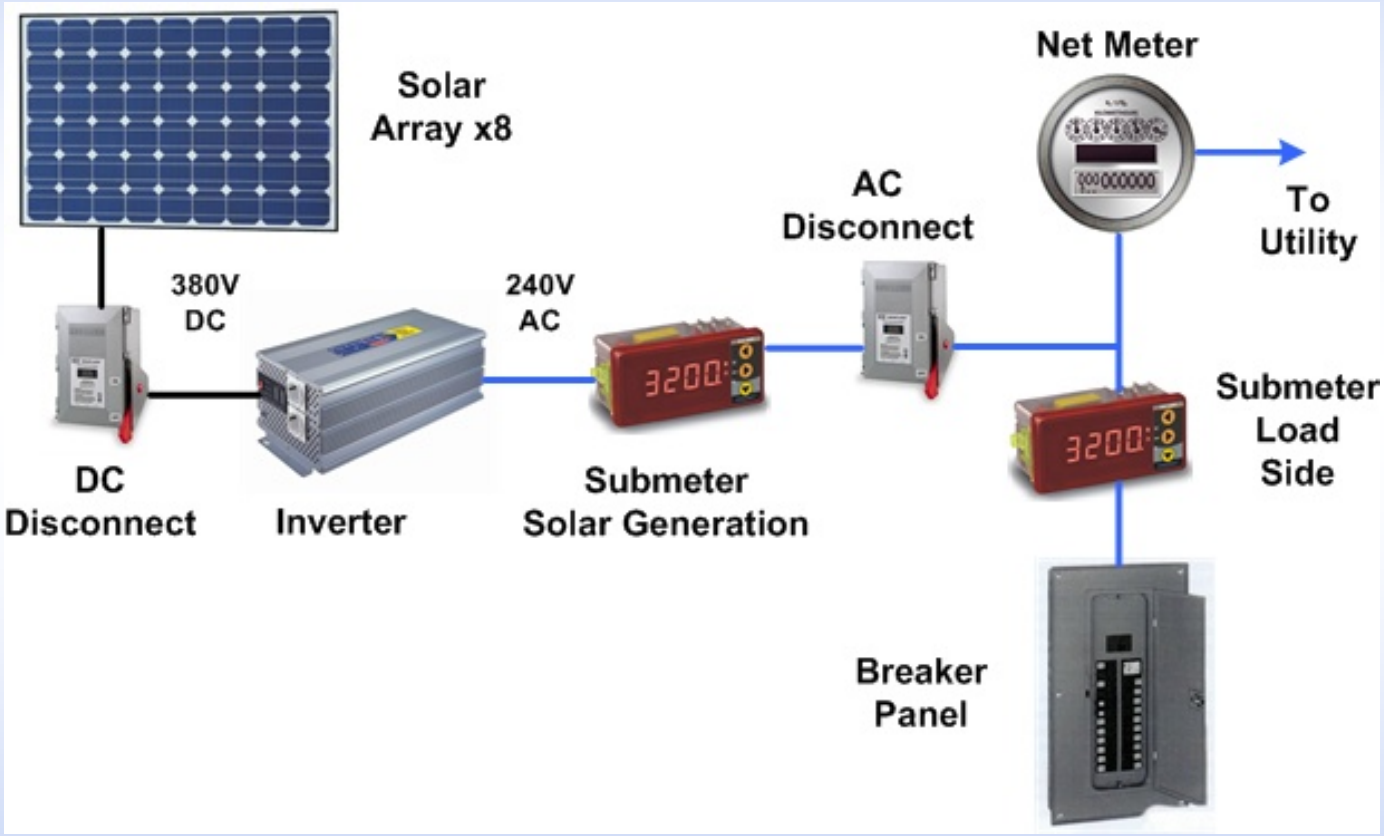
Solar DC System



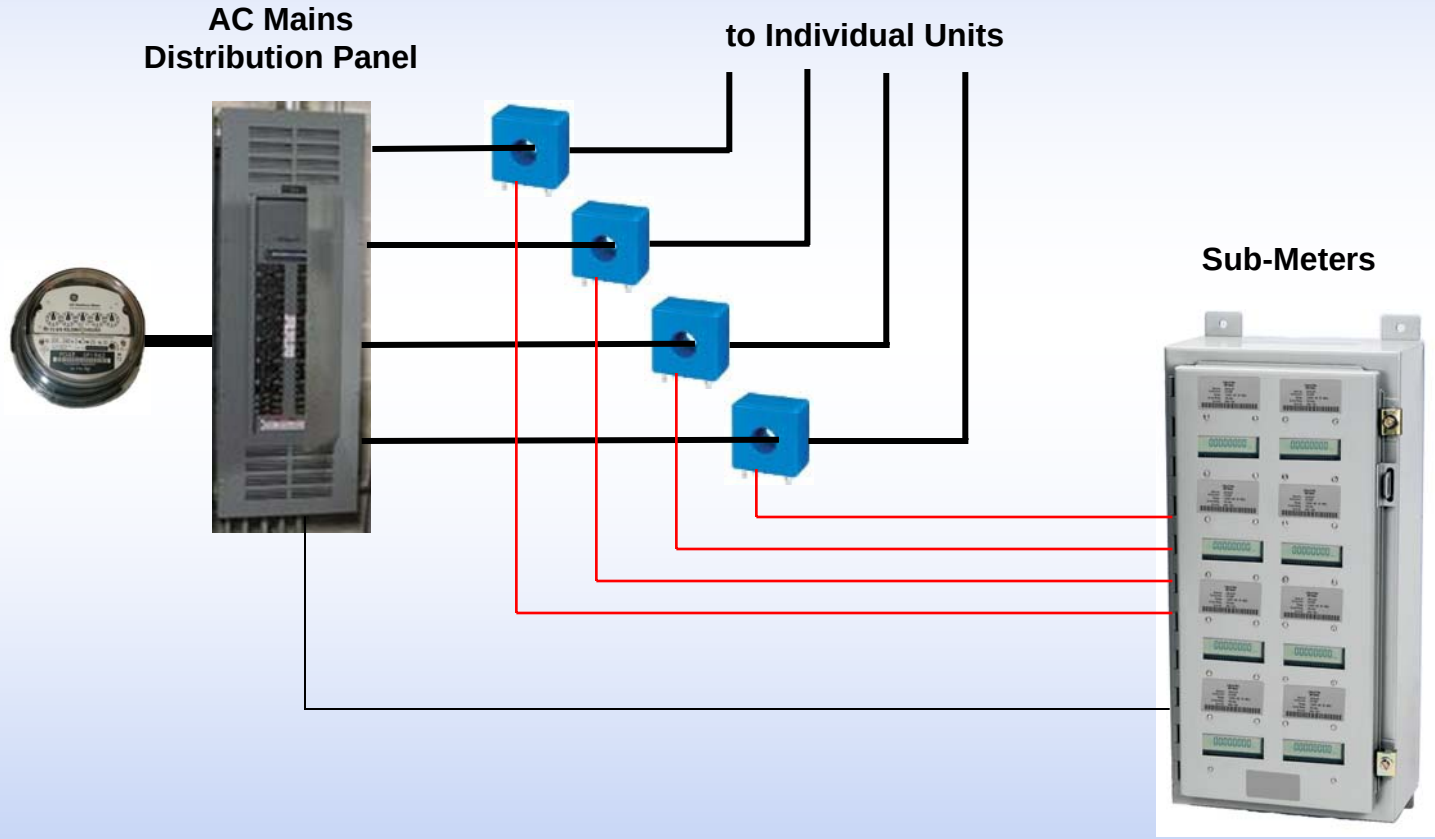
Solar AC System



Grid Connected System



Sub-Metering



Commercial Sub-Metering

Data Collection

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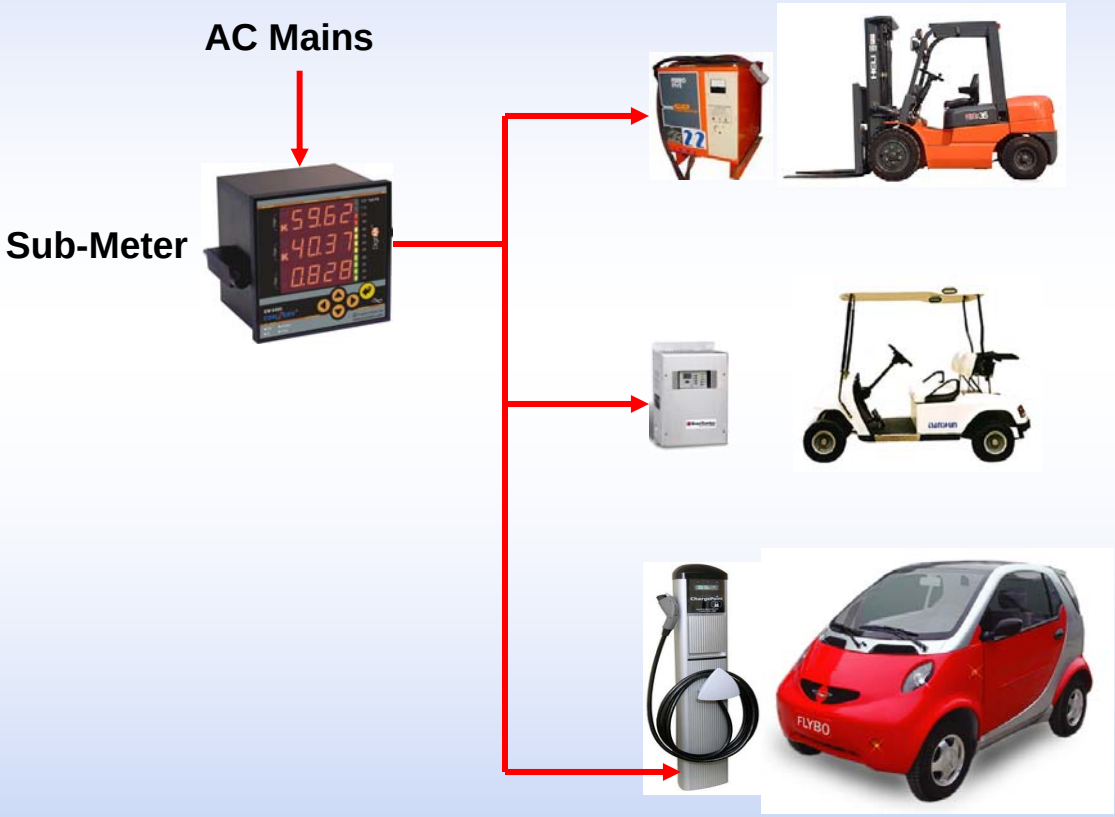
Other Sub-Metering Applications

- Building Management
  - HVAC
  - Lighting
- Computer/Server Arrays
- Factory Work Cells
- Processing Plant Stages

Vehicle Charging



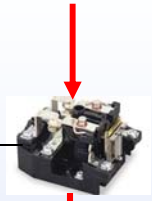
Demand Management

- Monitoring
- Manual Load Shedding
- Automatic Load Shedding

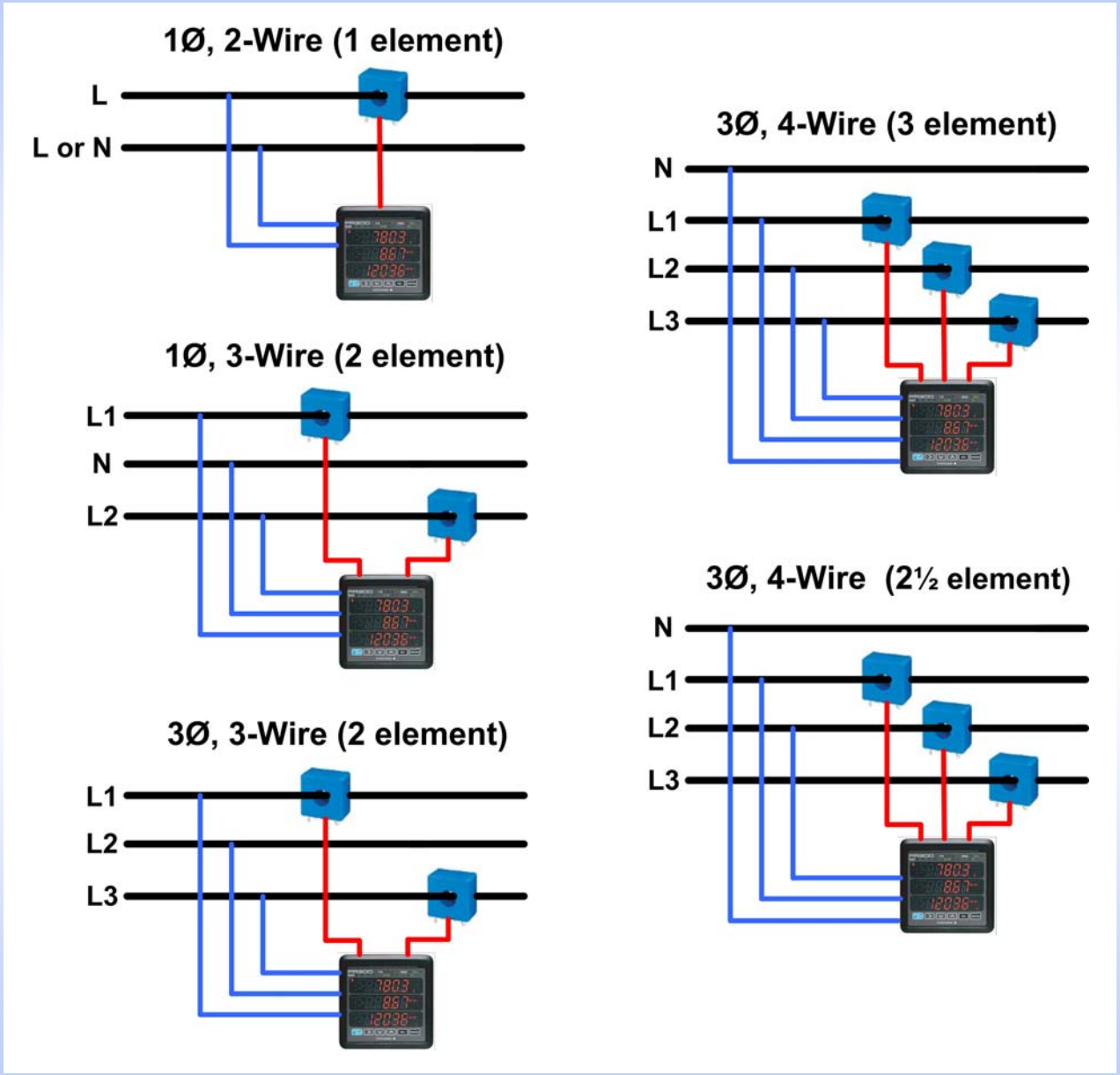
Demand Controller

Limit Alarm

Branch Circuit



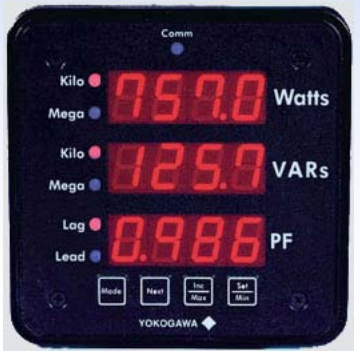
System Configurations



Industrial Products

- Panel Instruments
- Systems
- Wireless Products
- Smart Meters
- Services

Panel Instruments



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Energy Meter Parameters

- kWh delivered & received
- kVAr delivered & received
- kW real time
- kW per phase
- kVAr real time
- kVAr per phase
- kVA real time
- kVA per phase
- % Power Factor
- Power Factor per phase
- Total Amps
- Average Amps
- Amps per phase
- Average volts, line to neutral
- Average volts, line to line
- Volts to neutral per phase
- Volts line to line
- Average phase angle
- Phase angle per phase
- Frequency

Current Transformers

- Solid core for cost, reliability
- Split core for easy retrofit
- Specified by ratio, accuracy class & burden
- Burden sets maximum secondary load R
- Metering CTs may require heavy leads

Current Transformer Wire Length Chart

Size	Max Length	Gauge	Size	Max Length	Gauge
0.5VA (0.02Ω max)	2 feet	18 AWG	5VA (0.20Ω max)	22 feet	18 AWG
	3 feet	16 AWG		37 feet	16 AWG
	5 feet	14 AWG		60 feet	14 AWG
	8 feet	12 AWG		97 feet	12 AWG
	14 feet	10 AWG		156 feet	10 AWG
1.0VA	4 feet	18 AWG	6VA	27 feet	18 AWG

Systems

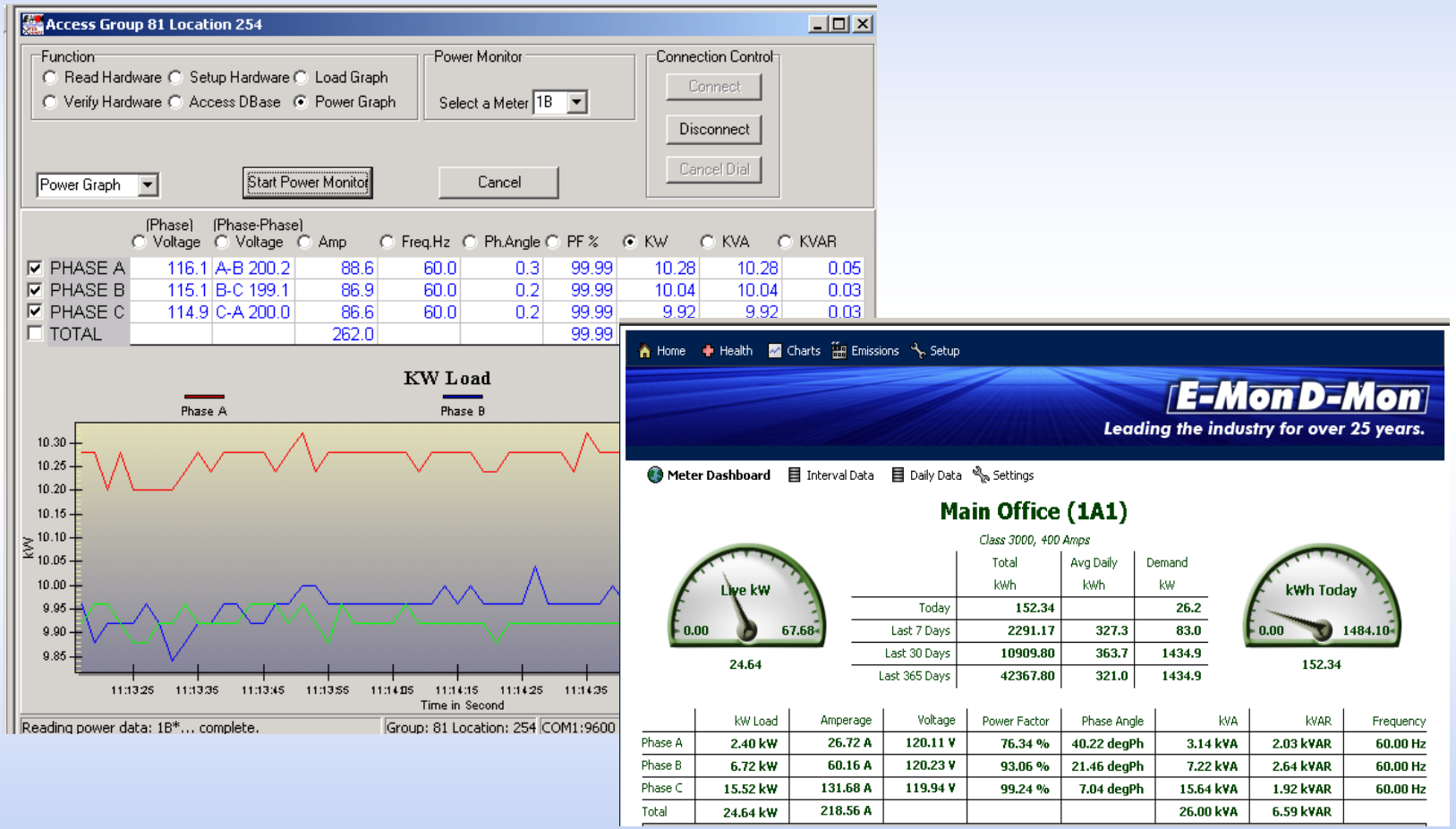
Current Transducer

- A:mV transducer
- Locate far from meter with no accuracy loss

"Green" Meter

- kWh in dollars
- Estimated cost per hour, based on current load
- CO_2 emissions in pounds, based on DOE data
- Estimated hourly CO_2 emissions based on current load
- Net metering, including utility delivered vs. user-generated power

Software



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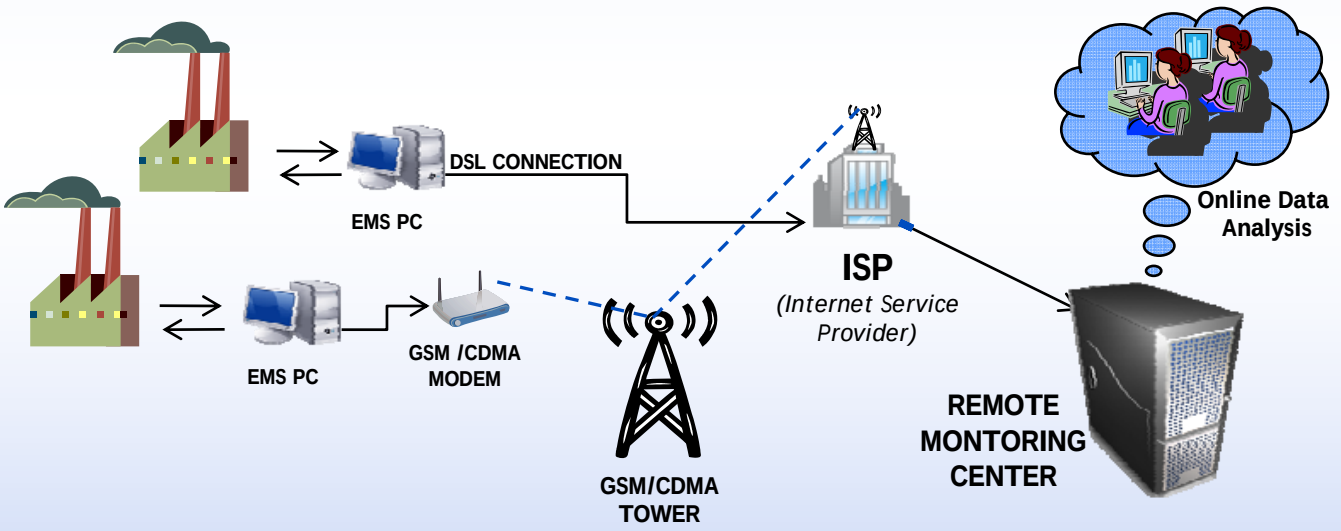
Wireless Products

Smart Socket Meters

- Accurate energy measurement
- Advanced power quality recording
- Wire or wireless communication

Services

- Energy Audit
- Remote Energy Monitoring



Case Study

Chemical Plant

$k/mo	Production	Energy	Profits
Before	**1943**	**357**	**93**
After	**1943**	**300**	**140**

16% energy savings resulted in >50% profit increase

Test Equipment

- Power Monitors
- Power Quality Analyzers
- Power Dataloggers

Power Quality Analyzer

- PQ Parameters
  - Dips & Swells
  - Harmonics
  - Interruptions
  - Flicker
  - Inrush
- Graphical Display
  - Scope,
  - Phasor Diagrams
  - Setup Prompts
- Analysis

Calculations

APPENDIX A

MATHEMATICAL FORMULAS FOR VARIOUS PARAMETERS

Half-period Voltage and Current RMS Values

$$Vdem[i]=\sqrt{\frac{1}{NSHC}\cdot\sum_{n:Zero}^{Next\ Zero}V[i][n]^2}$$ Single rms voltage half-period i + 1 phase

$$Udem[i]=\sqrt{\frac{1}{NSHC}\cdot\sum_{n:Zero}^{Next\ Zero}U[i][n]^2}$$ Compound rms voltage half-period i + 1 phase

$$Adem[i]=\sqrt{\frac{1}{NSHC}\cdot\sum_{n:Zero}^{Next\ Zero}A[i][n]^2}$$ Rms current half-period i + 1 phase

NSHC: number of samples per half cycle (between two consecutive zeros)
n: sample (0; 255)
i: phase (0; 1; 2)

MIN / MAX Values for Voltage and Current

$Vmax[i]=\max(Vdem[i])$, $Vmin[i]=\min(Vdem[i])$, $Vavg=1/6000\ \Sigma\ Vdem[i]$

$Umax[i]=\max(Udem[i])$, $Umin[i]=\min(Udem[i])$, $Aavg=1/6000\ \Sigma\ Adem[i]$

$Amax[i]=\max(Adem[i])$, $Amin[i]=\min(Adem[i])$ (Avg calculation on 1s)

Various Types of Energy

$$Wh[0][i]=\sum_{Tint}\frac{W[i]}{3600}$$ Active energy consumed phase i + 1

$$VAh[0][i]=\sum_{Tint}\frac{VA[i]}{3600}$$ Apparent energy consumed phase i + 1

$$VARhL[0][i]=\sum_{Tint}\frac{VAR[i]}{3600}\ \text{for}\ VAR[i]\geq 0$$ Reactive inductive energy consumed phase i + 1

$$VARhC[0][i]=\sum_{Tint}\frac{-VAR[i]}{3600}\ \text{for}\ VAR[i]\leq 0$$ Reactive capacitive energy consumed phase i + 1

Total active energy consumed:
Wh[0][3] = Wh[0][0] + Wh[0][1] + Wh[0][2]

Total apparent energy consumed:
VAh[0][3] = VAh[0][0] + VAh[0][1] + VAh[0][2]

Total reactive capacitive energy consumed:
VARhC[0][3] = VARhC[0][0] + VARhC[0][1] + VARhC[0][2]

Total reactive inductive energy consumed:
VARhL[0][3] = VARhL[0][0] + VARhL[0][1] + VARhL[0][2]

$$Wh[1][i]=\sum_{Tint}\frac{W[i]}{3600}$$ Active energy consumed phase i + 1

$$VAh[1][i]=\sum_{Tint}\frac{VA[i]}{3600}$$ Active energy consumed phase i + 1

$$VARhL[1][i]=\sum_{Tint}\frac{-VAR[i]}{3600}\ \text{for}\ VAR[i]\leq 0$$ Reactive inductive energy consumed phase i + 1

$$VARhC[1][i]=\sum_{Tint}\frac{VAR[i]}{3600}\ \text{for}\ VAR[i]\geq 0$$ Reactive capacitive energy consumed phase i + 1

Total active energy consumed:
Wh[1][3] = Wh[1][0] + Wh[1][1] + Wh[1][2]

Total apparent energy consumed:
VAh[1][3] = VAh[1][0] + VAh[1][1] + VAh[1][2]

Total reactive capacitive energy consumed:
VARhC[1][3] = VARhC[1][0] + VARhC[1][1] + VARhC[1][2]

Total reactive inductive energy consumed:
VARhL[1][3] = VARhL[1][0] + VARhL[1][1] + VARhL[1][2]

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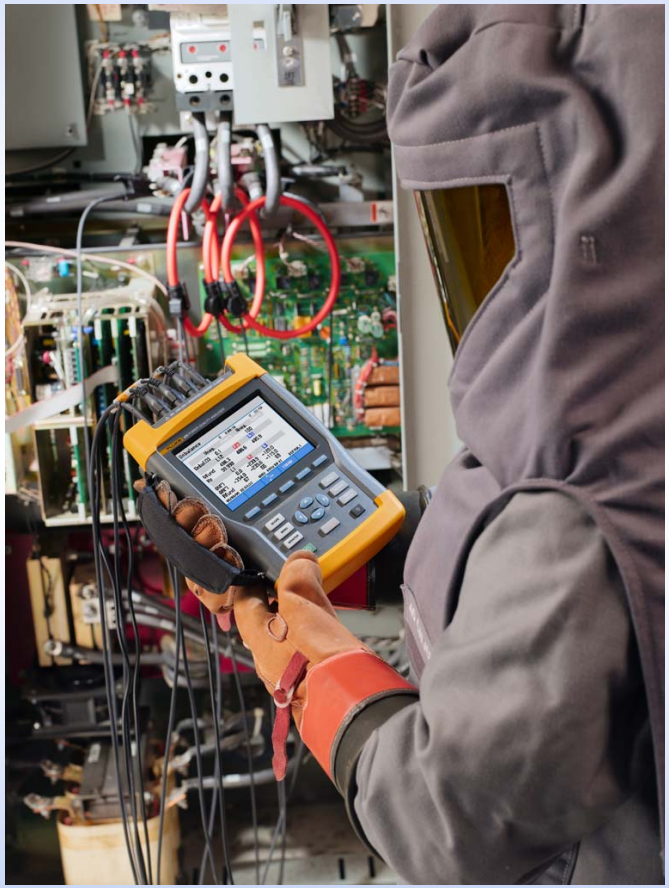
Connections



Summary

Key Factors in Equipment Selection:

- Permanent or Temporary Installation
- Turn-key or Build your Own
- Parameters to be Measured
- Mains Configuration
- Distance to Sensors
- Type of Display Needed
- Computer Interface/Software
- Control or Alarm Outputs
- Size, Cost…….

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Final Thoughts

- Energy costs are controllable
- Easier to reduce than other cost factors
- ARRA 2009 provides $20B for energy efficiency programs
- State & Federal tax incentives also available
- Measure & Verify required to substantiate any improvement

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