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

- 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 ⇒ Need to Measure
Key Terms

- **Active Power**
  \[ W = VA \quad (\text{DC source}) \]
  \[ W = VA \cdot PF \quad (\text{AC source}) \]

- **Apparent Power**
  \[ S = VA \]

- **Reactive Power**
  \[ Q = VAr \]

- **Power Factor**
  \[ PF = \frac{W}{VA} \quad \lambda \]

- **Active Energy**
  \[ \text{kWh} \]

- **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
Commercial Applications

- Generation
- Load Monitoring
- Demand Management
Solar DC System

Generation
Solar AC System
Grid Connected System
Sub-Metering

AC Mains Distribution Panel to Individual Units

Sub-Meters

Load Monitoring
Commercial Sub-Metering
Data Collection
Other Sub-Metering Applications

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

AC Mains

Sub-Meter

Load Monitoring
Demand Management

- Monitoring
- Manual Load Shedding
- Automatic Load Shedding
System Configurations
Industrial Products

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

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<th>Size</th>
<th>Max Length</th>
<th>Gauge</th>
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<td>0.5VA</td>
<td>2 feet</td>
<td>18 AWG</td>
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<tr>
<td>(0.02Ω max)</td>
<td>3 feet</td>
<td>16 AWG</td>
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<tr>
<td></td>
<td>6 feet</td>
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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
- CO₂ emissions in pounds, based on DOE data
- Estimated hourly CO₂ emissions based on current load
- Net metering, including utility delivered vs. user-generated power
Software
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

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<th>Energy</th>
<th>Profits</th>
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<td>1943</td>
<td>357</td>
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<tr>
<td>After</td>
<td>1943</td>
<td>300</td>
<td>140</td>
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</tbody>
</table>

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

\[ V_{\text{rms}}[i] = \sqrt{\frac{1}{N}} \sum_{n=0}^{N} V[n] \quad \text{Single rms voltage half-period } i + 1 \text{ phase} \]

\[ I_{\text{rms}}[i] = \sqrt{\frac{1}{N}} \sum_{n=0}^{N} I[n] \quad \text{Compound rms voltage half-period } i + 1 \text{ phase} \]

\[ A_{\text{rms}}[i] = \sqrt{\frac{1}{N}} \sum_{n=0}^{N} A[n] \quad \text{Rms current half-period } i + 1 \text{ phase} \]

\(N\): number of samples per half cycle (between two consecutive zeros)
\(n\): sample (0, 255)
1 phase (0, 1, 2)

MIN / MAX Values for Voltage and Current

\[ V_{\text{max}}[i] = \max(V_{\text{rms}}[i]), V_{\text{min}}[i] = \min(V_{\text{rms}}[i]) \]
\[ U_{\text{max}}[i] = \max(U_{\text{rms}}[i]), U_{\text{min}}[i] = \min(U_{\text{rms}}[i]) \]
\[ A_{\text{max}}[i] = \max(A_{\text{rms}}[i]), A_{\text{min}}[i] = \min(A_{\text{rms}}[i]) \]

Power Quality Analyzer Model 3945-B

Various Types of Energy

\[ W_A[i] = \sum_{n=0}^{N} W_A[n] \quad \text{Active energy consumed phase } i + 1 \]

\[ W_{\text{VAR}}[i] = \sum_{n=0}^{N} W_{\text{VAR}}[n] \quad \text{Apparent energy consumed phase } i + 1 \]

\[ W_{\text{VAR}}[i] = \sum_{n=0}^{N} W_{\text{VAR}}[n] \quad \text{for } W_{\text{VAR}}[i] > 0 \text{ Reactive inductive energy consumed phase } i + 1 \]

\[ W_{\text{VAR}}[i] = \sum_{n=0}^{N} W_{\text{VAR}}[n] \quad \text{for } W_{\text{VAR}}[i] < 0 \text{ Reactive capacitive energy consumed phase } i + 1 \]

Total active energy consumed:


Total apparent energy consumed:

\[ W_{\text{VAR}}[0] = W_{\text{VAR}}[0] + W_{\text{VAR}}[1] + W_{\text{VAR}}[2] \]

Total reactive capacitive energy consumed:

\[ W_{\text{VAR}}[1] = W_{\text{VAR}}[1] + W_{\text{VAR}}[2] \]

Total reactive inductive energy consumed:

\[ W_{\text{VAR}}[2] = W_{\text{VAR}}[2] \]

\[ W_{\text{VAR}}[i] = \sum_{n=0}^{N} W_{\text{VAR}}[n] \quad \text{for } W_{\text{VAR}}[i] > 0 \text{ Reactive inductive energy consumed phase } i + 1 \]

\[ W_{\text{VAR}}[i] = \sum_{n=0}^{N} W_{\text{VAR}}[n] \quad \text{for } W_{\text{VAR}}[i] < 0 \text{ Reactive capacitive energy consumed phase } i + 1 \]

Total active energy consumed:


Total apparent energy consumed:

\[ W_{\text{VAR}}[i] = W_{\text{VAR}}[i] + W_{\text{VAR}}[i+1] + \text{VAR}[i+2] \]

Total reactive capacitive energy consumed:

\[ W_{\text{VAR}}[2] = W_{\text{VAR}}[2] + W_{\text{VAR}}[1] + W_{\text{VAR}}[0] \]

Total reactive inductive energy consumed:

\[ W_{\text{VAR}}[0] = W_{\text{VAR}}[0] + W_{\text{VAR}}[1] + W_{\text{VAR}}[2] \]
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

Thanks to E-MON, Conzerv, AEMC, Fluke & Yokogawa for providing material for this presentation.