Power Monitoring in Server Power Supplies

Challenges and Opportunities

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OUTLINE

- Why do we need power monitoring? The power of knowing the power. Which power are we measuring?
- Power Monitoring inside intelligent power supplies
  - Accuracy – cost/performance trade offs
  - Data acquisition and conversion
  - Communication and computation
- Power Supply performance optimization
- System level optimizations
- Conclusions
Power and Energy measurement is not a new problem
Why do we need power monitoring?

- Control power consumption and possibly limit it
- Optimize overall efficiency by implementing power policies
- Total heat output and airflow requirements
- Better utilization of existing resources
- PDU sizing
- Load spreading/sharing
- Power supply optimization
- Intelligent UPS management

- How accurate has to be?
- How often does it need to be measured?

It all depends from what you want to do with the information
Measure Power Where?

- Plant
- Rack
- System
- Power Supply Unit
IBM Power Executive
Power Monitoring Software

IBM PowerExecutive enables customers to monitor ACTUAL power draw and thermal loading information.
Monitored Power Distribution Units (PDUs)

- Rack/system power reading
- Expensive
- Slow
- Limited accuracy
## Power Analyzers

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Accuracy &amp; Wide Frequency Range</strong></td>
<td></td>
</tr>
<tr>
<td>Low Power Factor Error</td>
<td></td>
</tr>
<tr>
<td>Voltage (50/60 Hz) 1000 [Vrms]</td>
<td></td>
</tr>
<tr>
<td>Current Range: Direct Input</td>
<td>0.5/1/2/5/10/20/30 [A]</td>
</tr>
<tr>
<td>External Input</td>
<td>50m/100m/200m/500m/1/2/5/10 V</td>
</tr>
<tr>
<td>Voltage Range</td>
<td>15/30/60/100/150/300/600/1000 V</td>
</tr>
<tr>
<td>Data Update rate</td>
<td>50 ms to 20 sec</td>
</tr>
<tr>
<td>Effective input range</td>
<td>1% to 130%</td>
</tr>
<tr>
<td>Basic Power Accuracy</td>
<td>±(0.02% of reading + 0.04% of range) hi-end</td>
</tr>
<tr>
<td></td>
<td>±0.2% total accuracy - low-end</td>
</tr>
<tr>
<td>Price</td>
<td>$2,000 to $30,000</td>
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</table>
Adding power measuring functionality to the power supply

- Power Supply Unit level detail
- Voltages and Currents are already measured inside the PSU
- Input and Output Power Monitoring
  - Power drawn from the line is measured as well as power delivered to the load
- Information can be used to adjust operation of the PSU
- The PSU can store and retain the data between reads or in case of a failure (flash memory)

- Needs to be:
  - cost effective
  - accurate enough
  - reliable
  - Stable over the lifetime of the PSU
AC and DC Power Monitoring
Problem Statement

- Main issues are
  - Accuracy of measurements and acquisition
    - Location and type of sensor
    - Calibration, zeroing and auto scaling
  - Sampling Frequency
  - Averaging methods and averaging window size
  - Speed of data transfer between point of measurement and destination
  - Computational power (amount and location)
  - Simultaneity of Voltage and Current measurements
Input Current Sensing Location

- **EMI**
  - Real AC input current
  - Needs HV isolation
  - AC Low Frequency component (no CT)
  - Exposed to line events (surge, lightning, etc)

- **Input Bridge**
  - Real AC input current
  - Needs HV isolation
  - AC Low Frequency component (no CT)
  - Protected from line events
  - EMI filter introduces errors

- **PFC Stage**
  - Ground referenced signal
  - Need 2 CT in most cases or one shunt
  - Indirect measurement (needs adjustments to compensate for bridge and EMI losses)
Power Measurement Accuracy

- The accuracy and linearity of the sensor is the main limitation
  - Linearity
  - Accuracy
  - Temperature drift
  - Life (aging)

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th>Linearity + Long Term Stability</th>
<th>Losses</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Transformer</td>
<td>± 5%</td>
<td>± 1%</td>
<td>Mid</td>
<td>$$</td>
</tr>
<tr>
<td>Hall Effect</td>
<td>± 0.7%</td>
<td>± 0.2%</td>
<td>Low</td>
<td>$$$</td>
</tr>
<tr>
<td>Shunt Resistor</td>
<td>± 0.1%</td>
<td>± 0.5%</td>
<td>High</td>
<td>$</td>
</tr>
</tbody>
</table>
AC Current Sensing Challenges

- Universal Input Voltage: 90V-264V
- Max Voltage drop on sense resistor: 500mV

Example for 1kW unit
- (ignoring efficiency effect, first order calculation)
  - 1 LSB = 122uV (500mV/4096 – 12bits)
  - Quantization error = 0.7% @ 10% load - hi line at the peak
  - Since we are measuring a sinusoid the overall error is actually larger

- We need to add ADC reference and current amplifier offset and errors
  - 0.5% to 1% typ.

\[
I_{IN} = 11.1 \text{Arms} \rightarrow 15.6 \text{Apeak}
\]
\[
R_{sense} \approx 30m\Omega
\]
\[
V_{sense} = 170mV_{peak} @ 264V_{AC} 100\% \text{ load}
\]
\[
V_{sense} = 17mV_{peak} @ 264V_{AC} 10\% \text{ load}
\]
Total Measurement Error (before calibration)

Calibration and auto scaling is required for the various line and load conditions in order to reduce error.
Calibration

- In line of principle it is possible to calibrate the power meter to reduce all these errors to less than 2% - but:
  - How to guarantee calibration over time? (Lab equipment gets sent to the calibration lab every 12 months....)
  - Calibration needs to be done for various AC lines and loads as well as for various environmental conditions (temperature, etc)
  - A precise calibration process can result to be:
    - Extremely time consuming (to cover all different conditions)
    - Expensive (lots of memory to store look up tables)
Time Scales of Data Communication

PMBUS Speed

@ 100kb/s → 900 reads/s (1.1ms)
@ 400kb/s → 3200 reads/s (312us)
AC Power Monitoring scheme

- The ADC will acquire multiple samples per AC line cycle
- The “True RMS” value of Voltage/Current is calculated across one line cycle
- The resulting value is then averaged over a programmable time and stored in a register
DC Power Monitoring scheme

- The ADC will continuously acquire the output parameters
- The resulting value is then averaged over a prefixed time (2.5ms to 10ms) and stored in a register
- This process is much less critical than AC power measuring
- Accuracies in the 2% range are easily achievable
Power Supply Real Time Optimization

- Once the power information is available inside the PSU it can be used for real time optimizations
  - Boost voltage optimization
  - Switching frequency fold back at lighter loads
  - Timing optimization of Power Switches and Sync Rectifiers
  - Phase shedding in the PFC stage
  - Phase shedding in the main DCDC (i.e. interleaved forward)
PFC Efficiency Comparison

Shed one phase, decrease switching frequency, decrease bus voltage

Efficiency is increased by about 3.29% @ 5% load!

@650W PFC, 110Vin

- 397Vo, 130K, two phase
- 368Vo, 90K, one phase

Efficiency is increased by about 3.29% @ 5% load!

Courtesy of Delta – Presented at DPF 2007

IBM 2007 Power and Cooling Symposium – Raleigh, NC
System level optimization

- The power supply can be much more aggressive in optimizing performance when more information about the load behavior is available.
- If the load ‘guarantees’ max power consumption the power supply can be resized dynamically, improving efficiency.
- Need to define more power states other than ‘STDBY’ and ‘POWER-ON’ and standardize communication with PSU.
Summary

- Power Monitoring is here now
- Best implementation is inside the PSU
- Accuracy in excess of 7% comes ‘almost’ free
- Going below 3% may involve a significant cost adder
  - How much accuracy is really needed?
- Efficiency improvements deriving from power measuring and real time optimization can offset most of these cost and make power measuring cost effective
- Importance of communication to improve system level efficiency