Adaptive/Intelligent Control
and Power Management
Reduce Power Dissipation and Consumption

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Agenda

• ~ 400W Power System for Server Application
• Conventional Power Conversion Components
  – Key Characteristics
  – Efficiency/Power Losses
• Adaptive/Intelligent Power Conversion Components
  – Key Characteristics
  – Efficiency/Power Losses Savings
• Activity Based Power Management
Block Diagram Of Typical Power System

AC-DC Power Conversion

AC MAINS

Intermediate Voltage Bus

AC-DC Front End

40% Load

DC-DC conversion (POL regulators)

POL

1.2V@90A

POL

1.8V@45A

POL

2.5V@30A

POL

3.3V@15A

Power Consumption app. 313W

Typical 12V

40% Load,
Conventional/Passive Power System Characteristics

• Redundant AC-DC Front Ends
  – 12V intermediate bus
  – Operating ~ 30%-40% capacity
  – Efficiency optimized @ full load (~84%)
    • Typically dominated by Copper (IIR) losses
  – Efficiency compromised @ partial load (~82%)
    • Switching losses, overhead/housekeeping losses
  – Fixed/Passive operating parameters
    • Operating frequency, constant airflow, output conditions, etc
  – Limited/no monitoring capabilities

• DC-DC Converters
  – Fixed/passive operating parameters
  – Limited/no monitoring capabilities
Typical Efficiency of Conventional 12V Front End

Efficiency, %

Output Power, W

220V

110V
Efficiency of Non-Isolated DC-DC at Vin=12V
Power Losses In Conventional Power System

AC MAINS
AC Power app. 439W

AC-DC Front End
AC-DC Power Dissipation app. 79W

40% Load, 82%

Intermediate Voltage Bus

AC-DC Front End

40% Load, 82%

Overall System Efficiency=71.4%

POL Power Dissipation app. 47W

DC-DC
82.5%

1.2V@90A

DC-DC
88%

1.8V@45A

DC-DC
90%

2.5V@30A

DC-DC
92%

3.3V@15A

Power Consumption app. 313W

IBV Power app. 360W

AC Power app. 470W

82%

88%

90%

92%

40% Load, 82%

82.5%

88%

90%

92%
Intelligent/Adaptive Power System

- Redundant / Adaptive AC-DC Front Ends and DC-DC converters
  - Intelligent embedded monitoring and internal controls
    - Digital Embedded Controls and Power Management
    - High level of flexibility for modifying internal operating parameters
  - Dynamic adjustment of internal operating parameters to match application/operating environment
    - Software managed
      - Embedded algorithms for performance optimization
      - User managed software control
    - Optimizes efficiency/key performance over entire load range
      - ~86%-89% from 40%-100% rated load
  - Adaptive drivers minimize dead time and shoot-through
  - Internal monitoring of critical parameters
    - Input/output voltages, load condition, temperature
Efficiency of 12V Front End with Adaptive Controls

![Graph showing efficiency vs. output power for 220V and 110V inputs.](image)
Power Losses in Power System with Adaptive/Intelligent Front End

AC-DC Power Dissipation app. 54W

AC-DC Front End

Intermediate Voltage Bus

POL Power Dissipation app. 47W

DC-DC

82.5%

DC-DC

88%

DC-DC

90%

DC-DC

92%

Power Consumption app. 313W

1.2V@90A

1.8V@45A

2.5V@30A

3.3V@15A

AC MAINS

AC Power app. 414W

40% Load, 87%

AC-DC Front End

IBV Power app. 360W

40% Load, 87%

Overall System Efficiency = 75.7%
Adaptive Control for DC-DC Converters

• There is an optimal operating point for a given set of conditions
• Purpose of adaptive control is to continuously modify performance parameters of a power supply to keep its operation as close to optimal point as possible
• Example: 1.2V output
  – Non-optimized – 12V input, 1MHz switching frequency, standard driver. Efficiency is 80%
  – Optimized - 5V input, 500kHz switching frequency, adaptive driver. Efficiency is 85.5%
  – Power dissipation is reduced by 1/3 by optimizing operating point of the power supply
Efficiency Is A Complex Function Of Operating Conditions

Output Load

Output Voltage

Input Voltage

Switching Frequency
Further Power Reduction With Activity Based Power Management

- Enabled by digital power technology
- Managing System – reduction in both power dissipation and power consumption
  - Modify performance parameters of entire system as a function of system load, supply voltages, and temperature
- Managing Loads – reduction in power consumption
  - Change clock frequency and supply voltage as a function of processor load (DVS)
  - Intelligent control of cooling fans
Activity Based Power Management

**SYSTEM PROCESSOR:**
1. Calculates load
2. Selects optimal IBV setting for the load, temp, and mains
3. Sets output of AC/DC to maximize system efficiency

AC/DC FRONT END POWER SUPPLY

Efficiency = f(MAins, LOAD, IBV, TEMP)

INTERMEDIATE VOLTAGE BUS

INTERMEDIATE BUS VOLTAGE

CONTINUOUS LOAD MONITORING

REPORTING: VOLTAGE (IBV AND MAINS), AND TEMPERATURE

ADJUSTMENT: INTERMEDIATE BUS VOLTAGE

CONTINUOUS LOAD MONITORING AND ADJUSTMENT

REPORTING: VOLTAGE, CURRENT, AND TEMPERATURE FOR EACH OUTPUT

Z-ONE™ DIGITAL POINT OF LOAD REGULATORS

Efficiency = f(IBV, LOAD, VOUT, TEMP)

INDUSTRY STANDARD I2C COMMUNICATION BUS

Vo1
Vo2
Vo3
Von

AC MAINS

EFFICIENCY = f(IBV, LOAD, VOUT, TEMP)
Supply voltage clock scalable CPUs allow reducing power consumption by varying clock frequency and supply voltage as a function of utilization.
Activity Based Power Management With DVS

SYSTEM PROCESSOR RUNS ACTIVITY-BASED OPTIMIZATION ALGORITHMS

<table>
<thead>
<tr>
<th>POWER DISSIPATION REDUCTION</th>
<th>POWER CONSUMPTION REDUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. CALCULATES LOAD</td>
<td>1. DETERMINES CPU UTILIZATION</td>
</tr>
<tr>
<td>2. SELECTS OPTIMAL IBV SETTING FOR THE LOAD, TEMP, AND MAINS</td>
<td>2. SELECTS OPTIMAL CPU CLOCK FREQUENCY</td>
</tr>
<tr>
<td>3. SETS OUTPUT OF AC/DC TO MAXIMIZE SYSTEM EFFICIENCY</td>
<td>3. SETS CPU CLOCK FREQUENCY</td>
</tr>
<tr>
<td></td>
<td>4. DETERMINES AND SETS NEW CPU SUPPLY VOLTAGE</td>
</tr>
</tbody>
</table>

AC/DC FRONT END POWER SUPPLY
Efficiency = f(MAINS, LOAD, IBV, TEMP)

INTERMEDIATE VOLTAGE BUS

Z-ONE™ DIGITAL POINT OF LOAD REGULATORS
Efficiency = f(IBV, LOAD, VOUT, TEMP)

DATA PROCESSING LOADS
Vo1, Vo2, Vo3...

INDUSTRY STANDARD I2C COMMUNICATION BUS

CONTINUOUS MONITORING AND ADJUSTMENT
REPORTING: VOLTAGE, CURRENT, AND TEMPERATURE
ADJUSTMENT: OUTPUT VOLTAGE

CONTINUOUS MONITORING AND ADJUSTMENT
REPORTING: UTILIZATION, CLOCK FREQUENCY, TEMPERATURE
ADJUSTMENT: CLOCK FREQUENCY
# Power Savings Summary Per System

<table>
<thead>
<tr>
<th></th>
<th>Power Consumption, Watts</th>
<th>Power Losses, Watts</th>
<th>Overall System Efficiency, %</th>
<th>Annual Cost Savings, $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Power System</td>
<td>313</td>
<td>126</td>
<td>71.4</td>
<td>0</td>
</tr>
<tr>
<td>PS with Adaptive AC Front End</td>
<td>313</td>
<td>100</td>
<td>75.7</td>
<td>18</td>
</tr>
<tr>
<td>PS with Adaptive AC FE &amp; POLs</td>
<td>313</td>
<td>91</td>
<td>77.5</td>
<td>25</td>
</tr>
<tr>
<td>PS with Activity Based Power Management</td>
<td>313</td>
<td>86</td>
<td>78.5</td>
<td>29</td>
</tr>
<tr>
<td>PS with Activity Based PM and DVS</td>
<td>292</td>
<td>82</td>
<td>78.1</td>
<td>47</td>
</tr>
</tbody>
</table>

Assumes 75% equipment utilization and $0.11/kW energy cost
## Real World Examples Of Power Savings

<table>
<thead>
<tr>
<th>Industry/Location</th>
<th>Power Savings, Watts</th>
<th>Annualized savings, $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Office</td>
<td>~325 – 650</td>
<td>~235 – 470</td>
</tr>
<tr>
<td>Campus Environment</td>
<td>~3,200 – 6,500</td>
<td>~2,300 – 4,700</td>
</tr>
<tr>
<td>Data Centers</td>
<td>~32,000 – 65,000</td>
<td>~23,000 – 47,000</td>
</tr>
</tbody>
</table>

Assumes 75% equipment utilization and $0.11/kW energy cost
Conclusions

• Conventional Power Systems are not optimized for reduction of power losses

• System approach to Power Management results in reduction of both power consumption and power dissipation

• Digital Power Management enables users to implement
   – Continuous parameters monitoring, reporting, and adjustment
   – Optimization of operating parameters, including selection of properly rated power supplies
   – Activity based power management
   – Dynamic voltage scaling

• Substantial operating cost savings can be achieved
  - Up to $0.15/Watt of consumed power!
  - ~20% of power loss reduction
Thank You!

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