The Power Backbone of AI Infrastructure

Bob Zollo, Solution Architect / Product Planner for Power, EISG CoE
Keysight Technologies
5 November 2026

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May I introduce myself? Bob Zollo

- Solution Architect for Power Testing, Keysight Technologies
- Create battery testing solutions roadmap
  by researching customer and industry trends
- 40 years: Keysight, Agilent, HP (one company, 3 names)
  - R&D and Marketing
  - Power supplies, electronic loads, power analysers,
    data acquisition equipment, and test systems
  - Managed battery test systems business
- Located in New Jersey, USA

bob.zollo@keysight.com
+1-973-448-7208
http://www.keysight.com



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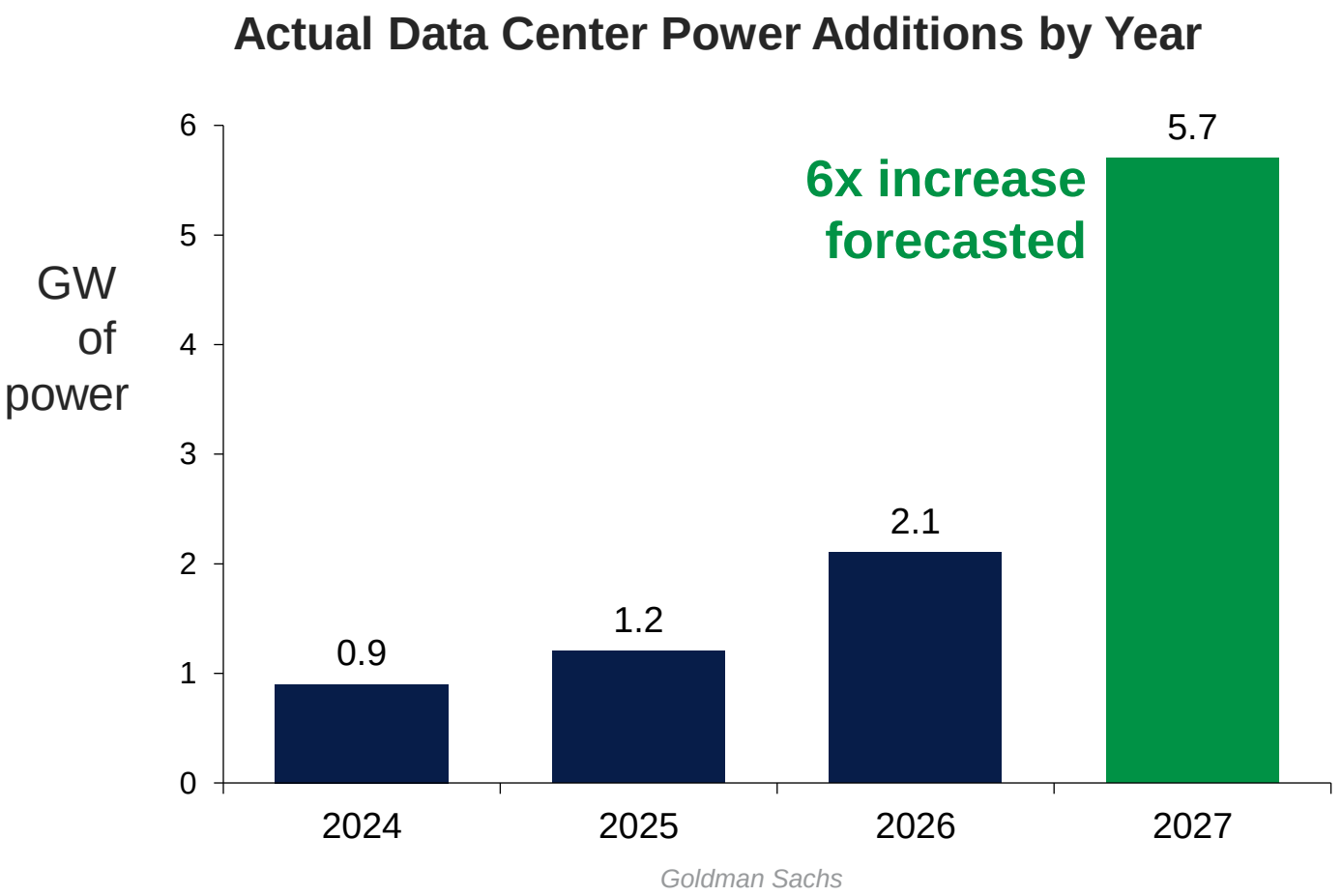
Global Leader in Test

Power Test Instrumentation
Cell/Battery Test Systems
Charger Test Systems
Grid Compliance Test

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AI / Data Center: Staggering Power Demand and Spending

As of Today



Goldman Sachs

By 2030

220 Gigawatts

Global data center power demand

$7 Trillion

Cumulative global spend
from 2025 to 2030
on AI Data centers and infrastructure

McKinsey

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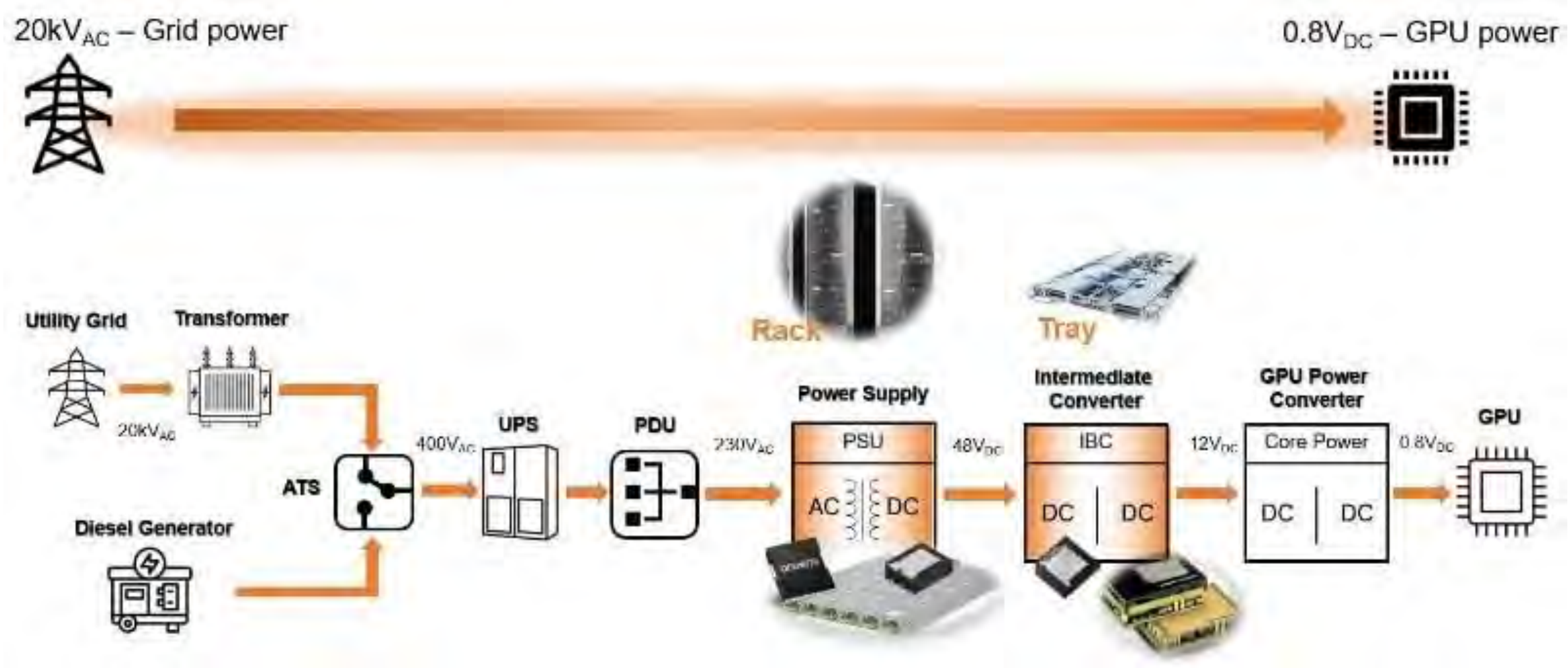
AI / Data Center Megatrends and Impact on Power Architecture

Trillions of $$$ being spent

Megatrend Explanation	Impact on Power Architecture
Rack power rising from 10–20 kW to 50–200 kW, toward 1 MW, making legacy architectures insufficient	Higher distribution voltage required ***Forces redesign of power distribution systems***
Shift from multi-stage AC systems to direct DC distribution; fewer conversions, with voltage evolving from 48V or 54V → 400V, +/- 400V → 800V+	Reduced current and I^2R losses with less copper ***Forces redesign of rack and power conversion systems***
End-to-end “grid-to-chip” optimization across full power chain	Full-stack efficiency gains stronger integration between infrastructure and compute ***Requires accurate measurement of efficiency***
Liquid cooling required beyond ~100 kW/rack	Less space for power hardware Shifts some power conversion outside rack ***Creates physical test opportunity: temp, pressure, flow***

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Today: Data Center Power Distribution Elements



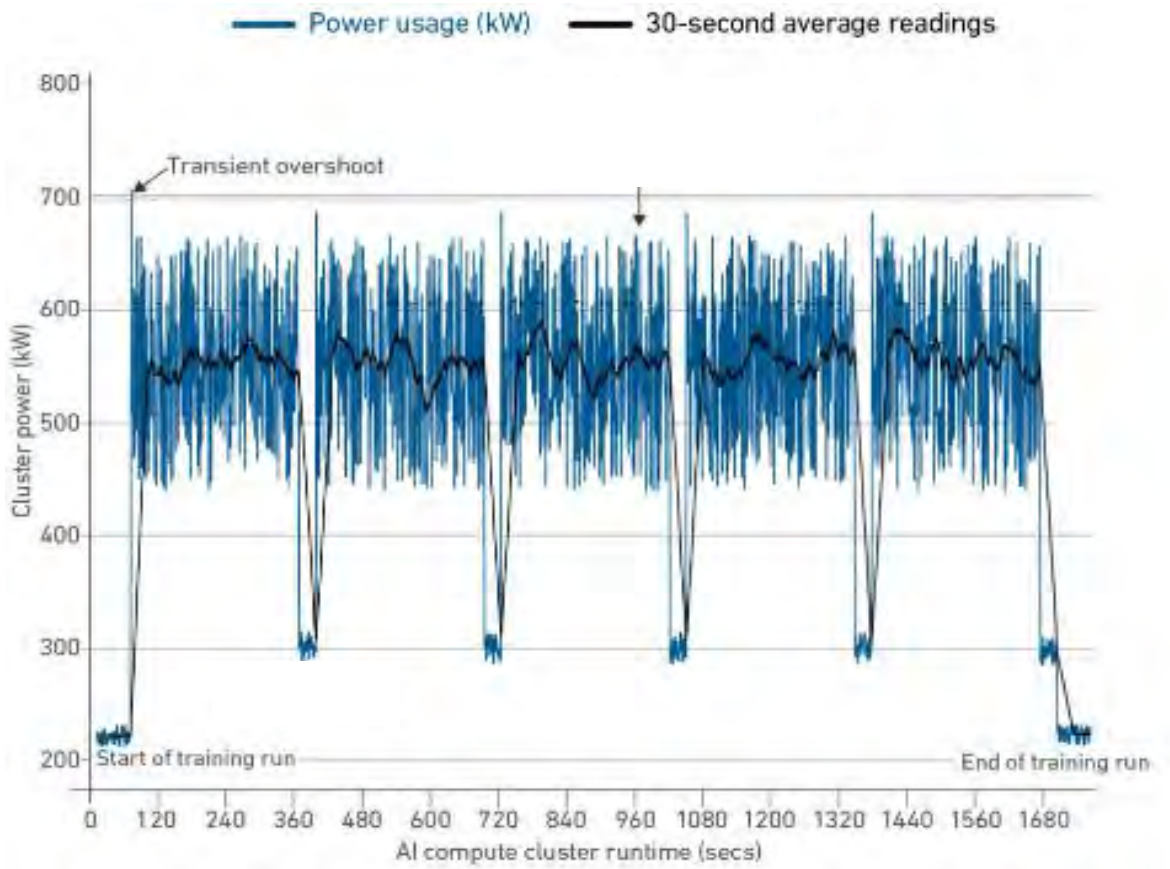
Courtesy: Onsemi

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Data Center Loading of the Grid is Highly Dynamic

- Power fluctuations in the 100's of MW
- Ramp speed could be almost instantaneous
- The Grid is not designed for this!

- Dangers
  - Voltage variation on the grid
  - Frequency/stability issues on the grid
  - Grid collapse (remember Spain, Apr 2025?)
  - Equipment stress in the data center and in the grid
  - Creates grid interconnection constraints, which in part, this drives > 5 year long queue for Grid Interconnection approval

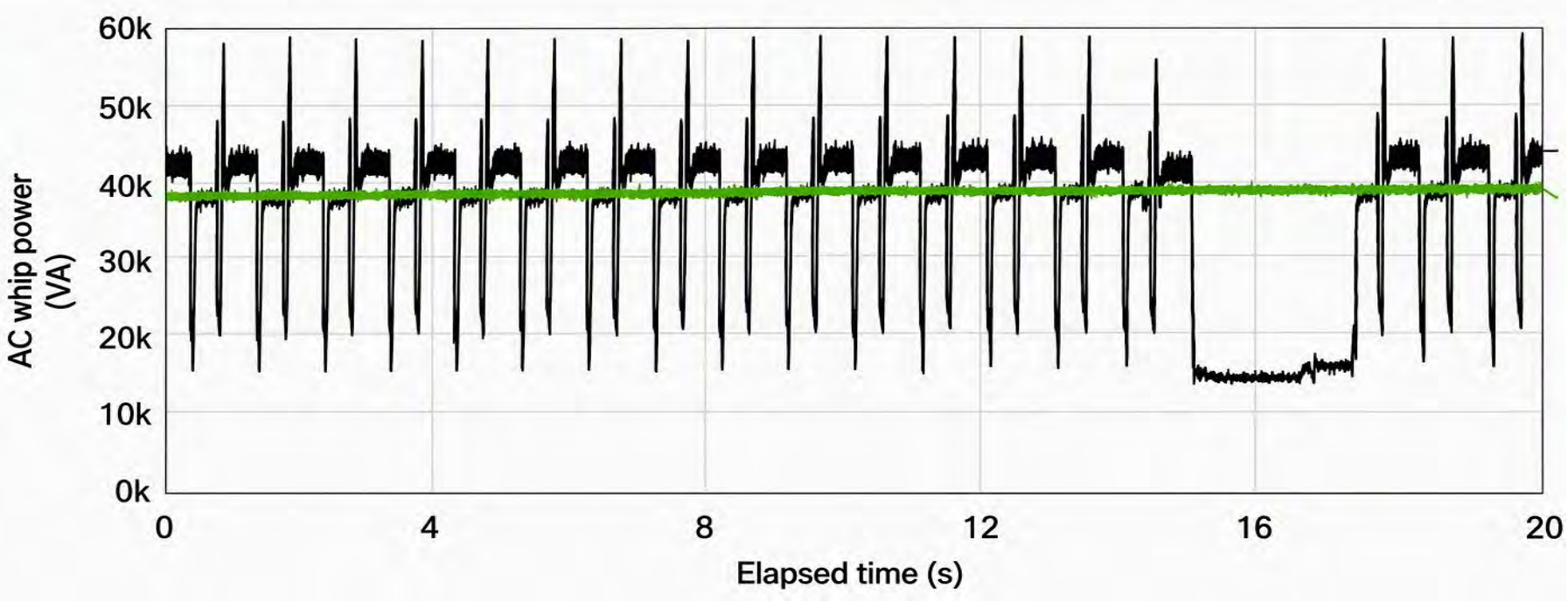


Courtesy: Uptime Institute 2025

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Server Power Consumption is Even More Dynamic

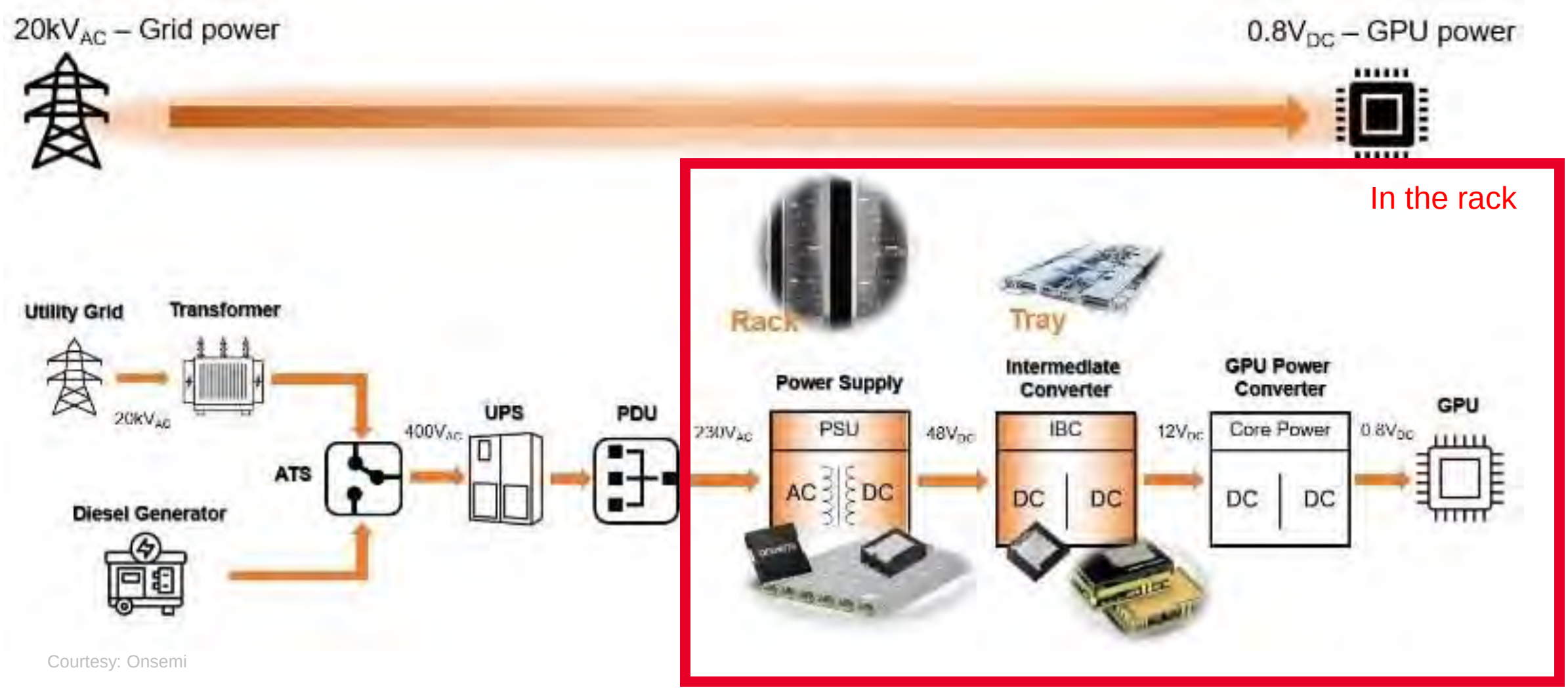
This type of power demand profile creates havoc on the power supplies that source current, as the server requires stable DC power in the face of these dynamic loads.



During development of server supplies, electronic loads are needed to create these waveforms.

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Today: Data Center Power Distribution Elements



Courtesy: Onsemi

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Power Conversion and Distribution Elements that Need to be Designed and Tested

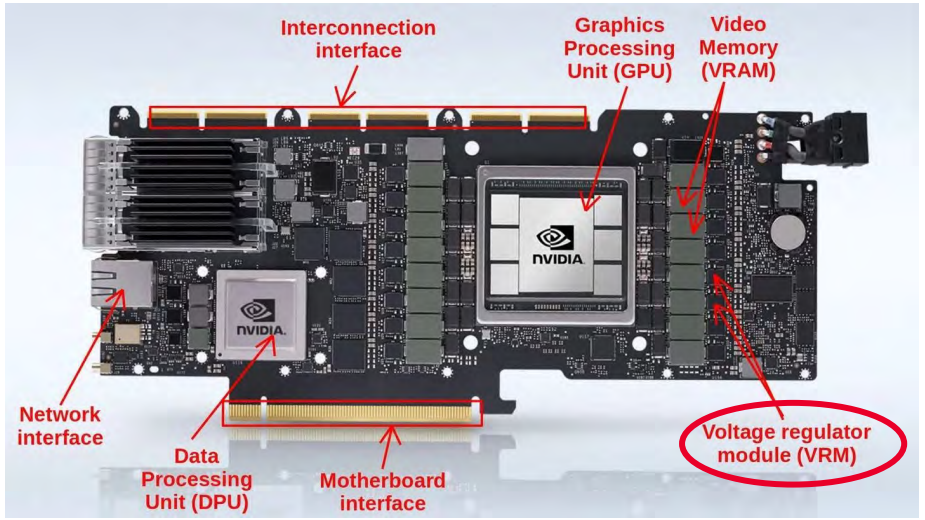
AC/DC Power Supply Unit Shelf



IBC or DC/DC



VRM / PMIC



Courtesy: NVIDIA

Supercap Backup
Battery Backup



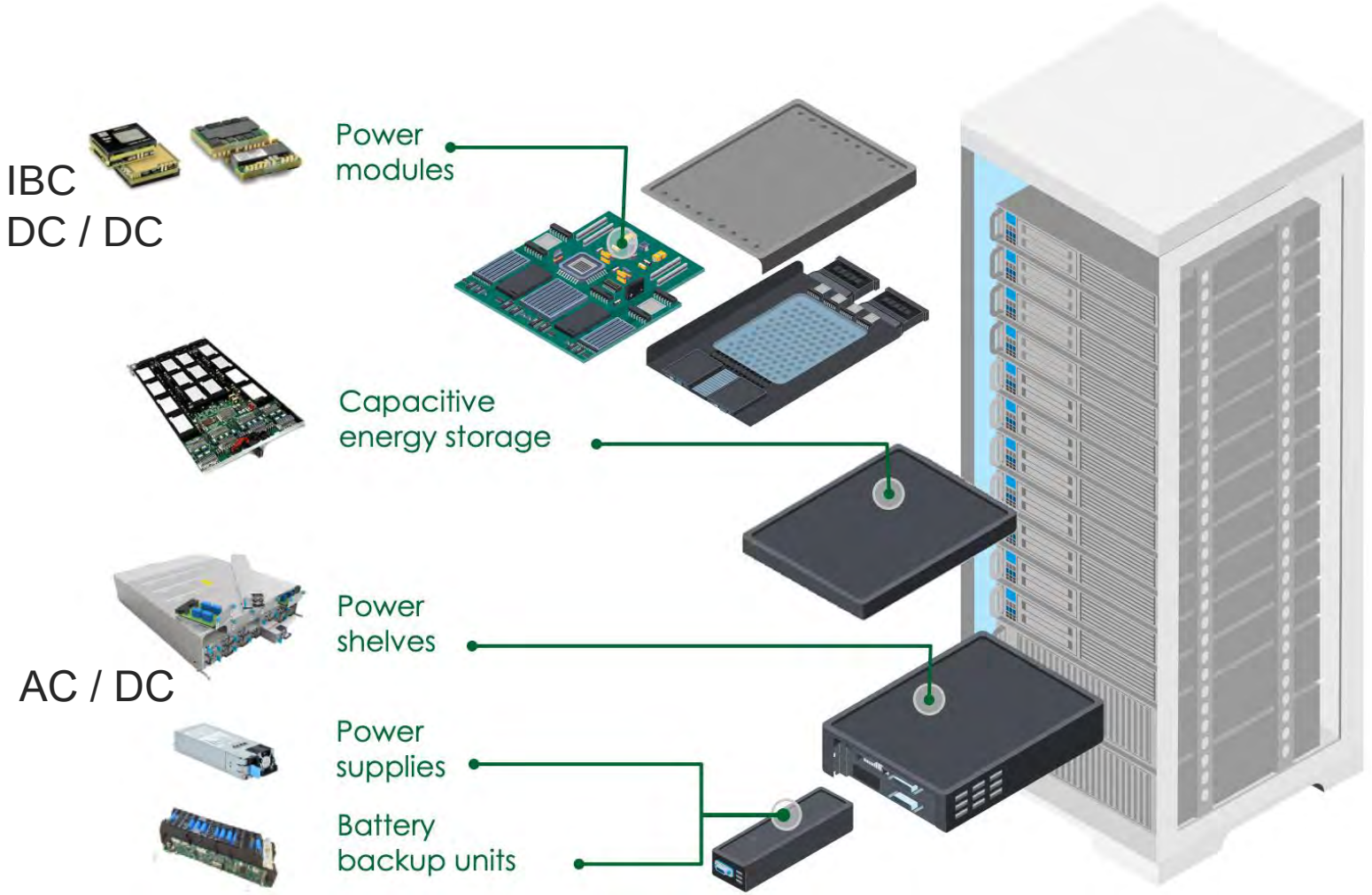
Courtesy: Yongming Electronics

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Power Conversion and Distribution Inside the Server Rack

Testing power converters in R&D and DV requires:

- Power Sources as inputs
- Eloads as outputs
- Measurement to characterize performance and efficiency
  - Oscilloscopes
  - Power Rail Probes (noise)
  - Differential Probes (floating)
  - Scope Power Analysis SW
  - DMM (Volts, Amps, Watts)
  - Data Acquisition (thermal testing)
  - Benchtop Sources and Loads
  - Battery Testing for BBU and CBU



Courtesy: Flex

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What Parameters are Important? What is Tested?

Tests using AC Sources, DC Sources and Eloads

- Measure output noise
- Measure efficiency
- Characterize inrush current
- Characterize sequencing (if multiple outputs)
- Validate performance at different temperatures
- Measure output stability under fast current transients, including special pre-determined test waveforms (EDPP)
- Measure output behavior under various line and load conditions, including power disturbances, blackout, brownout

Green =
Challenging tests that require dynamic sources and eloads with fast slew rates and high accuracy

Tests using Scopes and Probes

- Characterize startup / shutdown behavior
- Validate response to control signals
- Design PWM / switching analysis
- Perform spectral analysis / FFT
- Characterize control loop stability

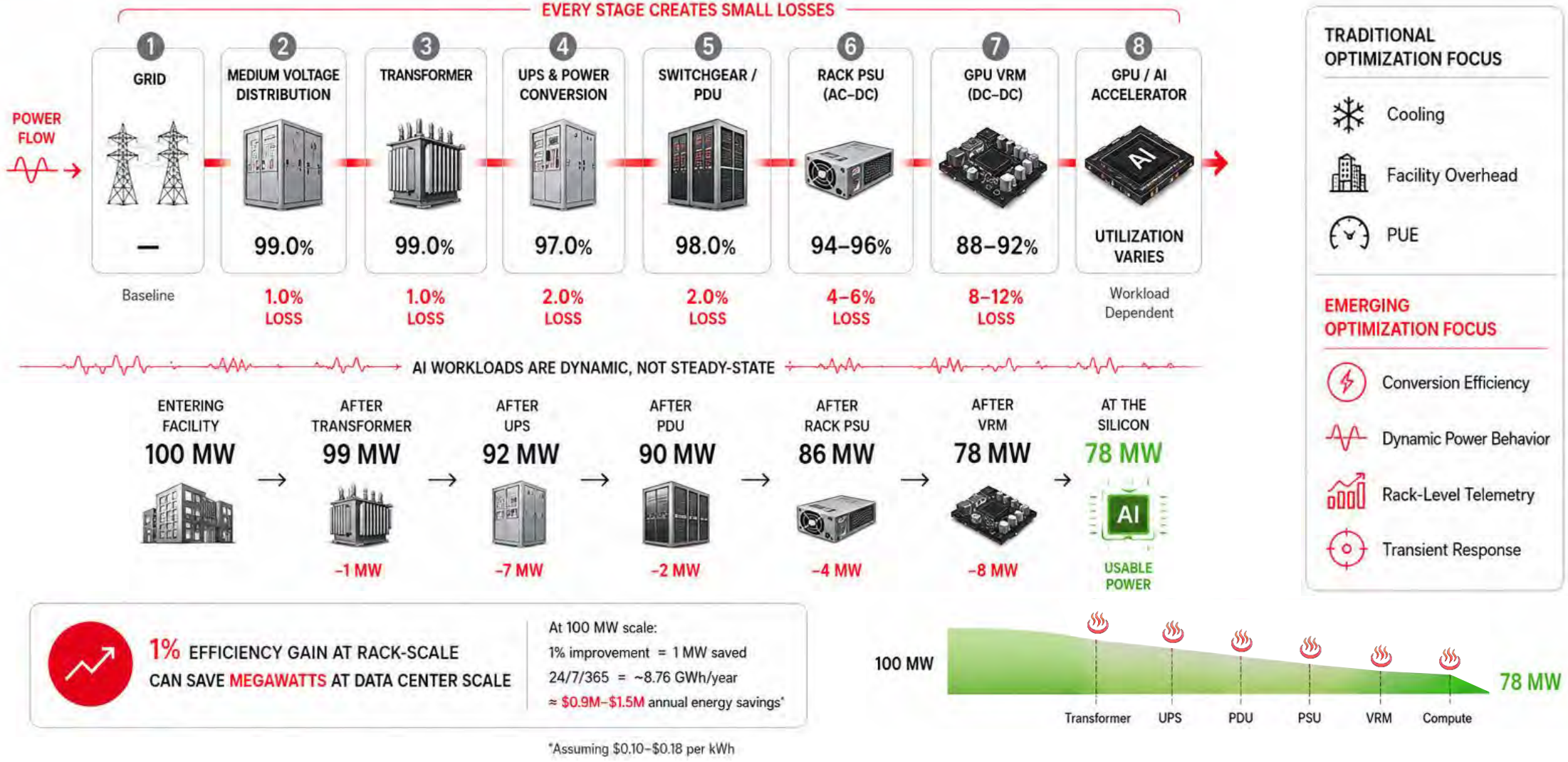
Other Tests

- Testing cooling system performance by simulating heat loads using power supplies and resistors

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Drill Down - Understanding Efficiency from Grid to Chip

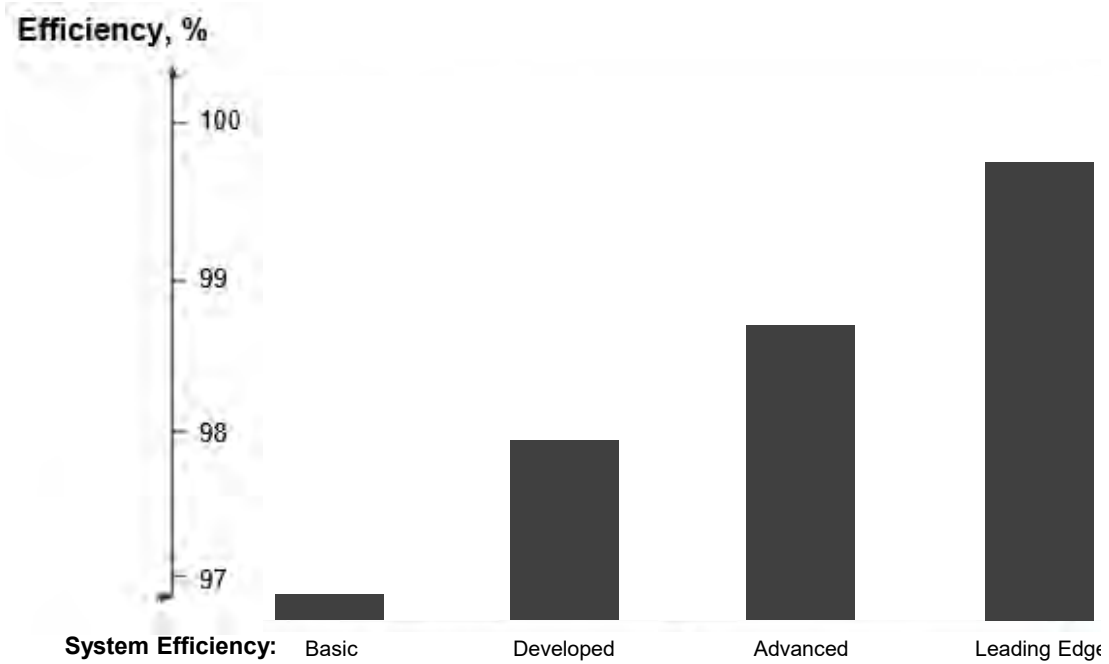
The Electron Journey



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Challenges of Measuring Efficiency

Accuracy Measurement Error Impact



Measurement Uncertainty can Overwhelm the Gain

Example:

99.5%
Measured Efficiency

±1%
Measurement Uncertainty

Possible True Efficiency Range:

98.5% **99.5%** 100.5%

The true efficiency could be either lower or higher than what you measured

…things to consider

- At 99% efficiency, a 1% power measurement error can completely hide the real system behavior
- Poor measurement accuracy can mathematically produce >100% efficiency

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Testing Data Center Power Conversion and Distribution Elements



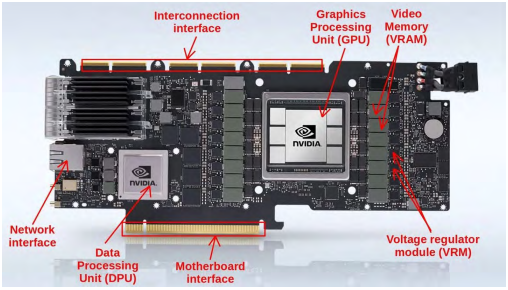
1 ph 240 Vac
3 ph 480 Vac



54 Vdc
± 400 Vdc
800 Vdc
> 800 Vdc (future)



15 Vdc
12 Vdc
6 Vdc
< 1 Vdc



AC/DC

AC Sources

E-Loads

DC/DC
IBC

DC Sources

E-Loads

PMIC
VRM

DC Sources

- GPU/CPU
- Server
- Compute

Power Design Tools	• Oscilloscopes and Probes	• DMMs	• Data Acq

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AC/DC Power Supply Unit (PSU) Shelf

Required for PSU Testing

- Integrated AC and DC power analysis
  with integrated AC and DC power disturbances (Load WF, Source WF)

SINGLE SOURCE on INPUT

AC Sources

Voltage ranges
- 240 Vac ph-ph 1Φ
- 208 Vac ph-ph 3Φ
- 480 Vac ph-ph 3Φ

Power ranges
- Up to 10 kW, 1 and 3Φ
- 30 kW, 3Φ
- 100 kW, 3Φ
- 300 kW, 3Φ
- 1 MW, 3Φ



Courtesy: Delta

SINGLE LOAD on OUTPUT

DC Eloads
- Require fast transient of 100A/µs
- At < 10 kW = Dissipative
- At > 10 kW = Regenerative

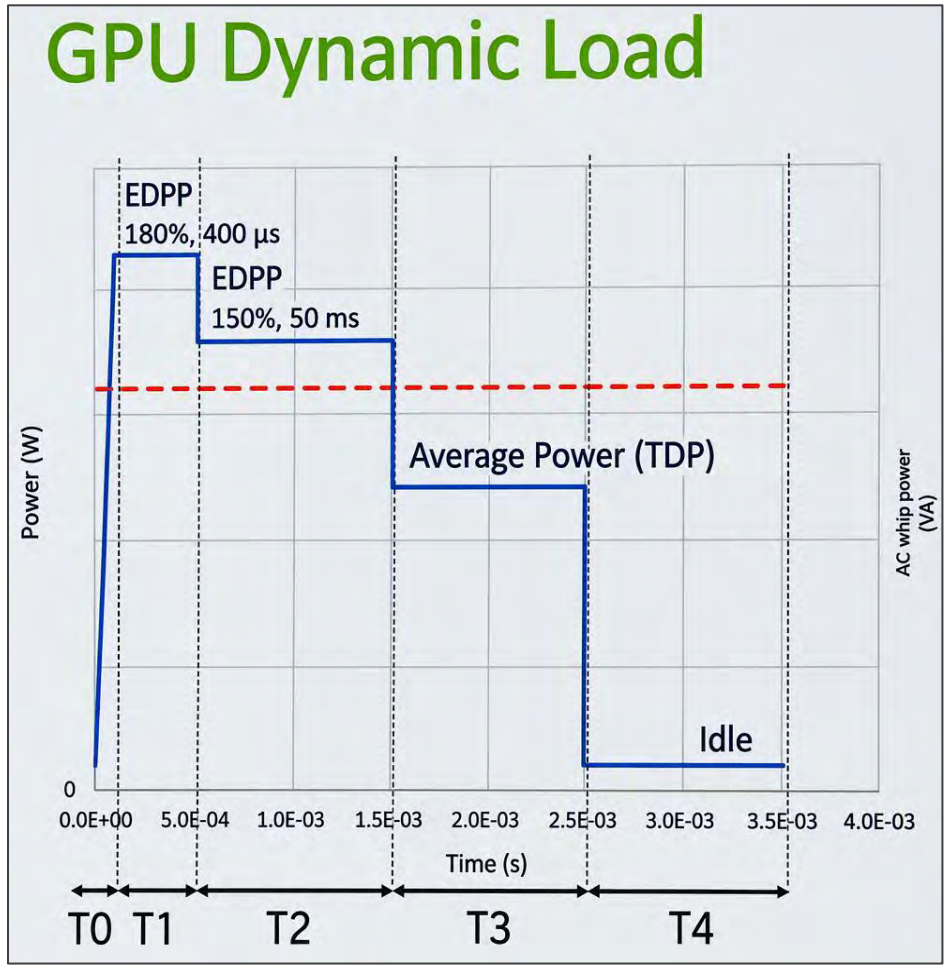
Voltage ranges
- 54 V
- +/- 400 V
- 800 V

Power ranges
- Up to 10 kW
- 30 kW
- 100 kW
- 300 kW
- 1 MW

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Data Center Server Rack Power Needs Fast Loads

High-Power, High-Speed Load Requirements to simulate the effects of GPUs on Server Rack Supplies



Key Characteristics of this EDPP waveform (from NVIDIA)

- Loading current used to check for voltage regulation
- Called EDPP (Electrical Data Peak Processing)
- Requires a load current risetime of 400 microseconds
- Total test pattern duration = 3.5 ms
- Requires 180% of nominal current (TDP = Thermal Design Power)

Interval	Duration per step
T0 → T1	**400 µs (risetime)**
T1 → T2	1.1 ms
T2 → T3	1.0 ms
T3 → T4	1.0 ms

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Intermediate Bus Converter (IBC) = DC/DC

Required for IBC Testing

- Integrated DC volts, amps, power measurement and analysis
- Integrated DC power disturbances (Load WF, Source WF)

SINGLE SOURCE on INPUT

DC Sources

Voltage ranges
- 54 V
- +/- 400 V
- 800 V

Power ranges
- Up to 10 kW
- 30 kW
- 100 kW



Courtesy: Flex

MULTIPLE LOAD on OUTPUTS

DC Eloads
- Require fast transient of 1000A/µs
- At < 10 kW = Dissipative
- At > 10 kW = Regenerative

Voltage ranges
- 6 V to 54 V
- 1 V to 5 V

Power ranges
- Up to 10 kW
- 30 kW
- 100 kW

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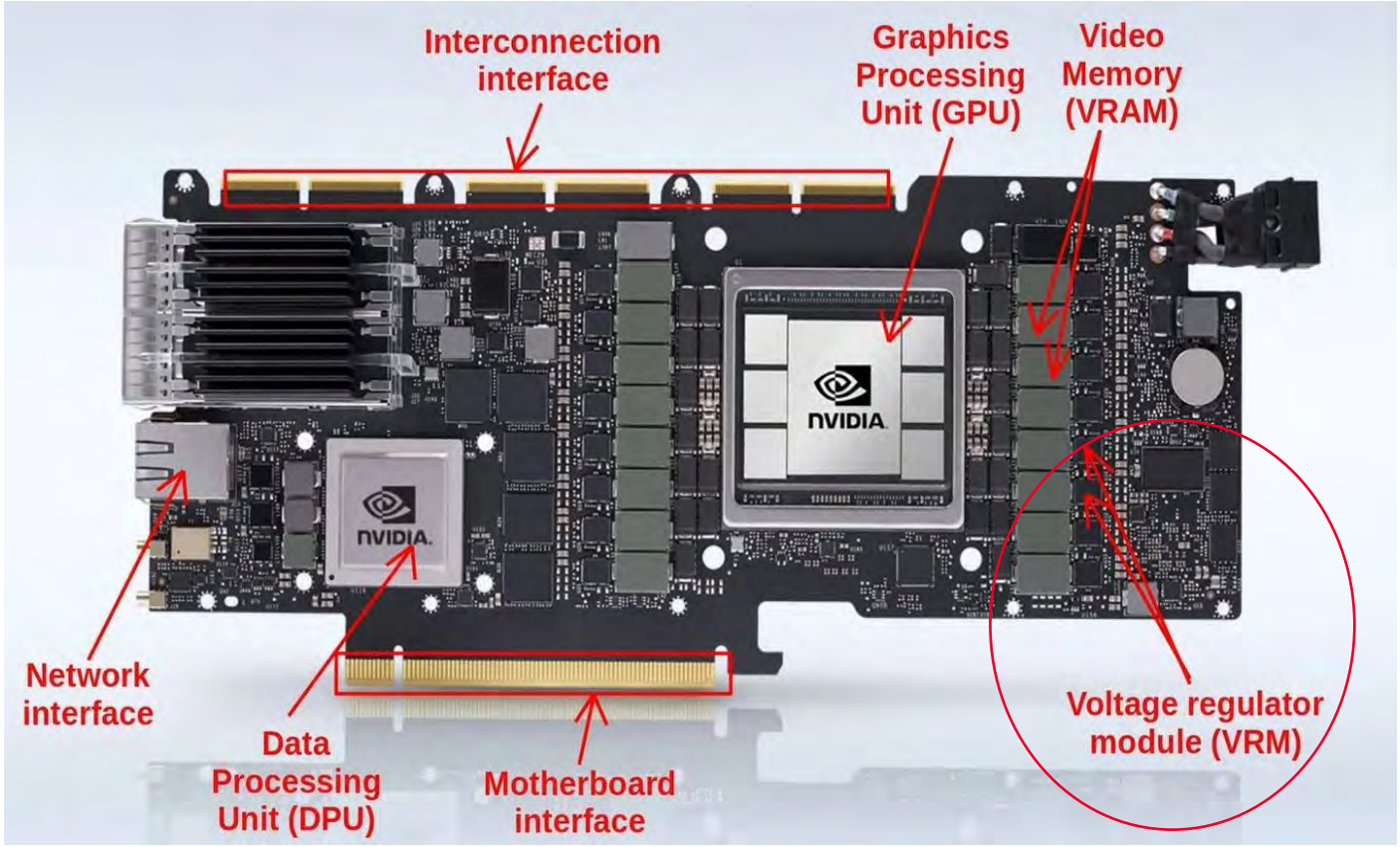
Voltage Regulator Module (VRM)
Power Management IC (PMIC)

SINGLE SOURCE on INPUT

- 1 to 5 V, 10-2000 A

SINGLE “LOAD” on OUTPUT

- Requires operating voltage of 0.2V to 1V
- Requires ultra-high slew rate load
  - 100 A per µs to 50 A per ns
- Typically, engineers must build their own loads



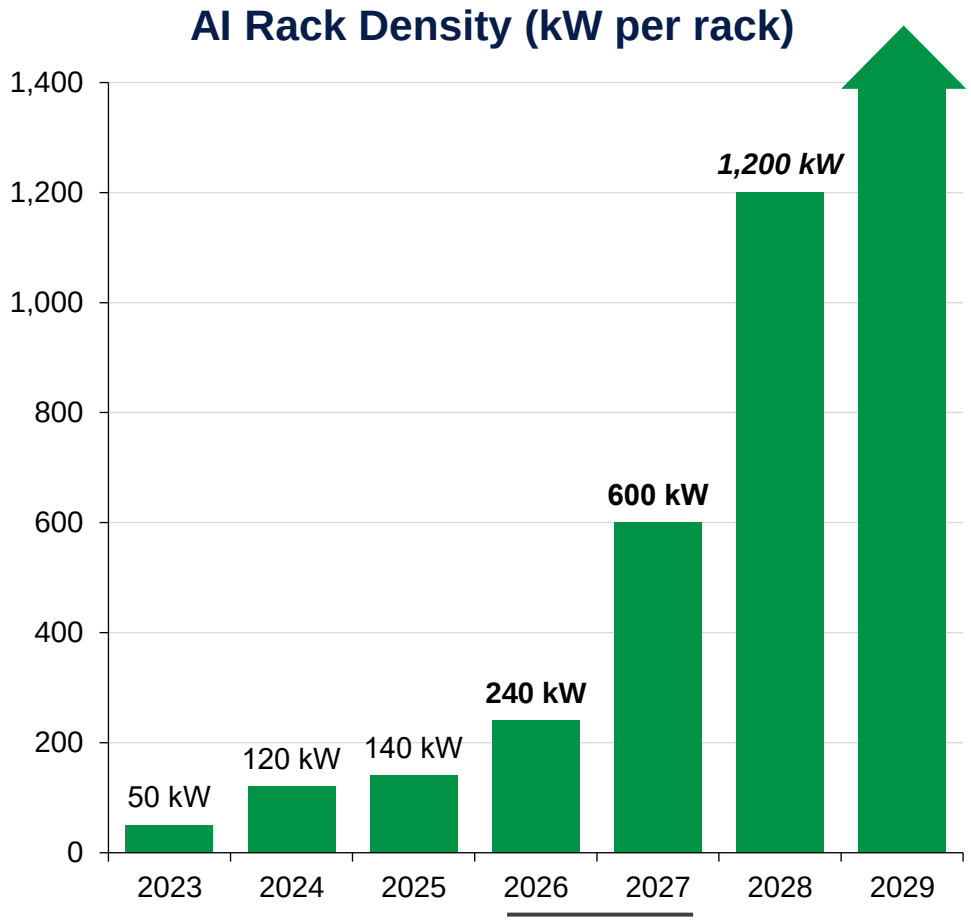
Courtesy: NVIDIA

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Looking to the Future

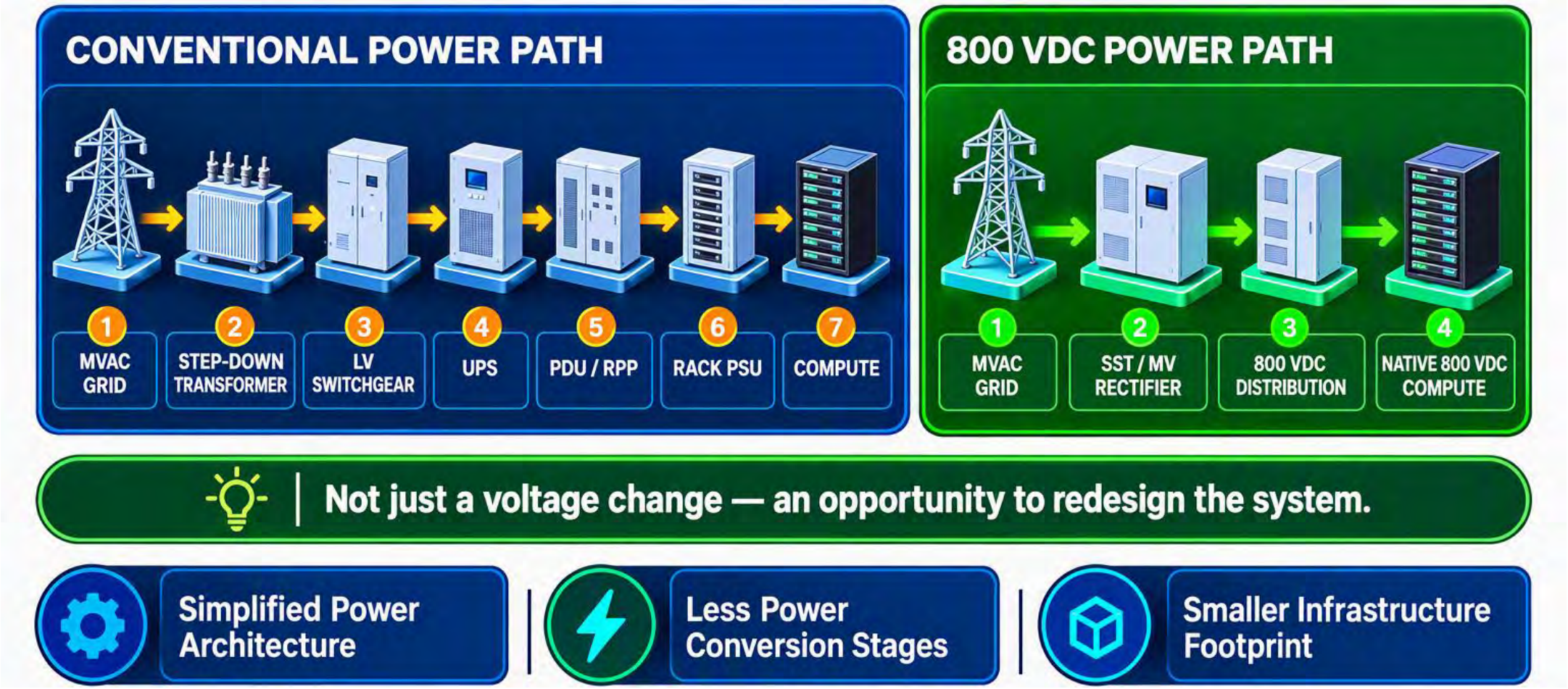
Challenges as AI Rack Density Increases

- Scale-up requires extremely low latency networking, thus forcing compute servers closer together in the rack
- Power and cooling compete for space in server racks
- Distributing 480 Vac 3Φ to racks faces current, copper size/weight/cost, heat and space limitations
- Distributing 54 Vdc in the rack faces current, copper size/weight/cost, heat and space limitations
- A new architecture is needed – move to 800 Vdc



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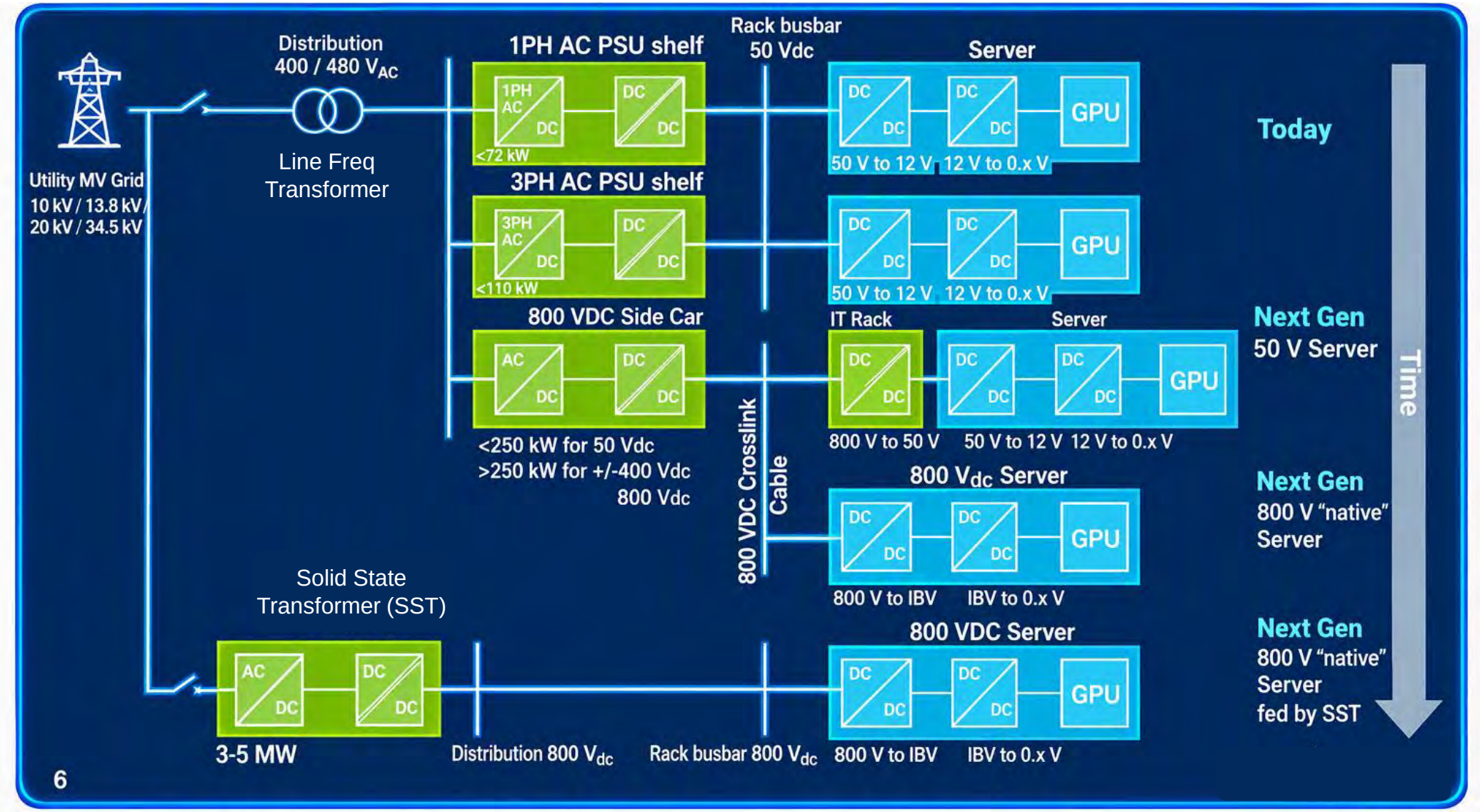
Evolving from Today to an 800 Vdc Future



Courtesy: Delta @ OCP

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800 Vdc Transition Plan: Transition Steps



Courtesy: Delta @ OCP

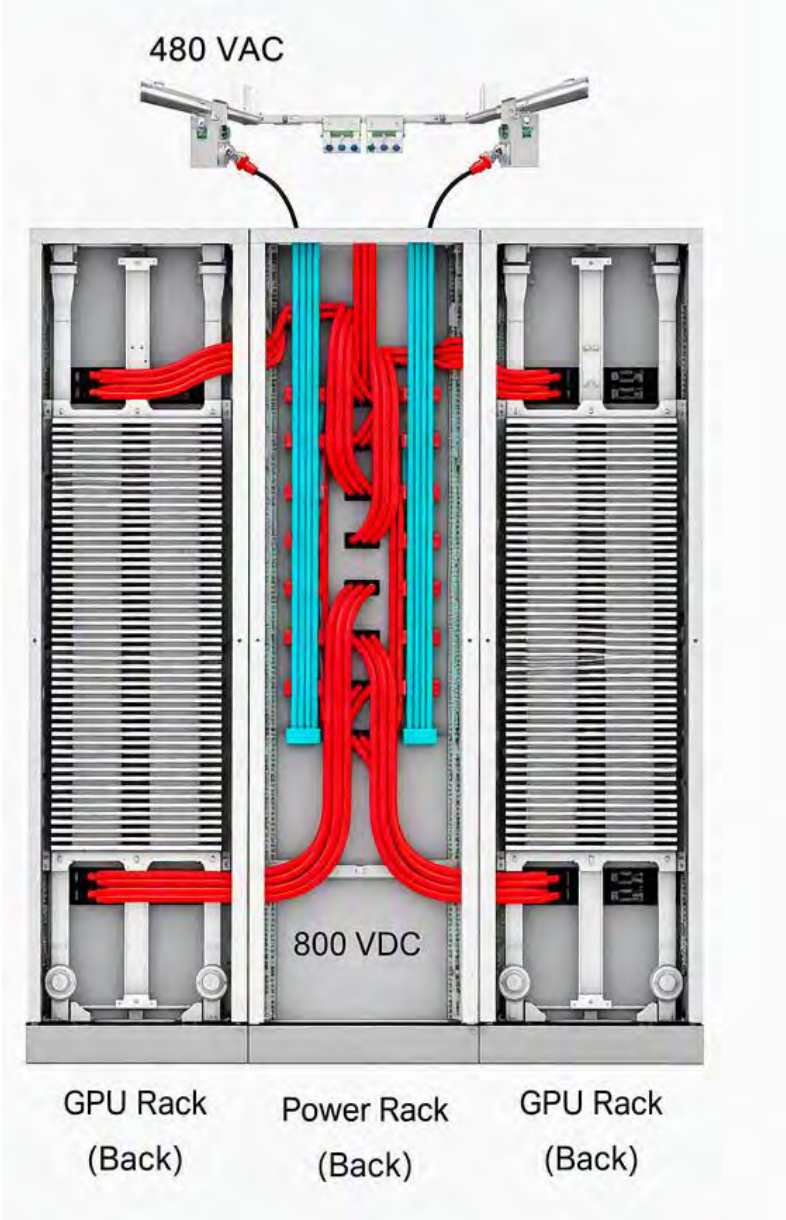
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Inside the Server Rack

Example of next evolutionary step

- Separate all power into its own power rack (aka sidecar)
- Power rack input = 480 Vac 3Φ
- Power rack output = 800 Vdc
- Distributes 800 Vdc inside the GPU (server) rack
- Inside Server Rack, use DC/DC to create Point-of-Load voltages (12V, 6V, 3V, 1V, etc)





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Let’s Not Forget About Cooling …

Cooling Unit for 3 MW of Servers

Dimensions	Height – 8’ Width – 6’ Depth – 4’
Weight	5000 lbs
Pipe size	6-in diameter connections
Coolant flow	800 gallons per minute *To compare:* *A car is 40 gallons per minute*
Power Consumption	24 kW (pumps, controls)



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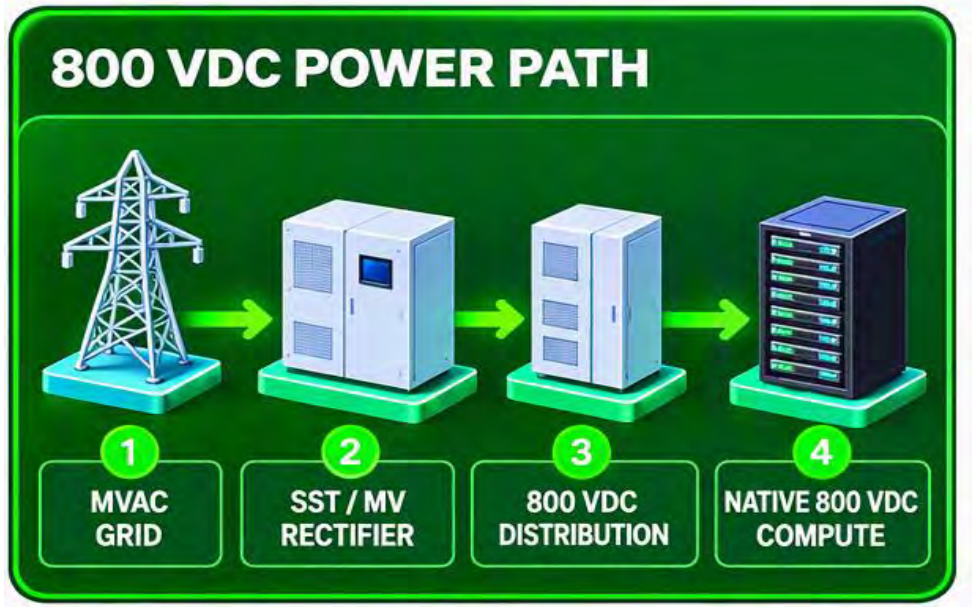
Summary

Power Backbone of AI Instructure from Grid to Chip

- AI data center demand is exploding: ~220 GW of power and ~$7T of spend by 2030
- Rack power is rising from 10–20 kW toward 1 MW and beyond, forcing a move from 54 Vdc to 800 Vdc
- Dynamic AI loads stress both the grid and the server power supplies
- Ever increasing compute power drives rack density and stringent requirements for power delivery and cooling
- Each conversion stage (AC/DC, IBC, VRM/PMIC) adds loss, so efficiency must be carefully measured and managed
- Accurate, fast sources, e-loads and measurement are essential to validate new architectures

220 GW
global data center power demand by 2030

800 Vdc
next-generation rack distribution voltage



>20%
of grid power can be lost before reaching the chip

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Questions?

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Power Test Instrumentation
Cell/Battery Test Systems
Charger Test Systems
Grid Compliance Test

Please feel free to contact me

Bob Zollo
Solution Architect for Power Testing

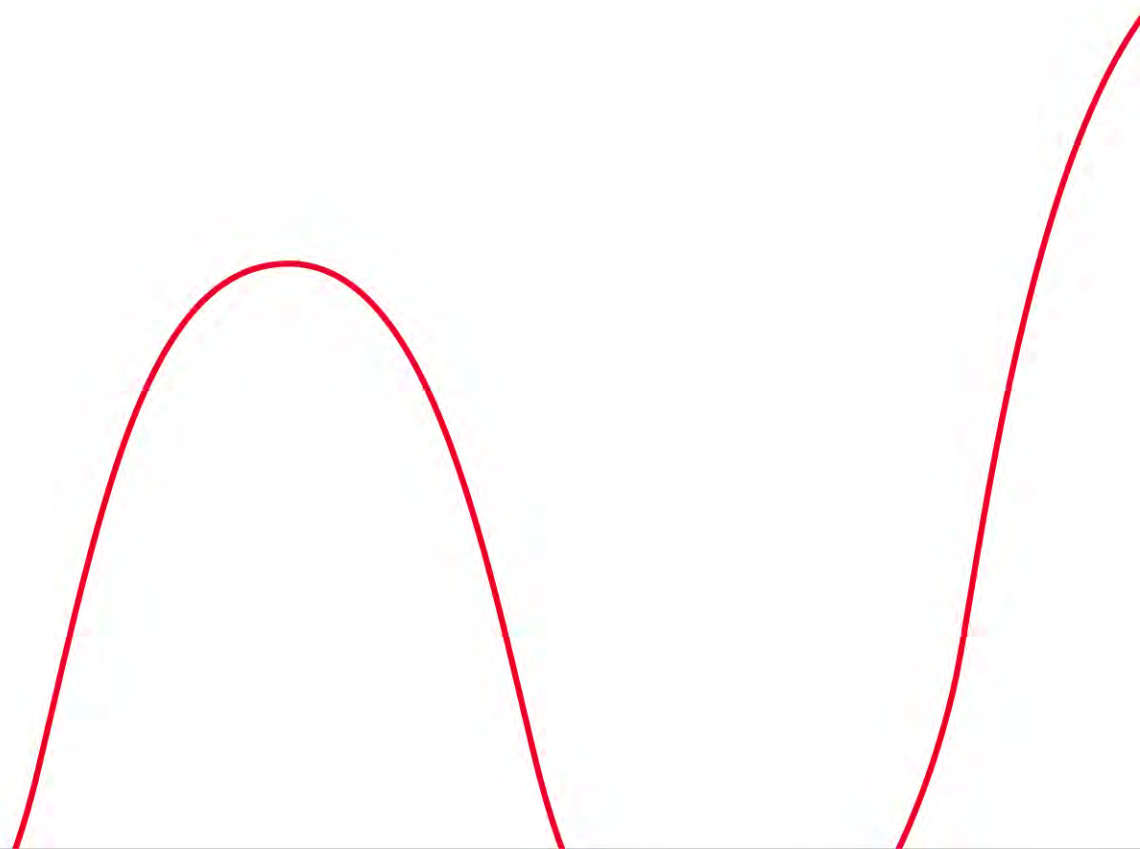
bob.zollo@keysight.com
+1-973-448-7208
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http://www.keysight.com

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