Report-back from INTELEC 2025

Key insights and trends

Lakshmi Priya Gandla

Researcher

RISE

Agenda

- INTELEC 2025- Context
- 99% Efficient Ultra- Compact Solid-State Transformers (SST) for future data centres.
- Evolution of Data Power Supply System in China.
- Circuit-AI: A Self-Hosted AI-Agent Language Model Framework

INTELEC 2025

- Leading global forum for advancing energy systems.
- What dominated the conference
  - Data centres.
  - Power conversion
  - AI into design and control
  - Microgrids and Space
- Tour of Texas centre for superconductivity
- Women in engineering.

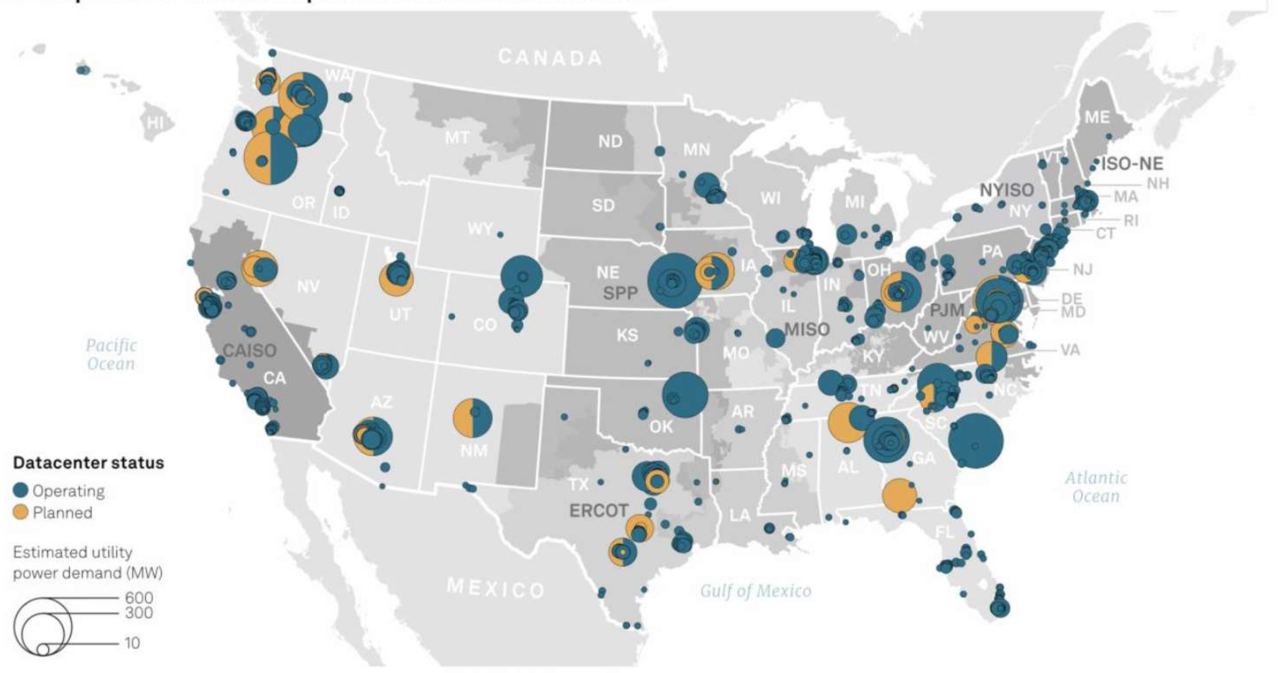
99+% Efficient Ultra-Compact Solid-State Transformers for Future Datacenters

Johann W. Kolar et al.
Swiss Federal Institute of Technology (ETH) Zurich
Advanced Mechatronic Systems Group
www.ams.ee.ethz.ch

Data centers are becoming Grid-scale infrastructure

- «Explosion» of AI — Hyperscale datacenters providing massive scalable could services
- Gigawatt- Power Levels — ≈7% of Global electricity demand / 130 GW (2% in 2022)

AI is expected to drive more power demand from datacenters



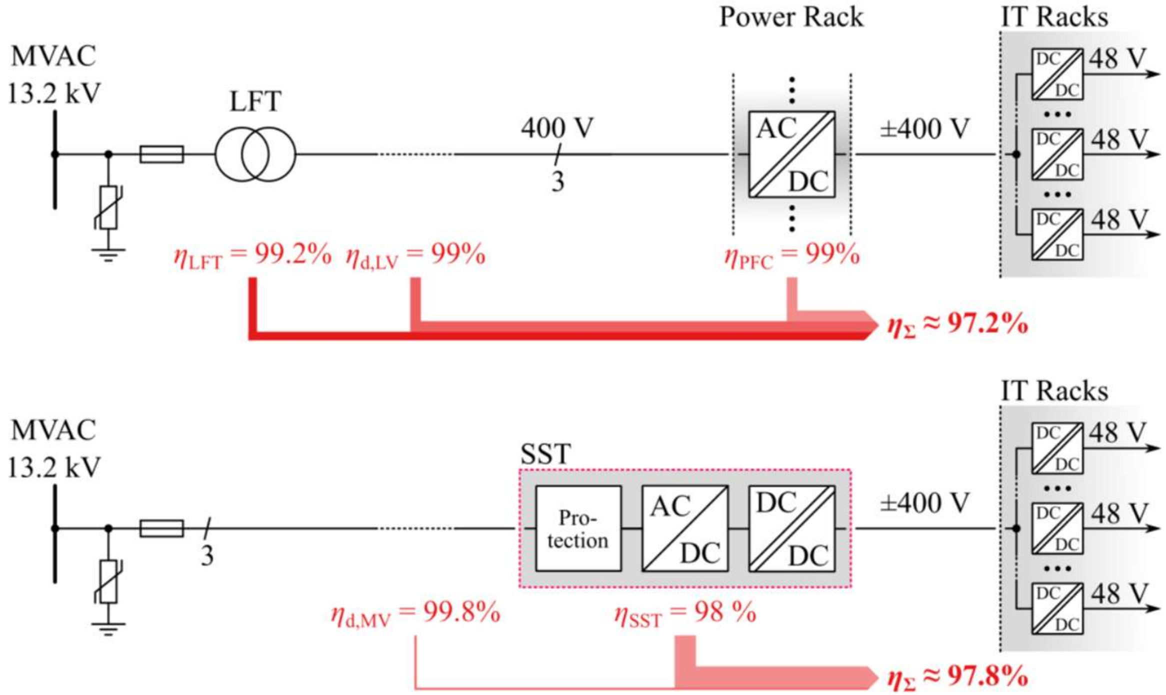
Sources: S&P Global Market Intelligence; 451 Research; S&P Global Commodity Insights

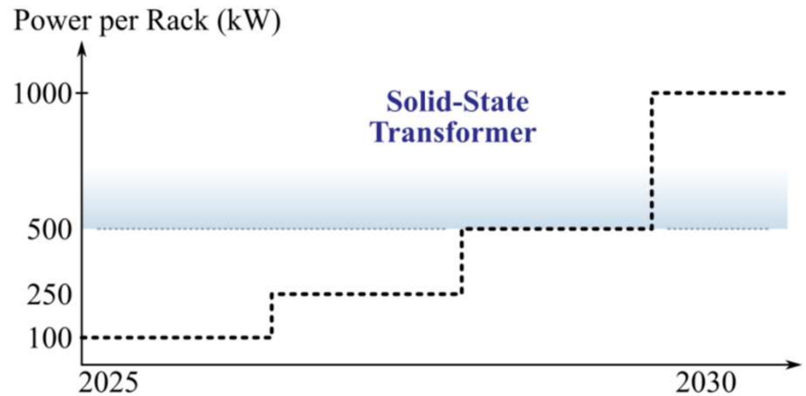
AI Racks are driving extreme power density

- Extreme Power Consumption of AI Supercomputing Modules Combining GPUs & CPUs
- 2 GPUs/1 CPU NVIDIA GB200 — 2.7 kW / Integrated Liquid-Cooling | 120kW per Cabinet (!)

Future 3-ΦMedium-Voltage AC/800V DC power supply

- Near Term — 3-*Φ*400 VAC or 480 VAC or 600 VAC Supply & AC//DC Power Racks / Side Cars incl. Battery Buffer Units
- Mid Term — Medium-Voltage AC Distribution & AC//DC Solid-State Transformers (SSTs) Replacing Power Racks

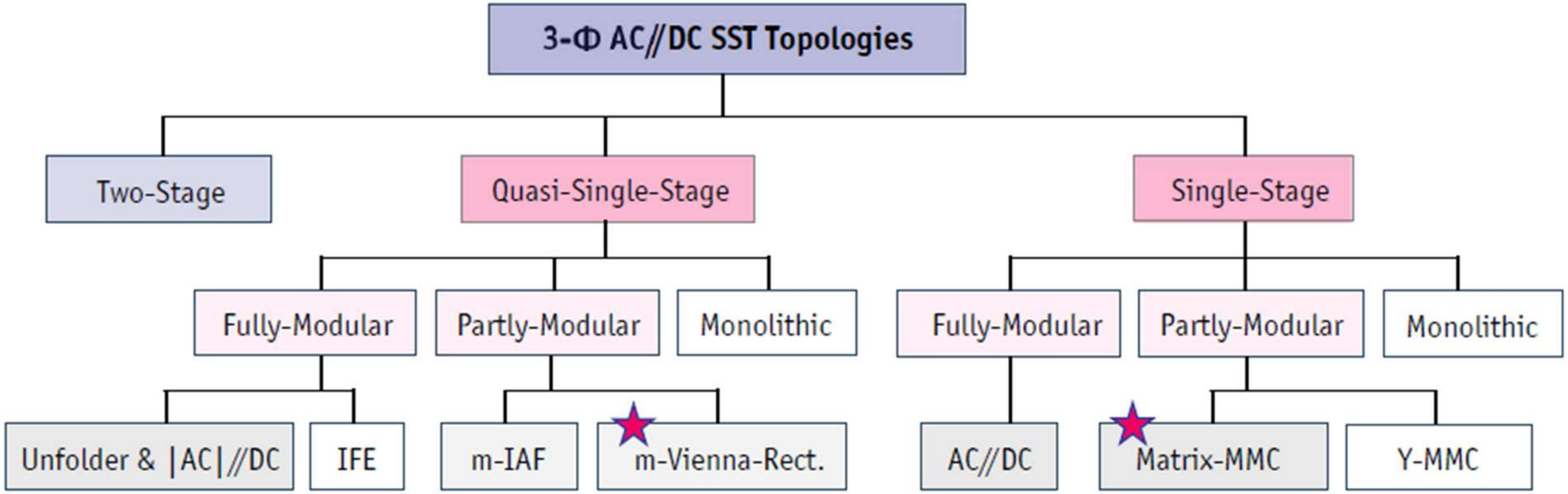




- IT Rack Power Levels Expected to Reach 1MW by 2030 — ±400 VDC or 800 VDC or ±750 VDC Replacing 54 VDC In-Rack Bus
- Medium-Voltage AC Supplied SSTs Feature ***ηd*** = 99,8% & Lower Busbar Cross Section vs. ***ηd*** = 98,9% of 400VAC System

Next-Generation SST Concepts

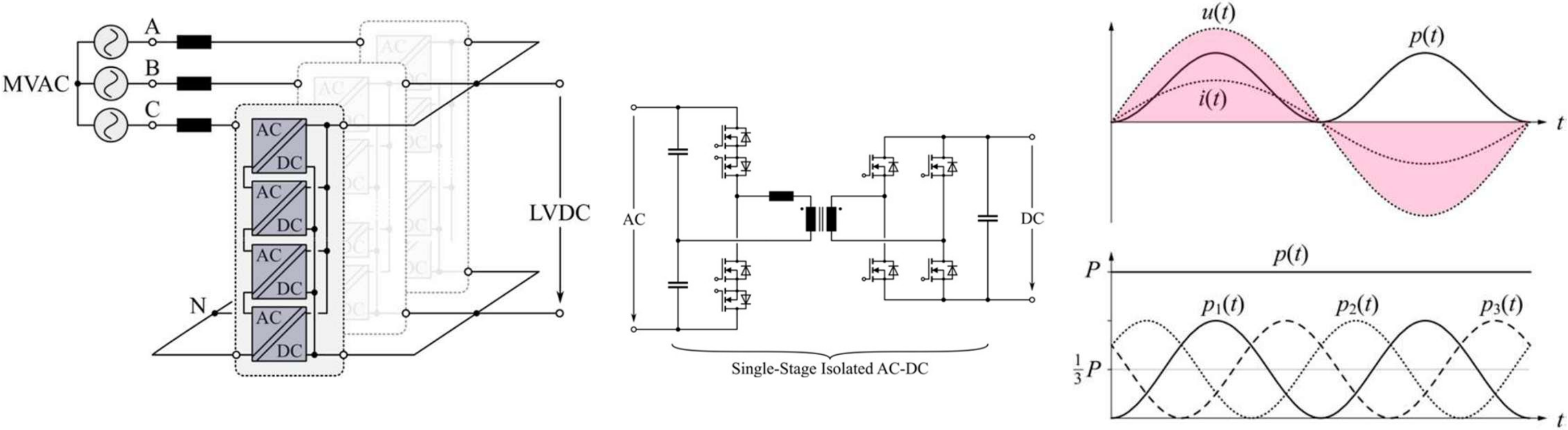
- Two-stage AC/DC-DC/ → Quasi-single-stage OR single-stage AC/
- Fully-modular topology →Partly-modular or Monolithic structure / Transformer scaling advantage
- IGBTs → SiC MOSFETs



- 99% AC//DC Power conversion Efficiency / 30% loss reduction
- 1MW/m3 Power density / factor 5...10 increase in compactness

3-Φ Phase-Modular Single-Stage AC//DC SST Topology

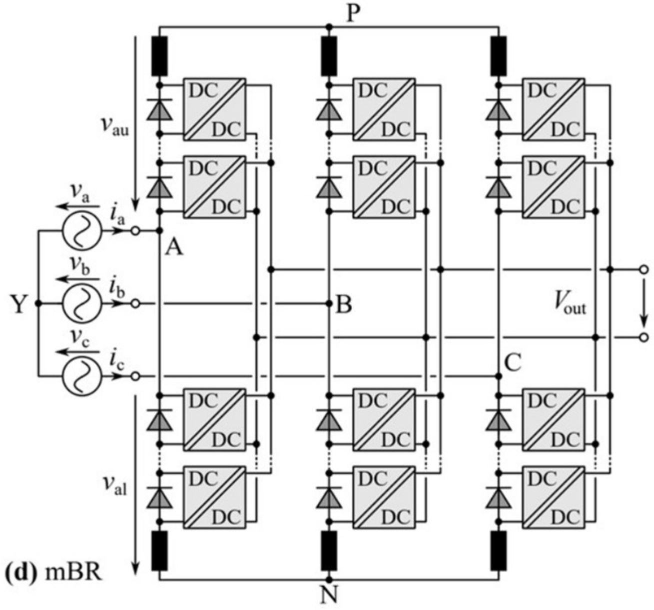
- AC-Switch-Based Dual-Active-Bridge-Type or Resonant AC//dc Converter Sub-Modules
- Half-Bridge Primary Minimizes Number of MV-Side Switches / Full-Bridge Provides Higher Control Flexibility

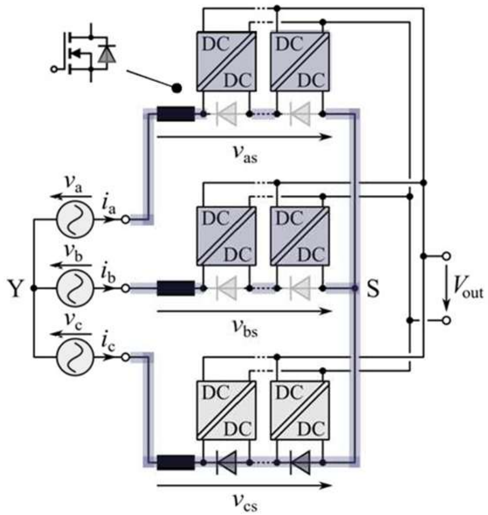


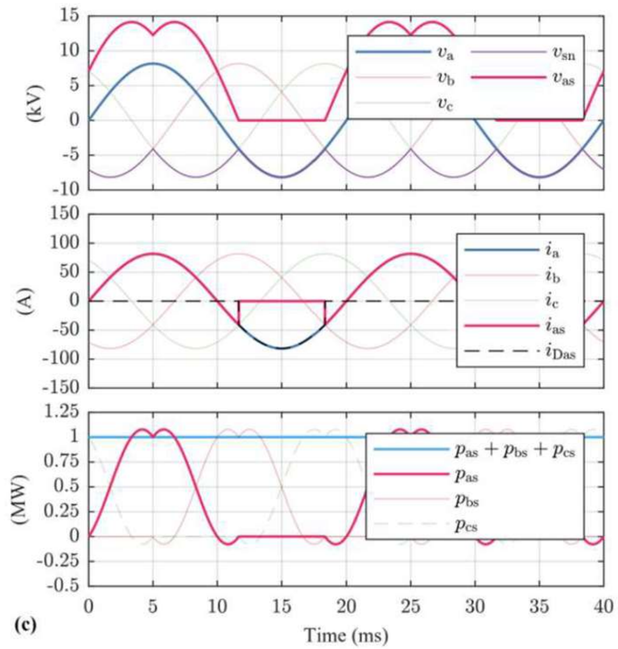
- 2x Grid Frequency Power Fluctuation of 1-Φ System / Rel. High Component Current Stresses
- 120° «Interleaving» of the Phases Results in Const. Instantaneous Overall Power Flow — No Storage Required (!)

Modularized 3-Φ Phase Bridge Rectifier & AC//DC Conversion

- Voltages Across Blocking Diodes Used as Unipolar Supply of DC//DC Stages.
- DC//DC Stage Operating Intervals Defined by the Mains Line-to-Line Voltages / Rel. Low Utilization.



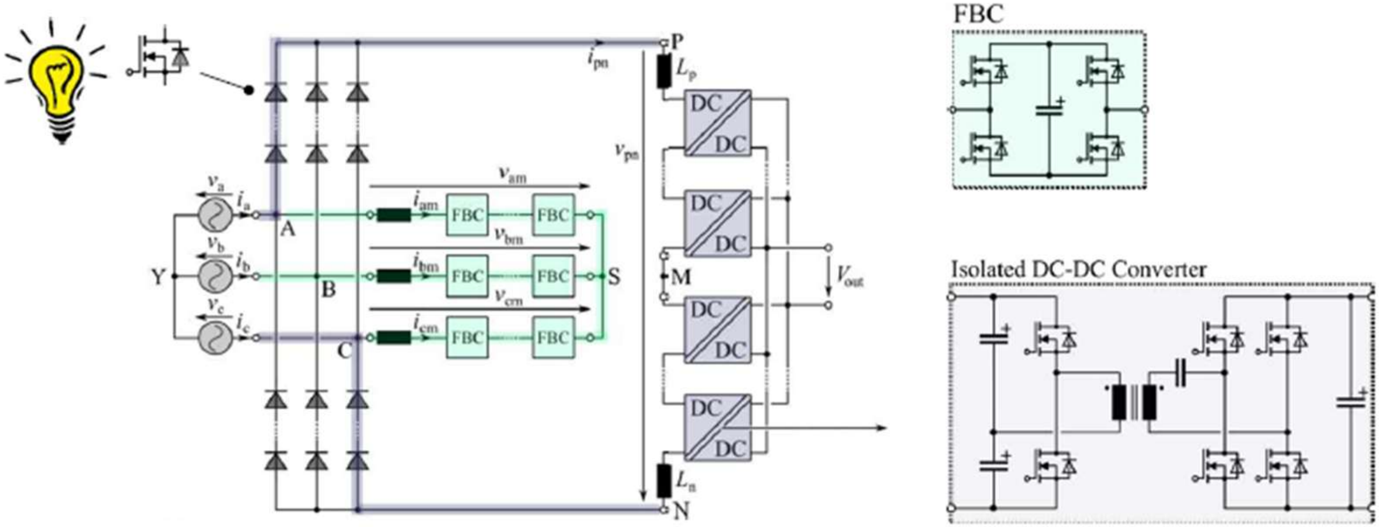




- Antiparallel Switches for Extension to Bidirectional Power Transfer
- Defined Voltage Sharing of Series Connected Diodes BUT Voltage Rating Defined by Line-to-Line Voltage

3-Φ Diode-Bridge & Active-Filter Front-End

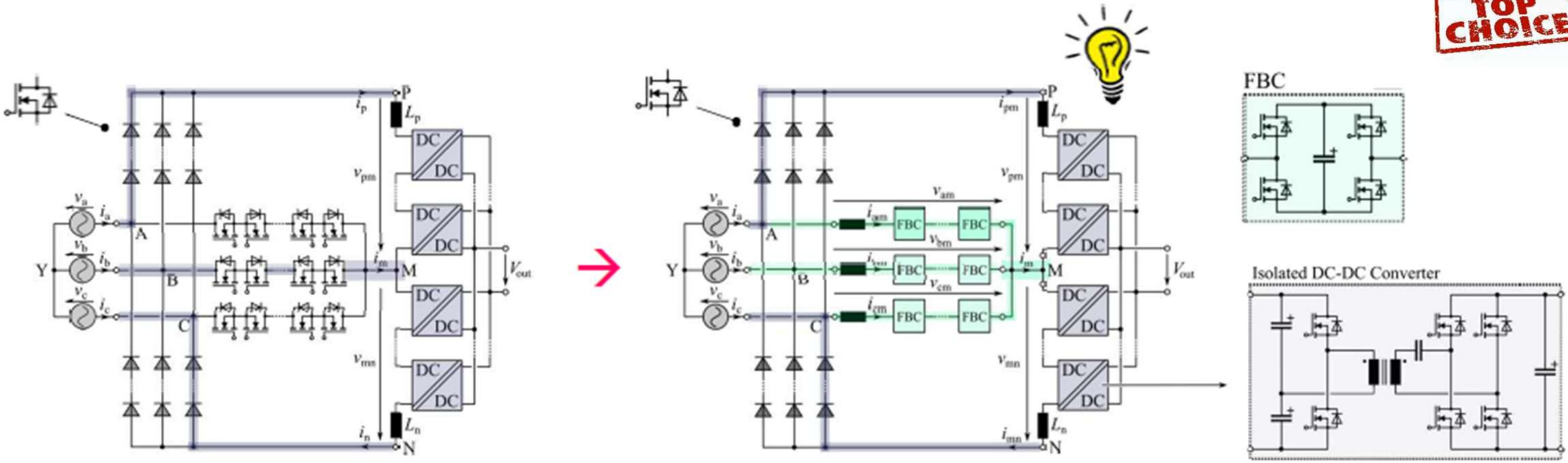
- Six-Pulse Shaped "DC" Input Voltage of DC//DC Converter String / High Converter Utilization
- AC-Connected Active Filter (AF) Ensures Sinusoidal Mains Current Consumption



- Lower Complexity Comp. to Three AC-Connected AC//DC Converter Strings
- High Reliability / Load Power Supply Not Dependent on AF Operation

3-Φ VIENNA-Rectifier-Type AC//DC SST

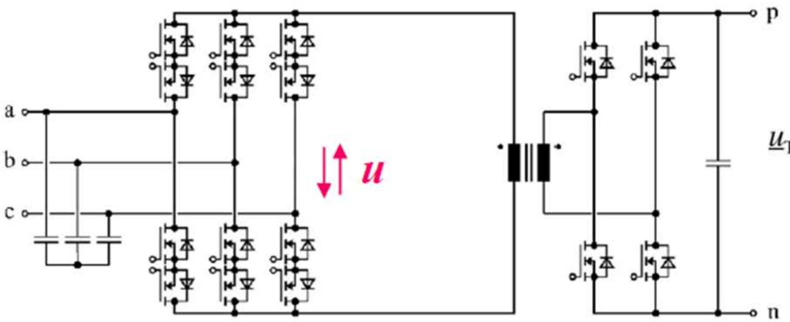
- Voltage Selector Switches of 3-Φ Unfolder Front-End Replaced by Full-Bridge Cells
- Active Voltage Balancing of Upper & Lower Half of DC//DC Converter String

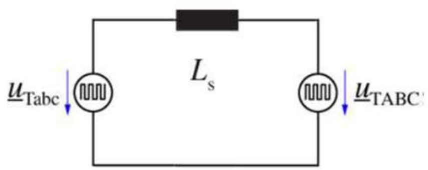


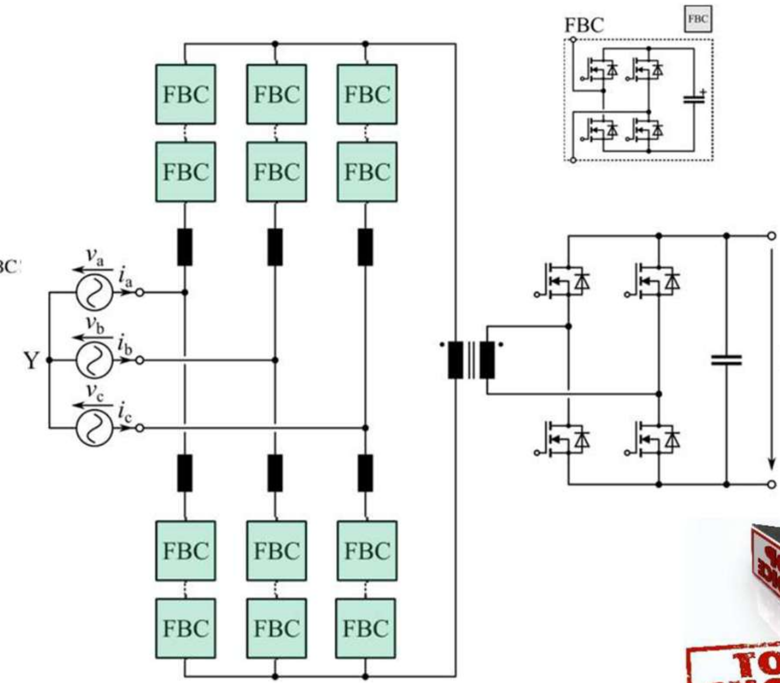
- Modularized VIENNA Rectifier Topology (mVR)
- String Voltages Def. by 1/2 Instead of √3/2 Mains Line-to-Line Voltage Amplitude / No AC-Switches

3-Φ MMLC-Based Matrix-Type AC//DC SST

- AC-Switches Replaced w/ Full-Bridge Cells Utilizing Unipolar Power Semiconductors / Voltage Scalability
- Modularity / Redundancy Limited to Power Semiconductors / Critical Components



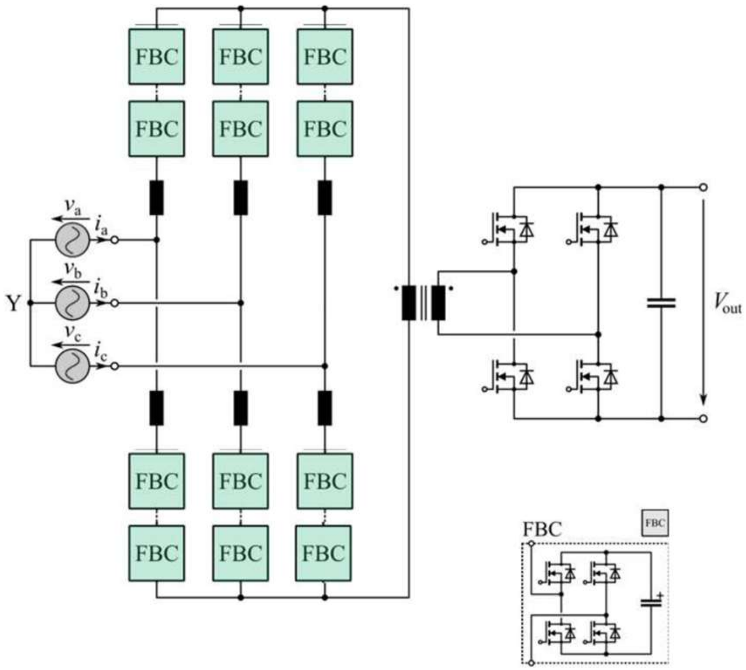


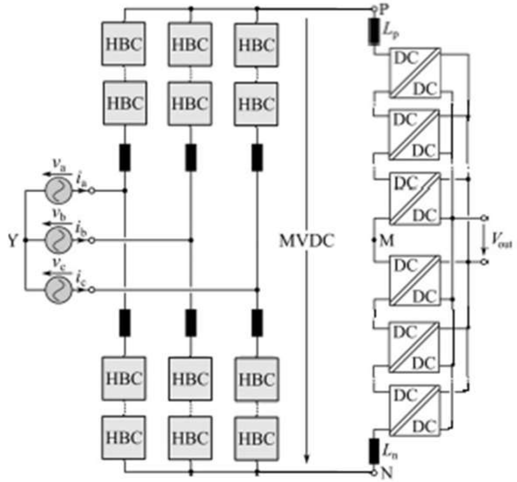


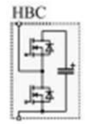
- Dual-Active-Bridge-Type Operation / No «Transformer Modularization Penalty» (!)
- Output-Side Current Splitting to Parallel Branches — Matrix Transformer Concepts

3-Φ Direct & Indirect MML-Based AC//DC SST

- Indirect Approach Features Higher Control Flexibility & Higher Transformer Utilization
- Overhead / Underground Coupling of High-Power Front-End to Multiple ±10…20kVDC //±800VDC DCX-Stages







- Comparative Evaluation of Power Semiconductor Stresses / Protection / Reliability etc. Still to Be Clarified

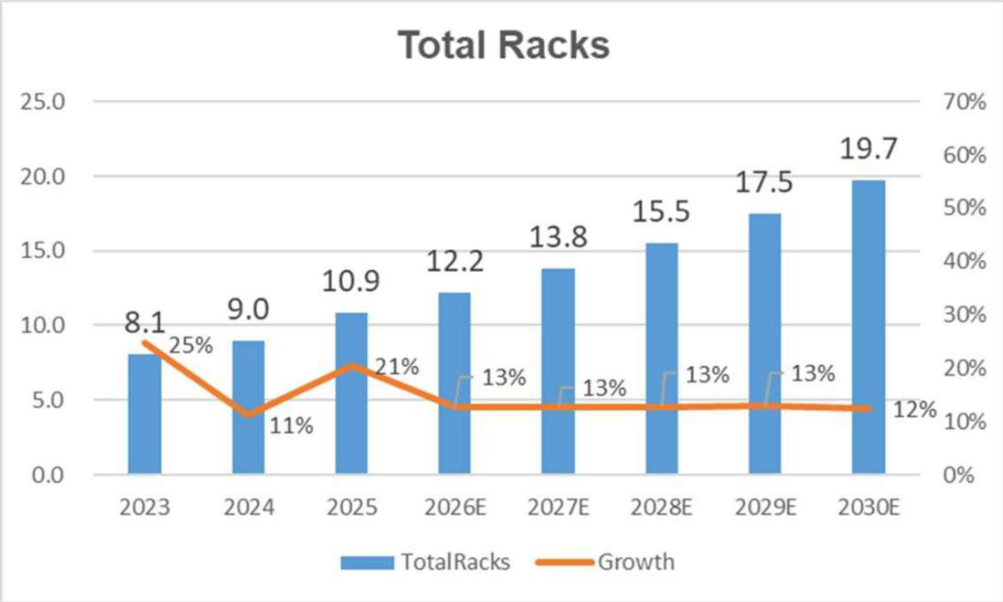
Summary

- AI-driven data centers are pushing **rack power toward hundreds of kW**
- **99%+ efficiency SSTs are technically feasible**, enabled by:
  - Wide-bandgap devices (SiC)
  - High-frequency isolation
  - 3-phase architectures
- **System architecture matters more than individual topologies**
  - Partial modularity often outperforms full modularity
  - 3-phase designs reduce energy buffering needs
- SSTs are **not yet plug-and-play**
  - Protection, reliability, and cost remain open challenges
- **Clear direction**: SSTs enable **medium-voltage distribution inside future data centers**

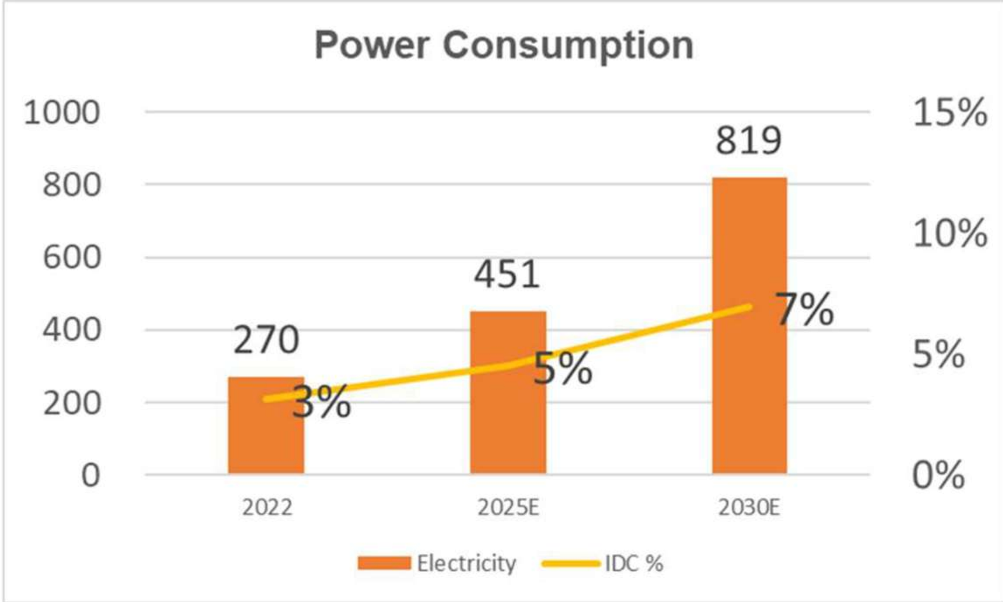
Evolution of Data Center Power Supply System in China

Prof. Dehong Xu, Dr. Yenan Chen
Zhejiang University, China

Data centers in China



China Total Racks(million)



Electricity Consumption Estimation

- In August of 2025, Rack count reach 10.9 millions. Estimated power capacity:70GW
- Total rack count will be doubled by 2030

- 2022: IDC consumes 270TWh, 3% power consumption
- By 2030, IDC estimated to reach 7% of China power consumption

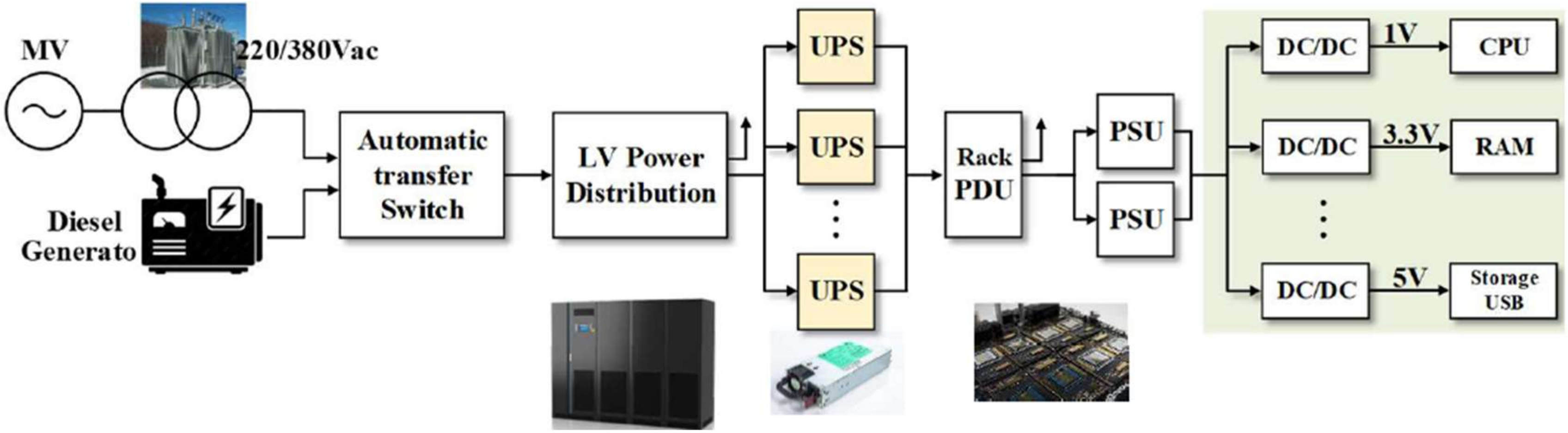
Requirement to Data Centers

- Power consumption of Data centers causes public concerns on its impact on environment
- On the other hand, it is a key infrastructure of modern society

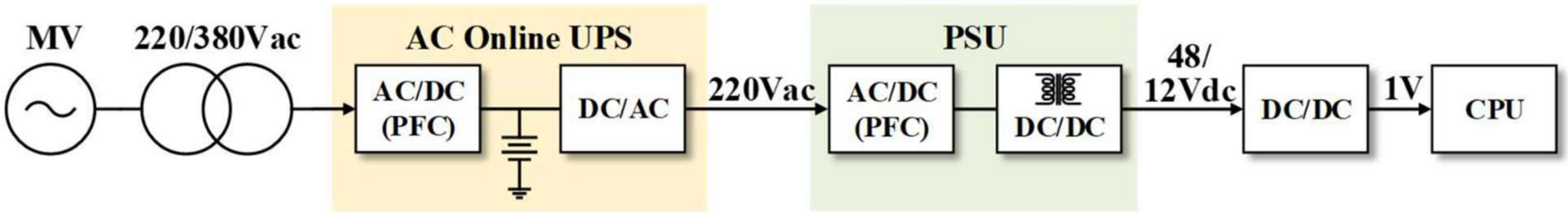
Demand

- Energy efficiency
- Green
- Reliability

AC UPS Power Architecture



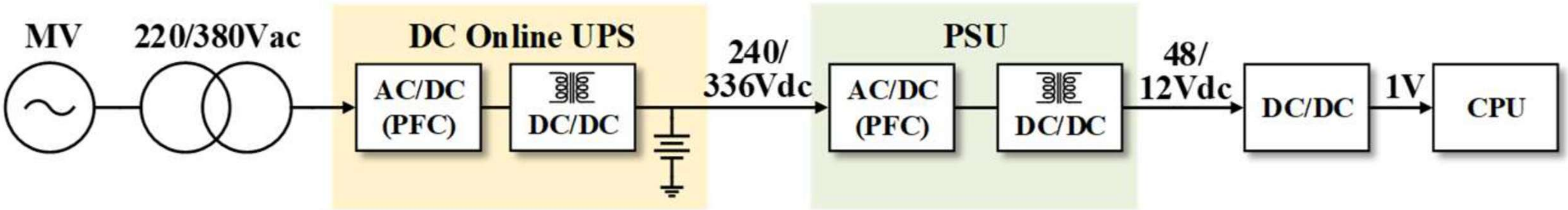
AC UPS power architecture



Simplified figure of AC UPS power architecture

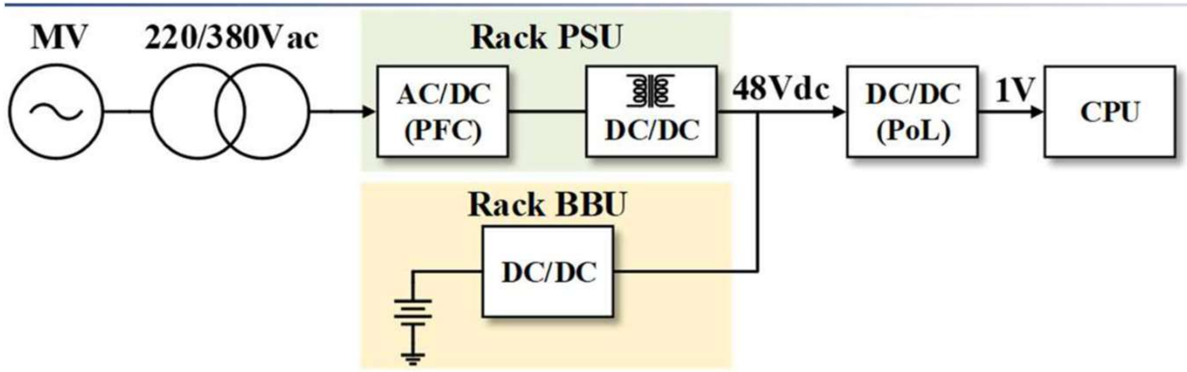
- AC UPS power architecture has existed over decades
- 80% Market share in China

HVDC Power Architecture



HVDC power architecture

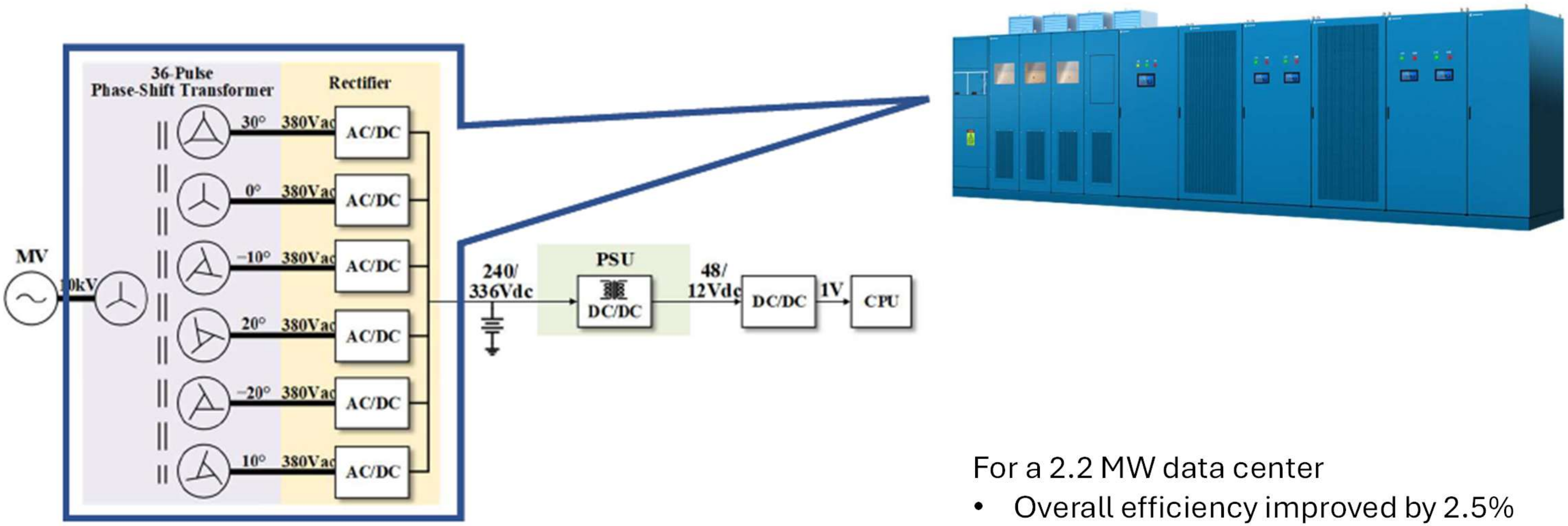
- 240Vdc/336Vdc DC UPS occurred
- Skipping inverter stage of the UPS, the battery is closer to servers. more reliable
- 240Vdc is compatible to AC PSU



48V DC power architecture

- 48V DC Architecture from Open Computing Project (Google) , integrating all in the rack, drives 48V ecosystem
- Fewer conversion stages, higher efficiency
- Battery capacity limited by shelf volume

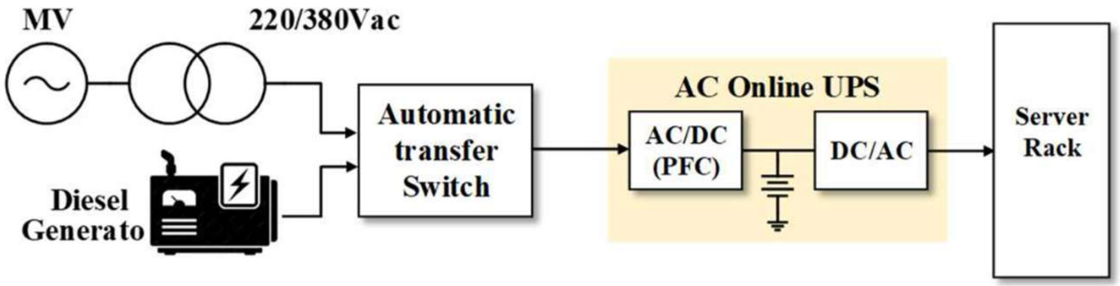
MV Architecture with Phase-shift transformer



For a 2.2 MW data center

- Overall efficiency improved by 2.5%
- 30% power supply space saving

Architectures for Green



- Global 60GW diesel engine for data centers
- high maintenance
- Try to replace diesel with battery, hydrogen, natural gas

Fuel type	CO2 emission	Fuel cost/diesel
Diesel	100%	100%
Natural gas	60%	50-75%
Hydrogen	10%	170%

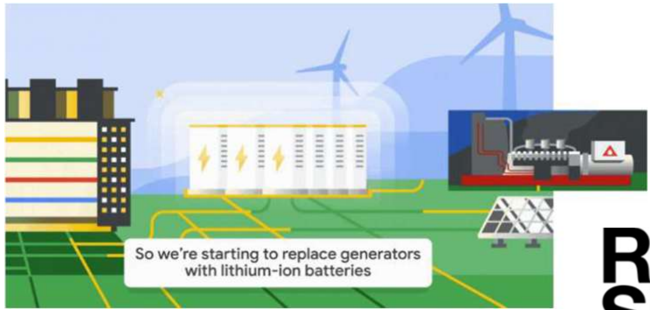
Microsoft: Hydrogen Fuel Cell

Microsoft used hydrogen fuel cells to power a data center for two days straight

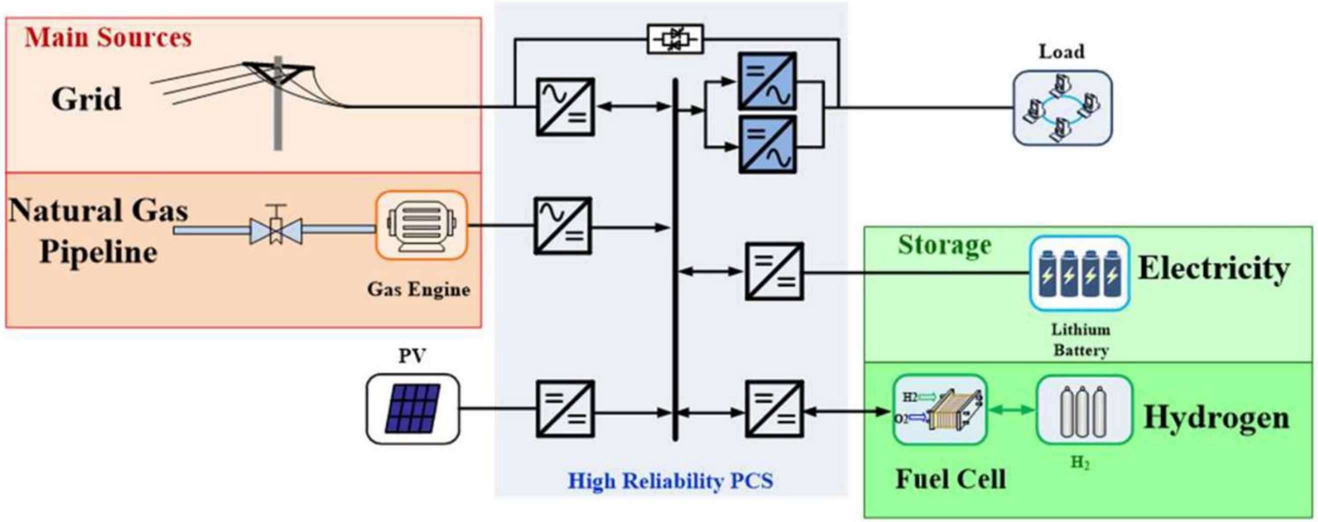
Microsoft announced Monday that hydrogen fuel cells powered a row of its datacenter servers for 48 consecutive hours, bringing the company one step closer toward its goal of becoming "carbon negative" by 2030. Microsoft is exploring how the clean technology could be used to fuel more aspects of its operations.

Microsoft used hydrogen stored in tanks on trailers parked outside a lab near Salt Lake City, Utah, to fuel hydrogen fuel cells that powered a row of datacenter servers for 48 consecutive hours.

Google: Battery + PV



Green & Resilient Power: China's Direction



Super-UPS = Double energy sources: Utility +Natural Gas + Redundant Power Conversion + Renewable integration

- Resilient to fail Resilient to failures of energy infrastructures
- Eliminate diesel engine
- Renewable integration to 750Vdc bus
- Standardized Conversion Units to build redundant power conversions of energy infrastructures

Standardized Conversion Unit

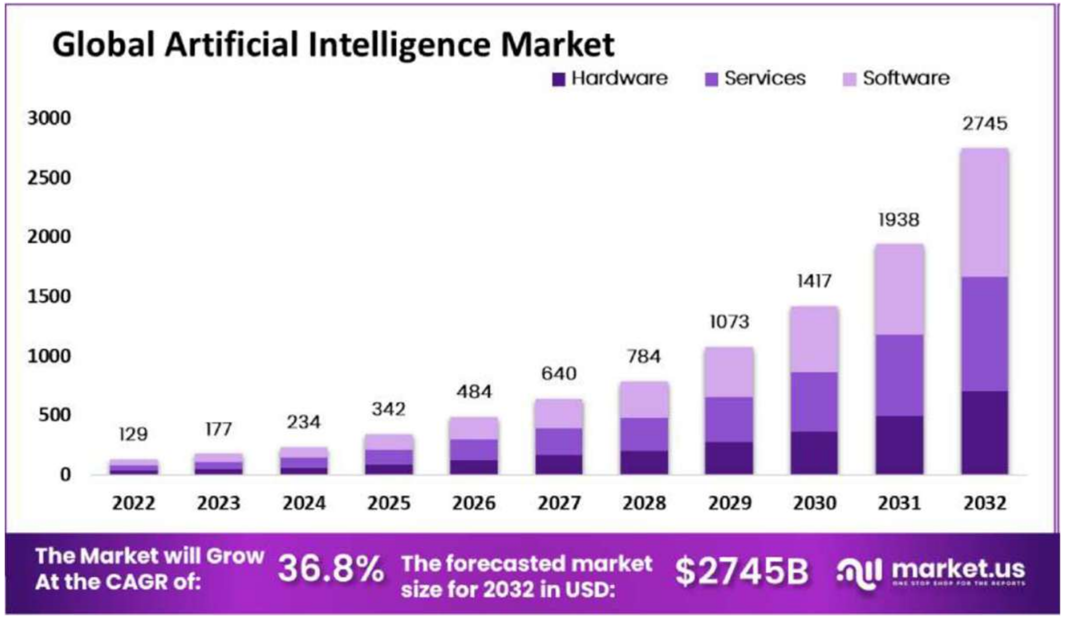
Item	value
Power capacity	100kW
Input voltage	380V
Output voltage	750V

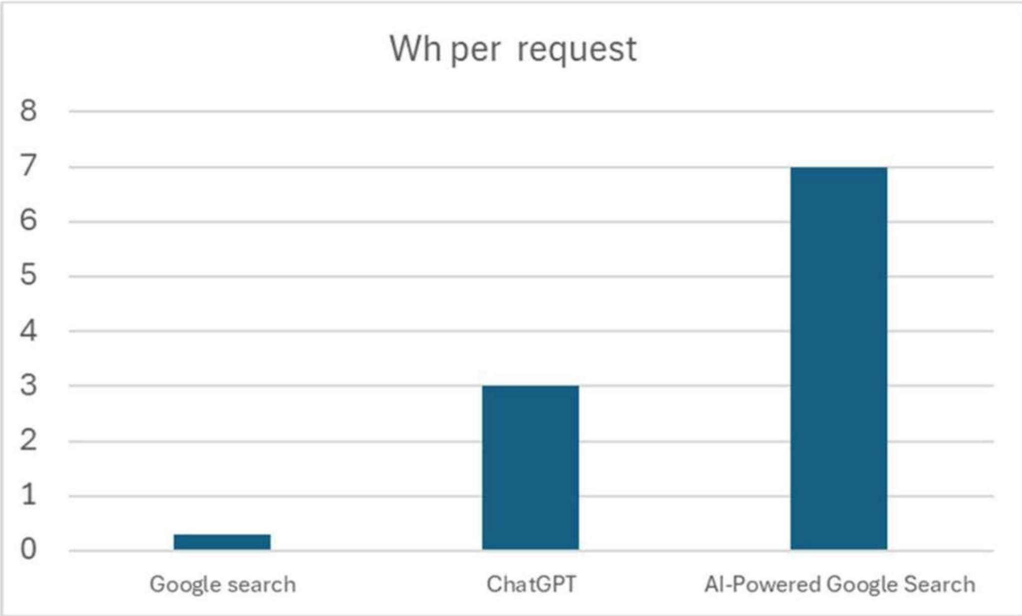
Item	value
Power capacity	30kW
Input range	200-400V
Output voltage	750V

Control Rack   Conv. unit rack   PDU

Conversion equipment

AI Accelerates Growth of Data Centers



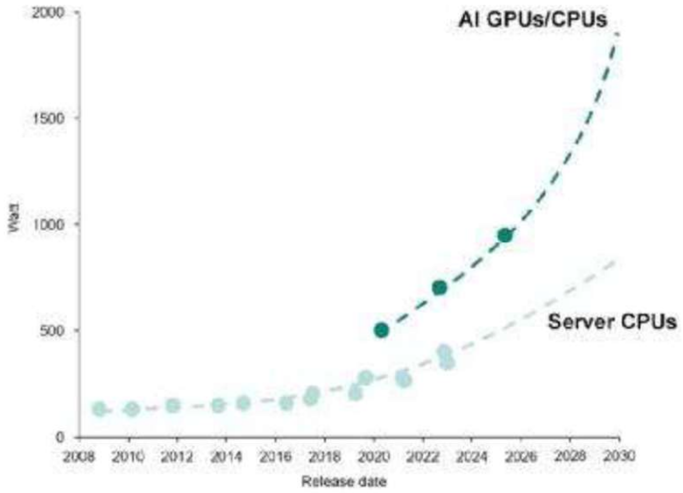


- World AI Market CAGR 36.8%
- $ 1.4T market by 2030

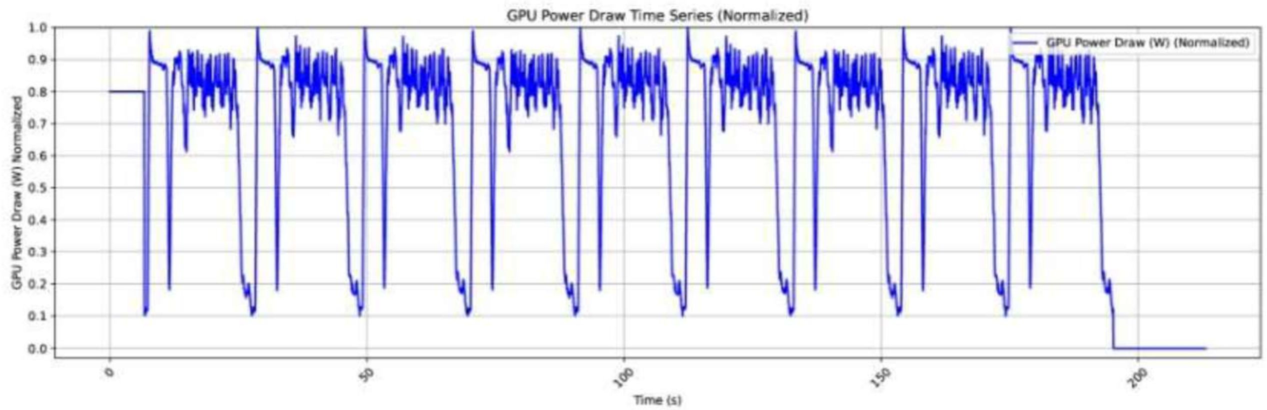
Wh/ChatGPT request=10 * Wh/ Google request

- AI drives the rapid growth of data centers
- Power demanded by AI grows explosively

Power Consumption of GPU load



AI GPU vs. CPU



Power readings from a training job on DGX-H100 racks

- GPU power will increase to 2kW in 2030
- Power for Sever Rack will increase from 15kW to 500 kW in a few years
- Power density of Sever Rack brings changes: power system architecture including DC bus voltage, conversion topology, new devices applications and cooling etc.
- GPU rack low-frequency load variation up tens of seconds is challenge to the utility

Summary

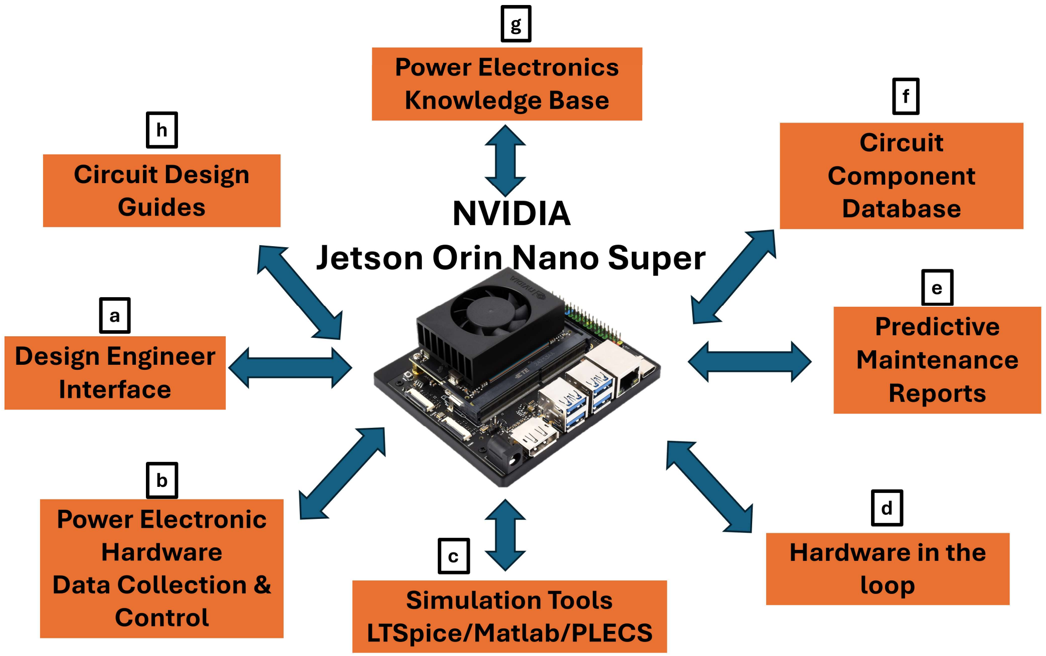
- Demand for digital services (AI, cloud computing, etc.) is growing explosively, driving the rapid growth of data centers
- High rack power due to AI will cause big change to PSU, VRM power conversion, cooling technique
- Load change in LLM training process will cause large disturbance to the grid. Cost- effective way is needed
- Energy efficiency, system resiliency, integration of renewables and cost will continuously push evolution of power system architecture and power electronics conversion, adoption of wideband-gap semiconductor devices and other new technology

Circuit-AI: A Self-Hosted AI-Agent Language Model Framework for Control Loop Implementation and Simulation

Vishwam Raval, Mohamed Zeid, Prasad Enjeti
Department of Electrical and Computer Engineering
Texas A&M University, College Station, TX, USA

Why AI in Power Electronics Now?

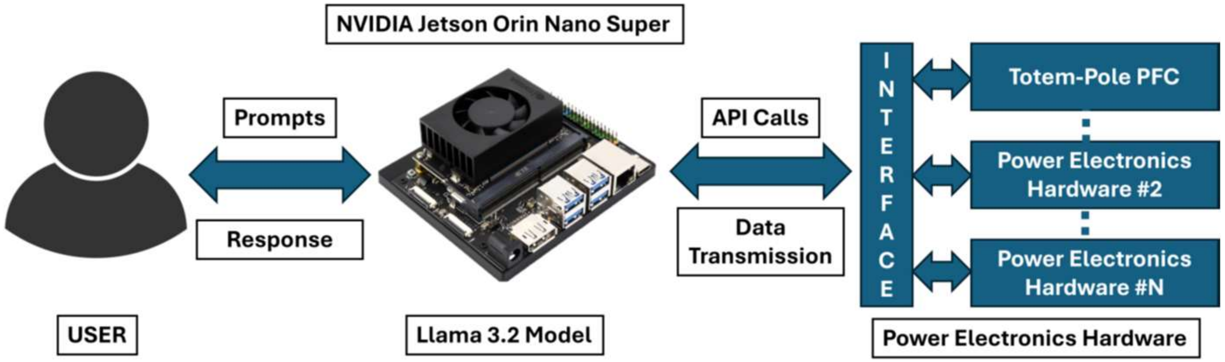
- Power electronics systems are becoming **more complex**: higher power, tighter control, faster iteration cycles
- Engineers rely heavily on **simulation, control tuning, and digital twins**
- Today's workflows are **tool-fragmented** (MATLAB, LTspice, HIL, scripts)
- This creates **time overhead, errors, and slow iteration**



Circuit-AI architecture overview

What Is Circuit-AI?

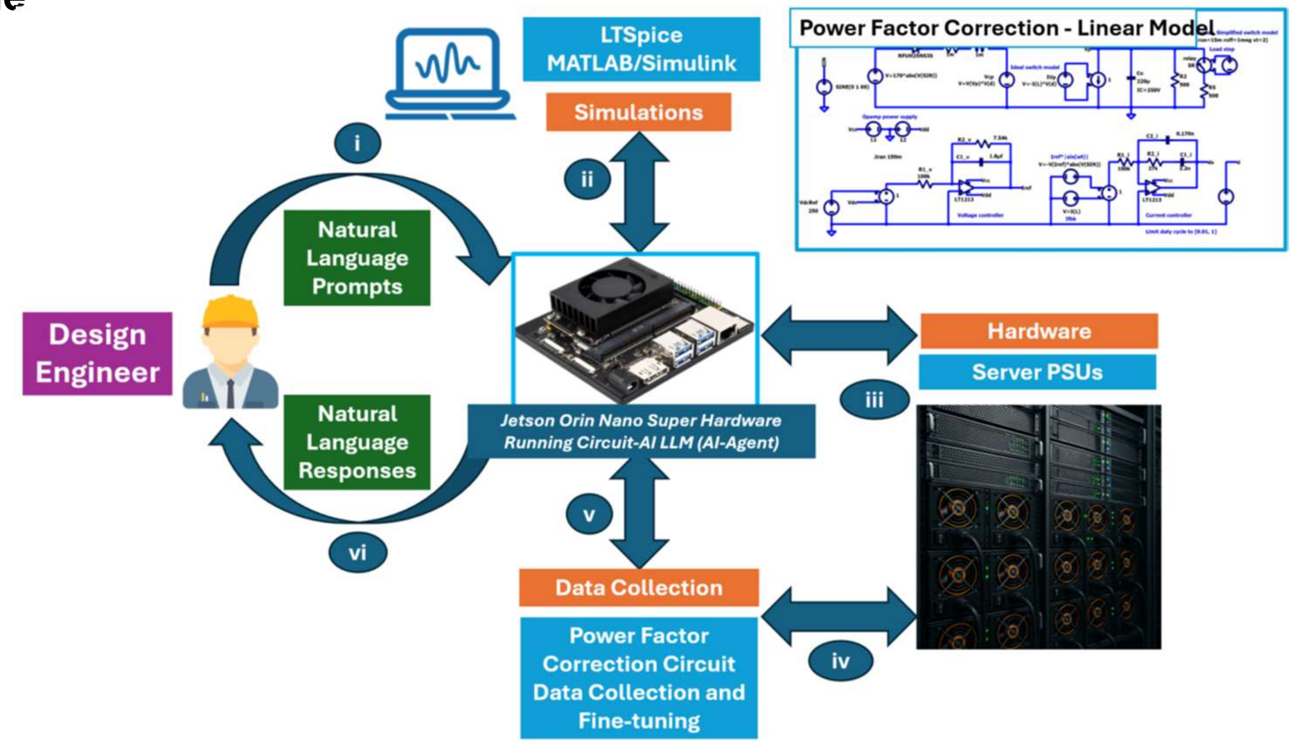
- Circuit-AI is a **locally deployed AI agent** (no cloud)
- Runs on **NVIDIA Jetson Orin Nano**
- Uses a **language model** to:
- Set up simulations
- Assist control-loop prototyping
- Interface with hardware & digital twins
- Designed for **air-gapped, secure, industrial environments**



System architecture of Circuit-AI

How Engineers Interact with It

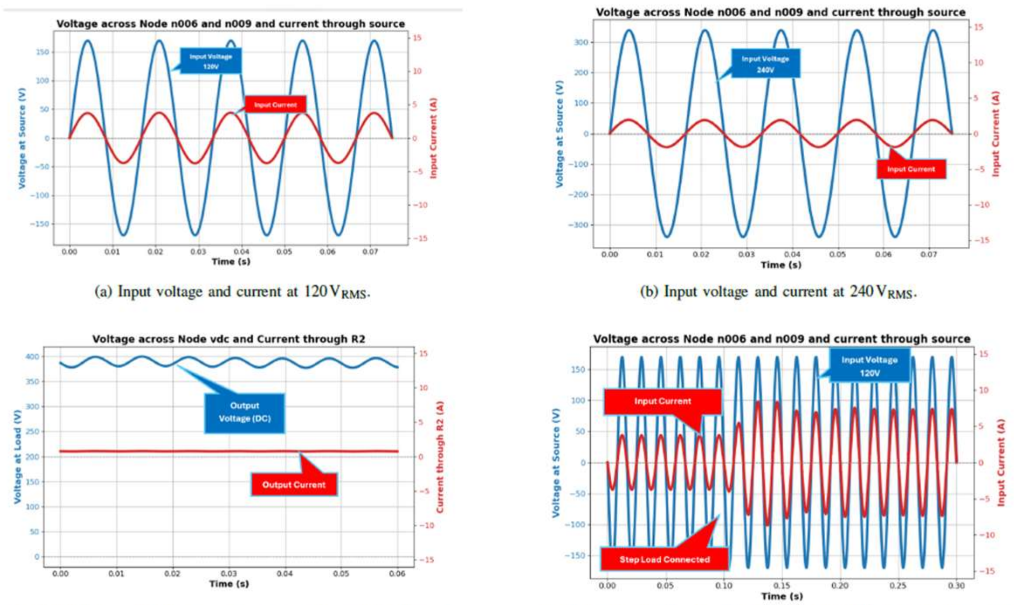
- Engineers interact using **natural language prompts**
  - “Run transient simulation”
  - “Change load and observe ripple”
- AI translates requests into:
  - Simulation runs
  - Parameter updates
  - Result summaries
- Human-in-the-loop:
  - Engineers review outputs
  - No autonomous decision making



Combined simulation, hardware, and AI interaction

Demonstration

- AI-assisted simulation of **PFC converters**
- Automated:
  - Transient analysis
  - Parameter variation
  - Result extraction
- Enables:
  - Faster iteration
  - Easier access for non-experts
  - Secure, offline operation



(a) Input voltage and current at 120 V_{RMS}.

(b) Input voltage and current at 240 V_{RMS}.

(c) Output voltage and current at node Vdc, with computed averages.

(d) Transient simulation from 0.4 s to 0.7 s with PWL applied to Vref1.

LTspice simulation results generated using Circuit-AI

Thank you