Advancing MVAC-LVAC Power Conversion for Next Generation Data Centers

Tyson Klein, Dr. Jun Wang

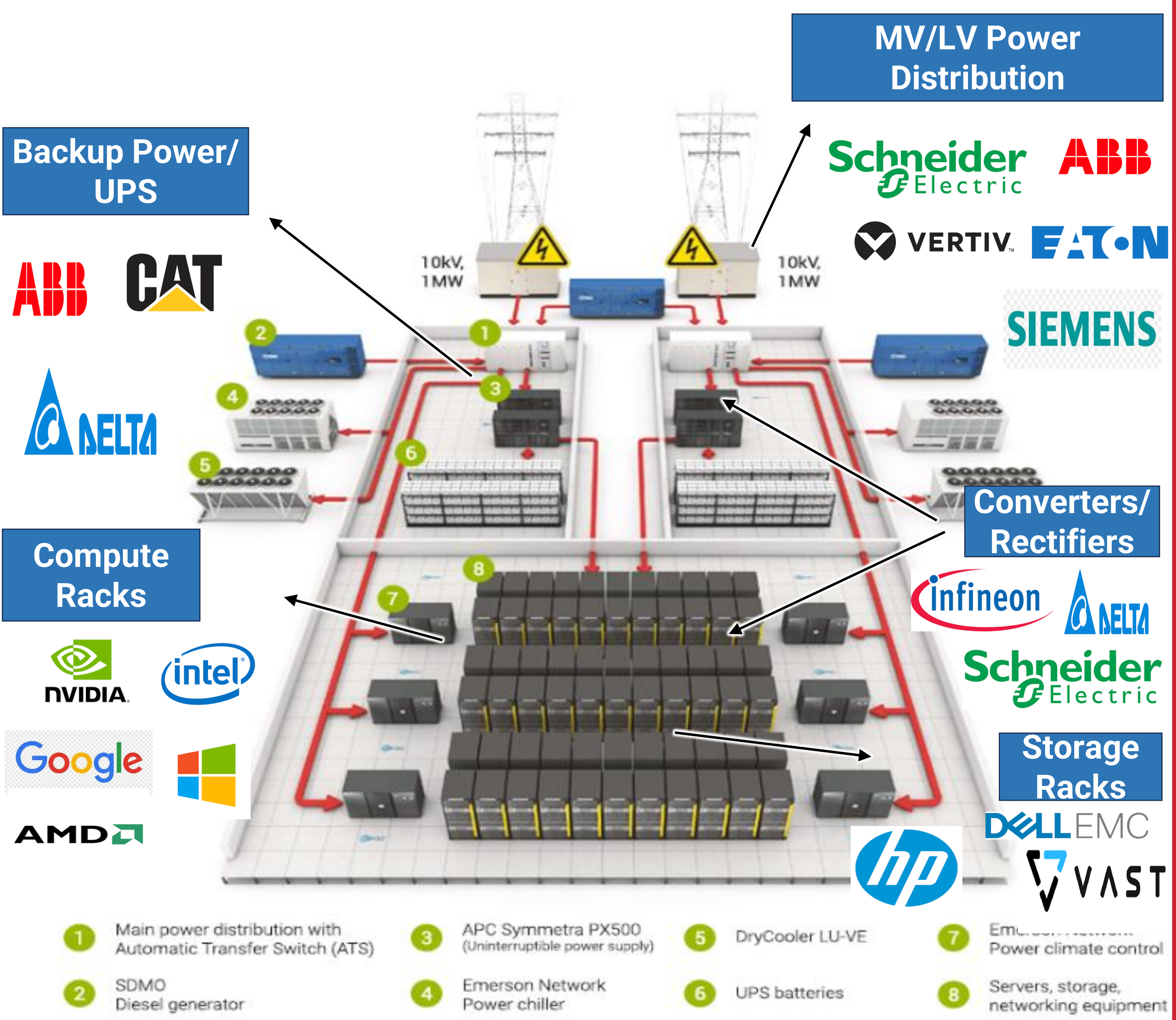
Department of Electrical and Computer Engineering

NEBRASKA CENTER FOR ENERGY SCIENCES RESEARCH

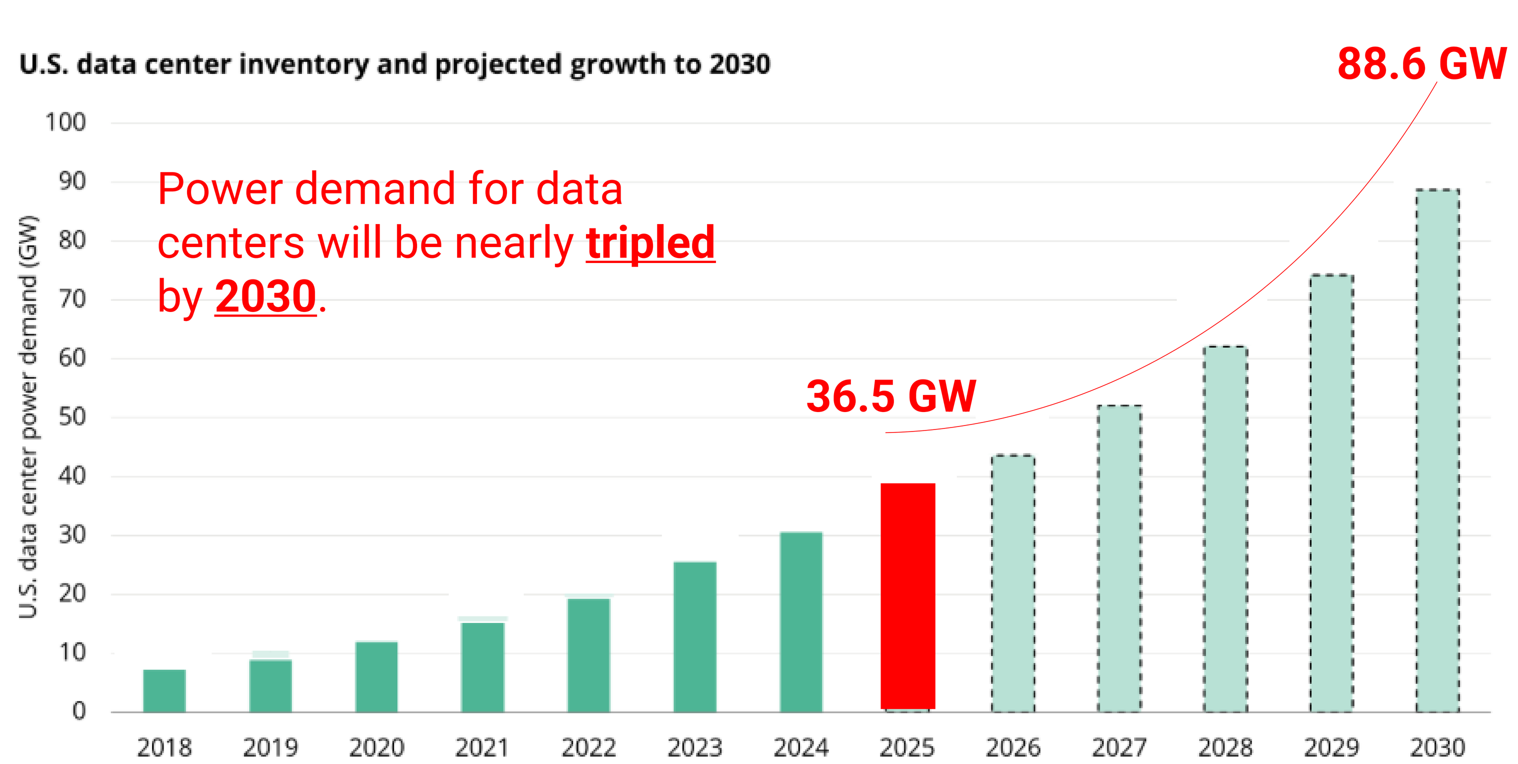
Background and Motivation

1 Current Data Centers

Traditional data centers use 60Hz MVAC (e.g., **4.16 kV**) stepped down to low voltage DC (**400-800 V**).

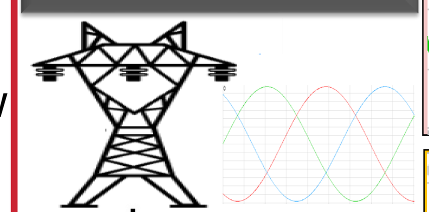


2 Power Consumption Projection

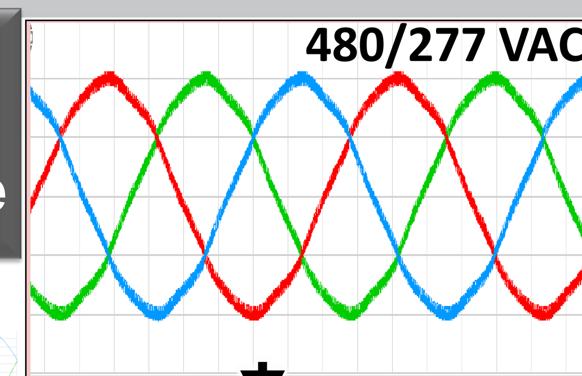


- Today's electrical infrastructure is outdated and not designed to handle emerging high-density energy demands.
- With increasing technology, industry leaders are working to redesign power architectures that improve efficiency, scalability, and reliability.

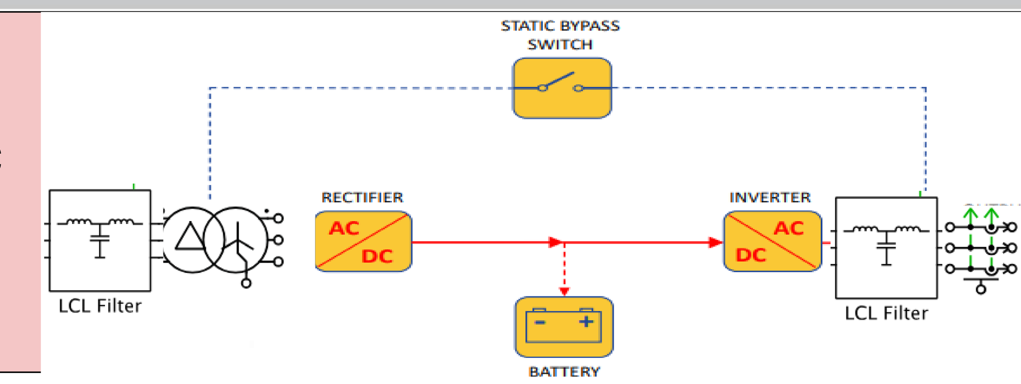
Current Architecture

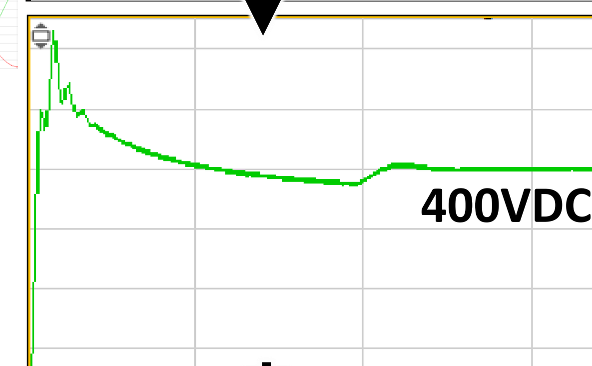


4160 VAC → **UPS** → 480 VAC → **Boost Rectifier** → 400VDC → **LLC Converter** → 48VDC → **Flying-Capacitor Converter** → 12VDC → **Multiphase Buck Converter**

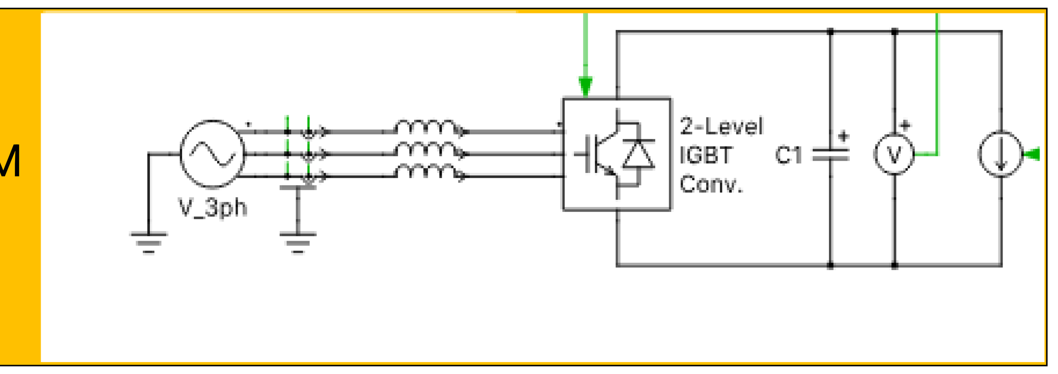


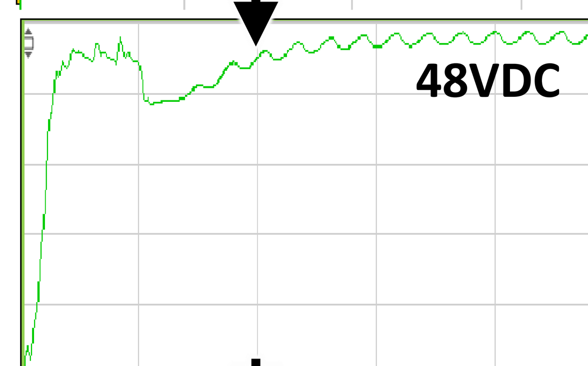
- **AC-DC-AC** double conversion Bulky 60Hz transformer to step **MVAC → LVAC**.
- LCL filter for sine waveform.



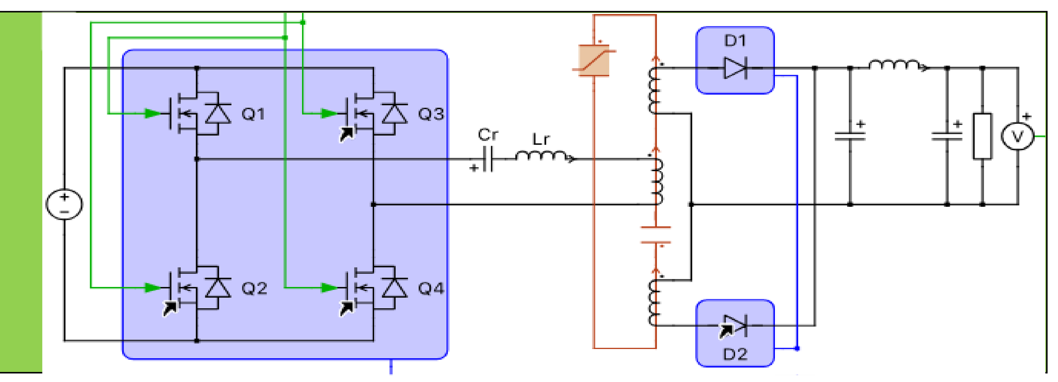


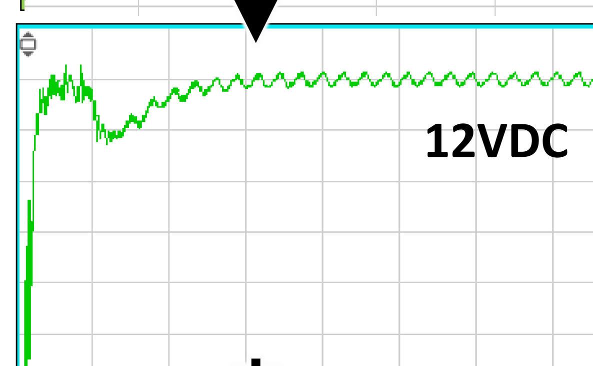
- Converts 3-phase AC to regulated DC.
- Utilizes Space-Vector PWM for PFC and low harmonic distortion (**THD**).



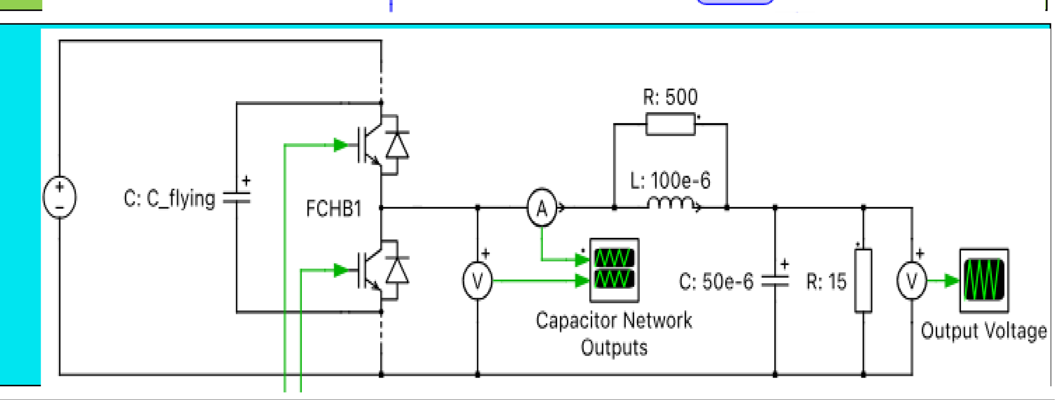


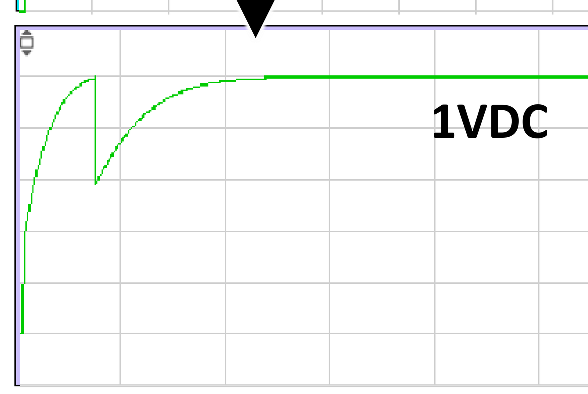
- High-frequency resonant converter.
- Uses a resonant tank to achieve **soft-switching**.
- Transformer provides galvanic isolation.



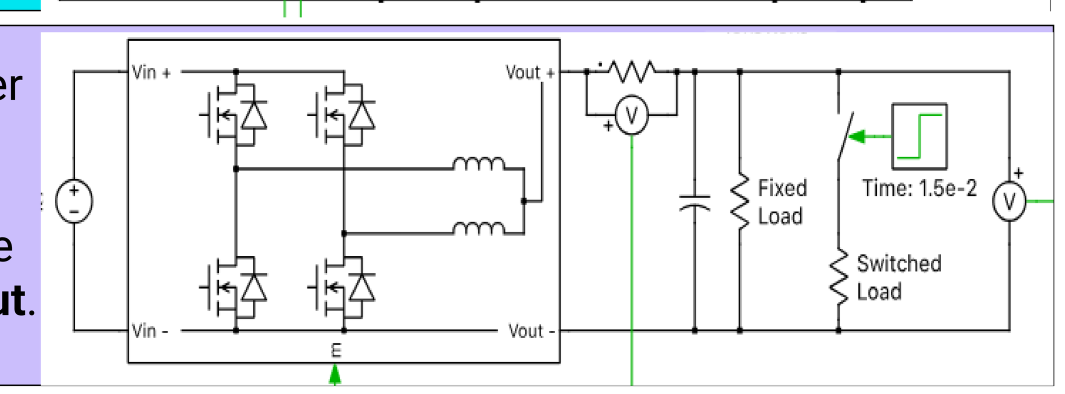


- Multi-cell switched capacitor structure.
- Uses fixed duty cycle to split voltage – reducing stress.

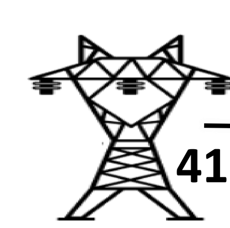




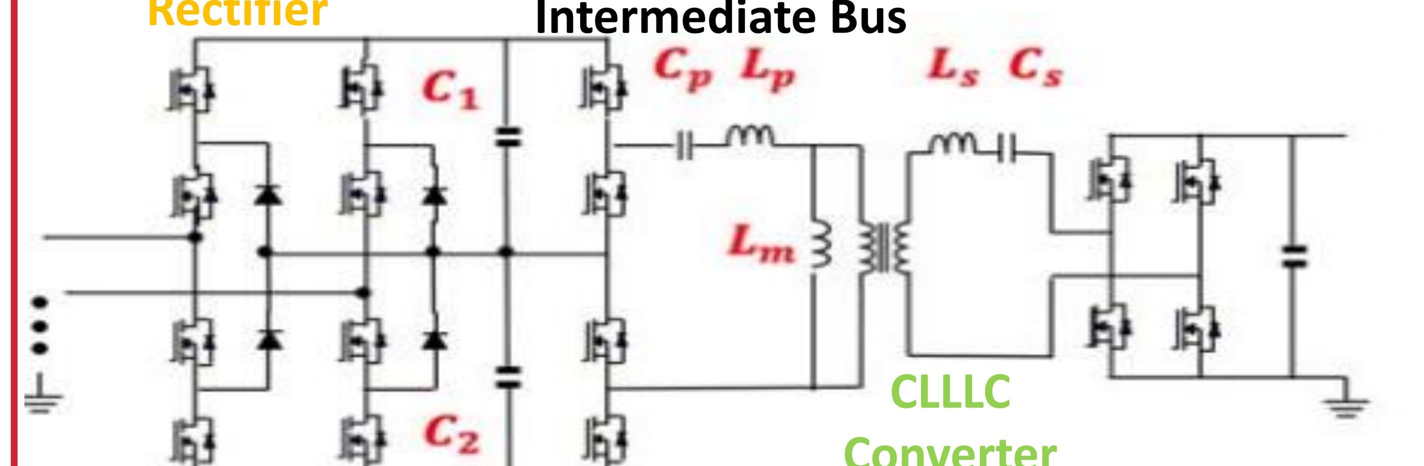
- Interleaved buck converter phases to supply high current to GPUs/CPUs.
- Two control loops provide tightly regulated **1V output**.



Next-Gen Architecture



4160 VAC → **Solid State Transformer** → 800VDC → **LLC Converter** → 48VDC → **Multiphase Buck Converter** → 1VDC



- 3-phase input rectified using cascaded H-Bridge.
- Each phase uses **9 H-bridge cells**-19 level staircase wave.
- Cells operate at low voltage → reduced stress per switch.

- Dual-active bridge topology with **CLLLC tank**.
- Operates under ZVS for reduced switching loss.
- Galvanic isolation + bidirectional power flow.

- Same high –frequency resonant LLC as in current design.
- Supports SST-wide soft-switching and galvanic isolation at 800 → 48 VDC.

- Identical interleaved buck design.
- Instead steps down **48VDC → 1VDC** in one step.
- Skipping **12V** rail reduces losses and simplifies power delivery.

1 Projected Efficiency

SST (CHB + CLLLC)	(97-99%)
LLC Converter	97%
Multiphase Buck	90%

Upstream: ~96%

Total: 85.5%

Limitations

- **Multiple conversion stages (AC/DC/AC)** → compounding losses
- **Bulky infrastructure** → longer build times
- **Low efficiency (Power density <$0.5 MW/m^3$)** → increased cost/waste

1 Current Efficiency

UPS	98%
SVPWM Boost Rectifier	96%
LLC Converter	97%
Flying Capacitor Converter	95%
Multiphase Buck	90%

2 Projected Path

- Reduce number of conversion stages (5→3) - improve total efficiency
- Step (4.16 kV AC → 800VDC) in one stage

Upstream: 91.2%

Total: 76.5%

Design Comparison

Current	Next-Gen
5 stages ~<u>91%</u> upstream efficiency	3 stages ~<u>96%</u> upstream efficiency
Hardwired Architecture – limited scalability	Modular Solid State Transformer – scalable and serviceable
Bulky/slow replication	Optimized for AI/server GPU loads

Acknowledgements

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