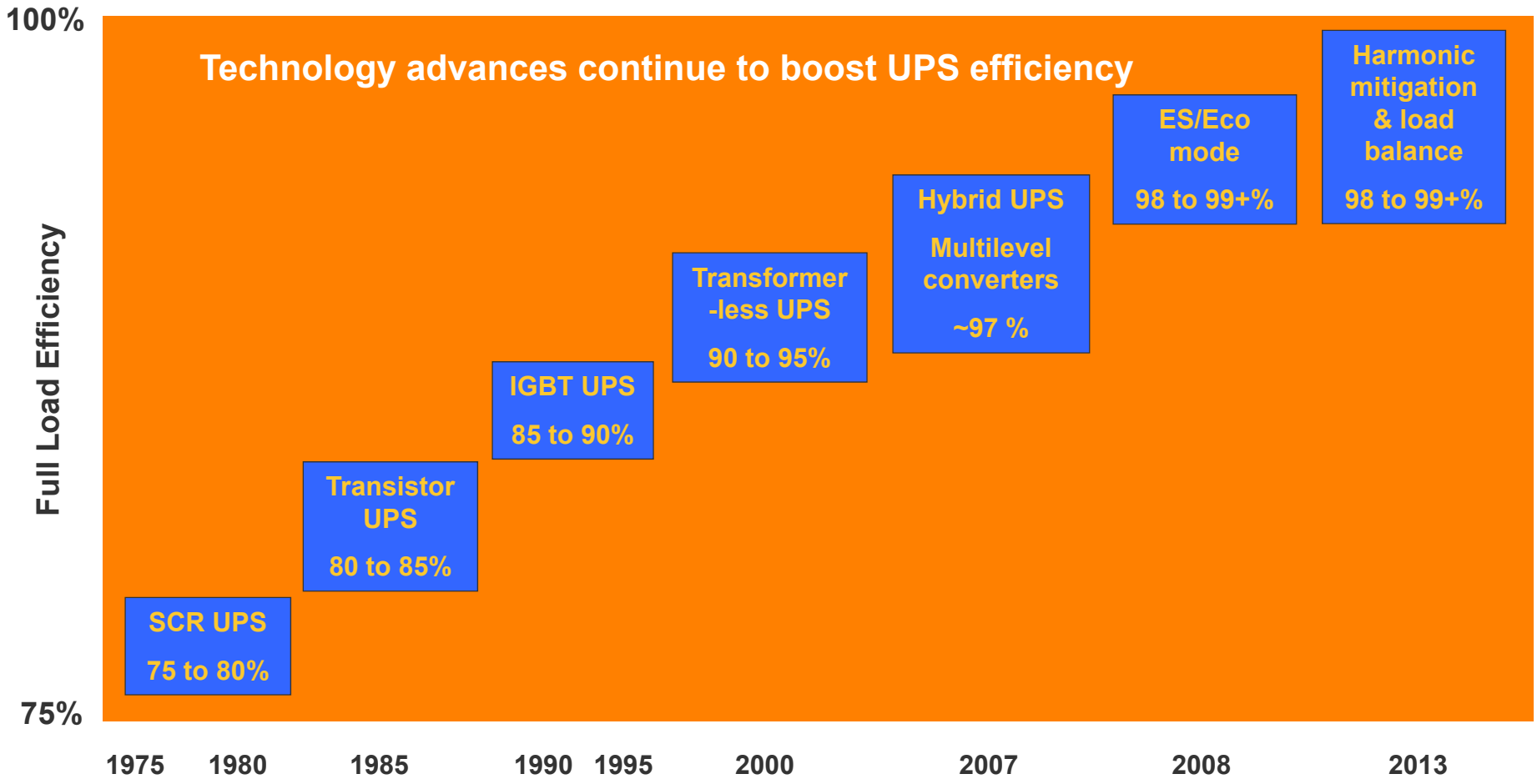
History and Trends in Data Center Powering

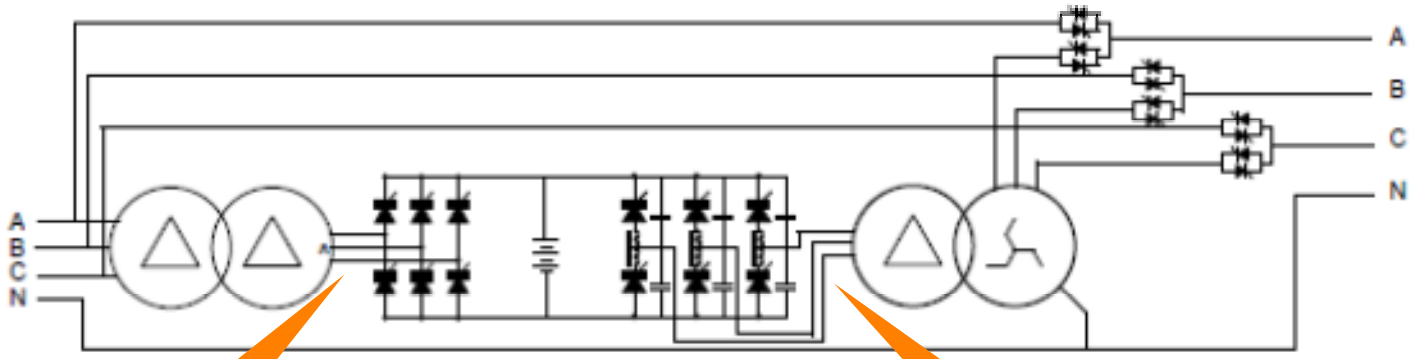
Ed Spears

Power Conversion Technology -over the years.....

Technology and Efficiency over the Years



Simplified SCR UPS Schematic—"Your Father's UPS…."



Input Transformer and 6-Pulse Rectifier

Force-commutated Inverter and Output Transformer

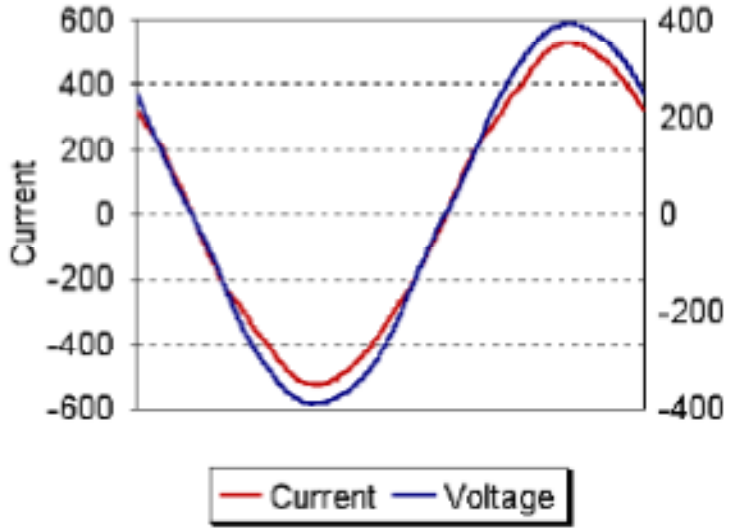
Now Replaced by Transformerless, IGBT-based Power Converters, for High Efficiency and Power Density

Active (IGBT) Rectifier Current Waveform Low THDi, High Power Factor

Site Friendly and Generator Compatible

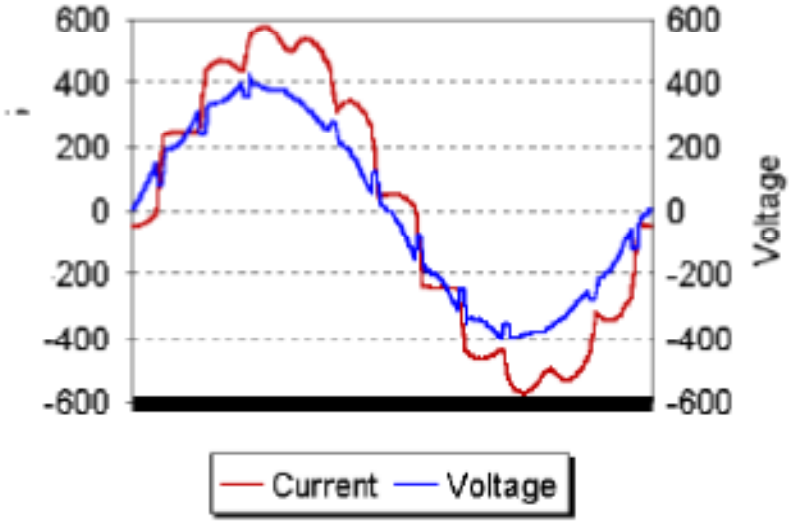
Typical IGBT Conv. UPS Input Waveform

Full Load, without filter, 2.6% THD



Typical 12 pulse Conv. UPS Input Waveform

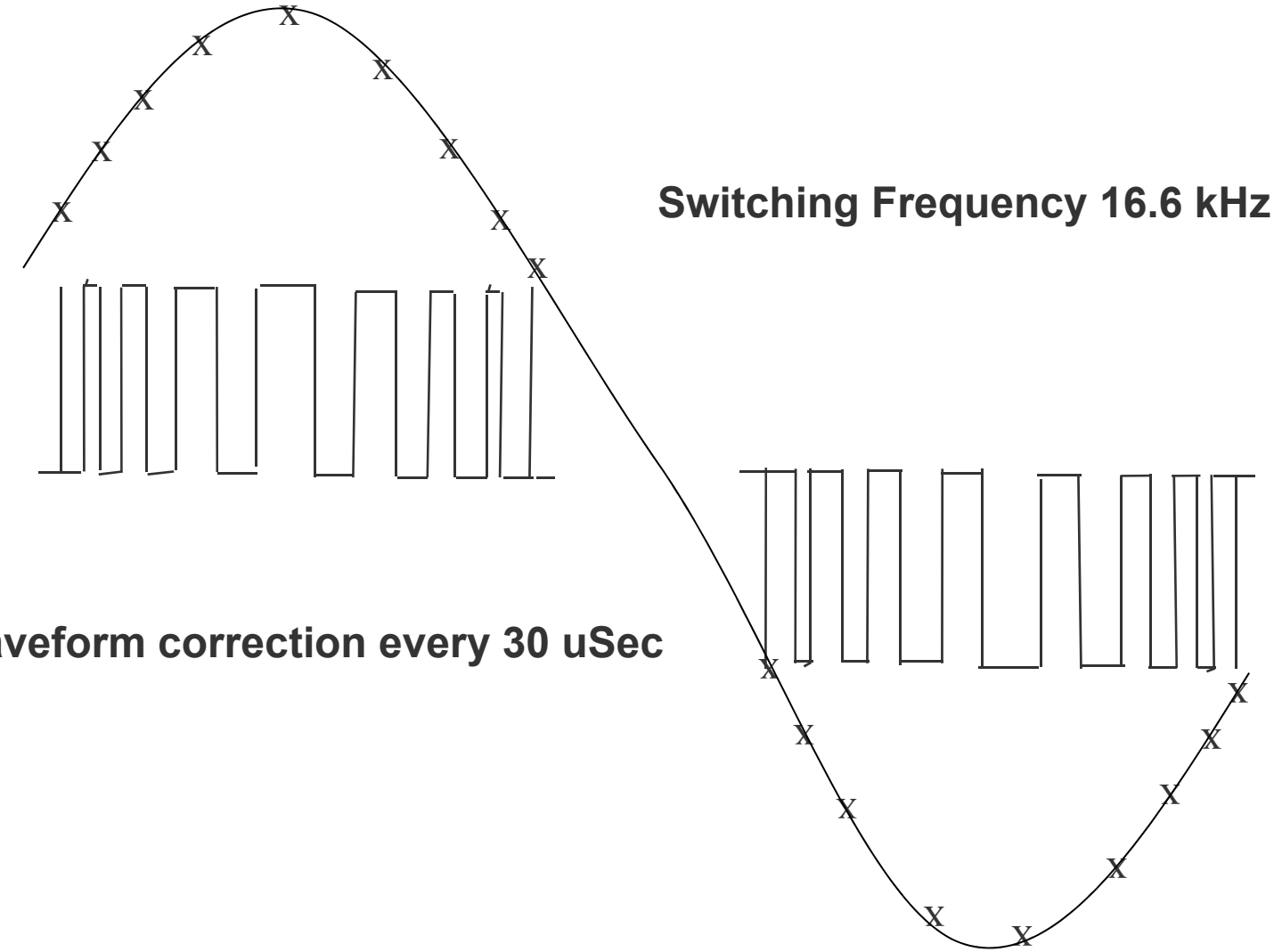
Full Load, without filter, 11.9% THD



IGBT-Based Inverter Circuitry

- Everyone has it now……why?
- Proven Technology
  - So what's new?

PWM (Pulse Width Modulation)



Switching Frequency 16.6 kHz

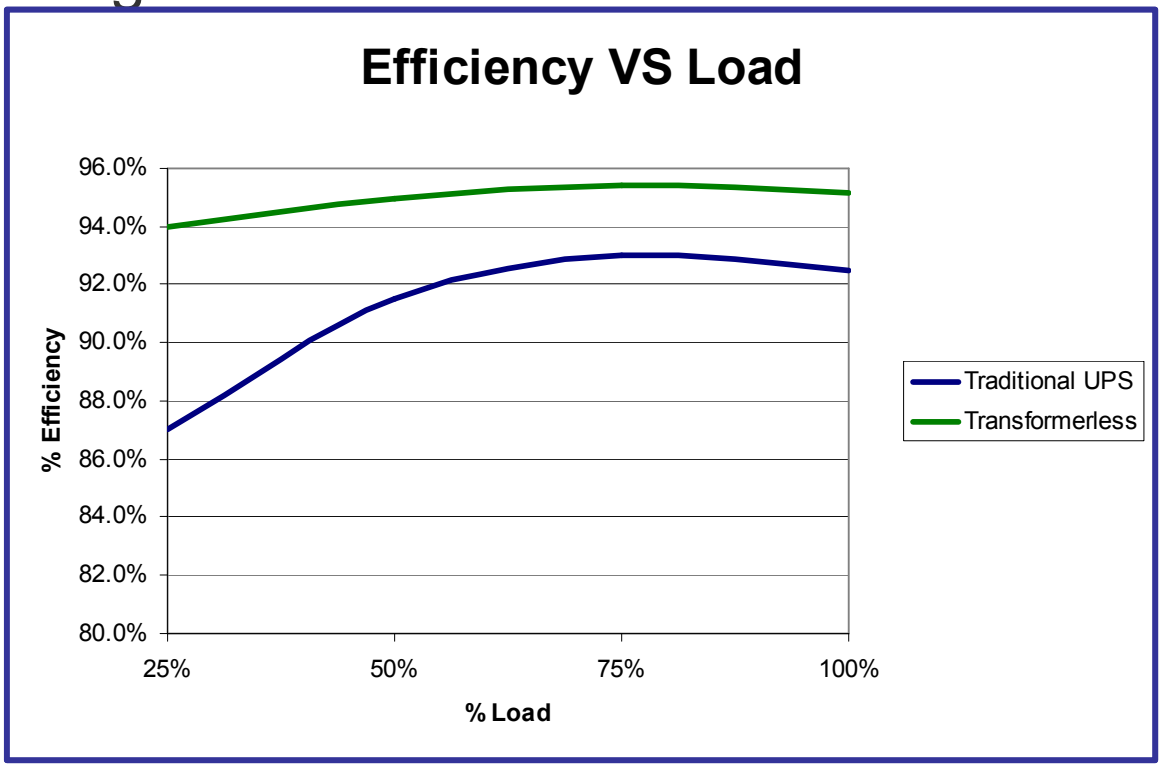
Waveform correction every 30 uSec

Design Comparison

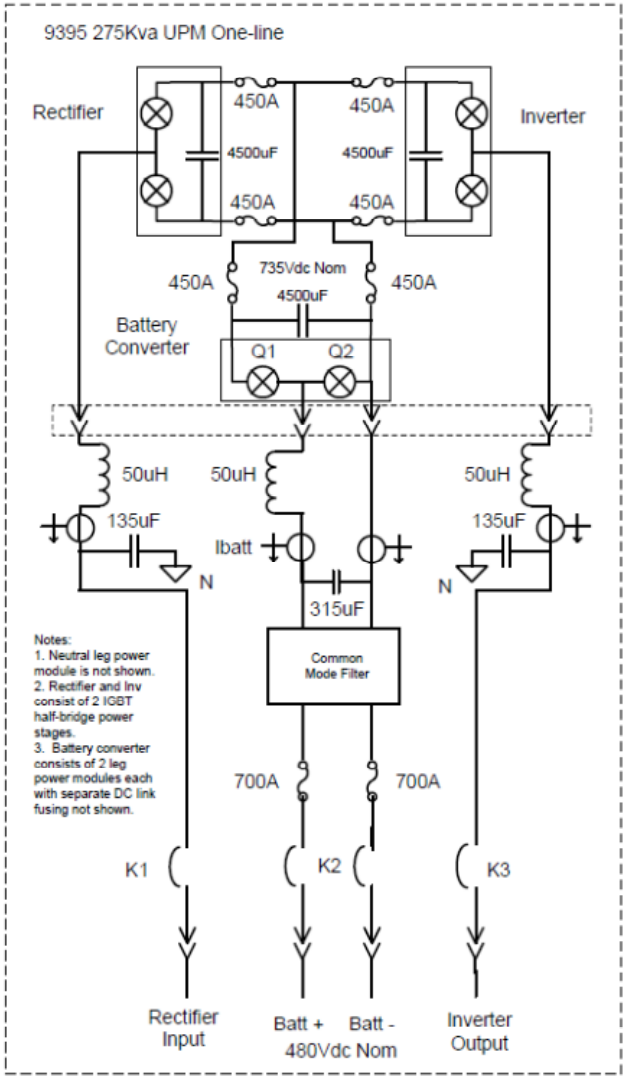
	Conventional transformer-based	Today's transformer-less
PWM effective Switching frequency	6.25 KHz	16.6 KHz
Output filter pole	650 Hz	2 KHz
Output Impedance	7%	2.25%

Improved Power Performance

- Latest generation IGBT
  - » Reduced switching and conduction losses
- Neutral modulation
  - » Reduced DC voltage and switching losses to produce AC RMS voltage



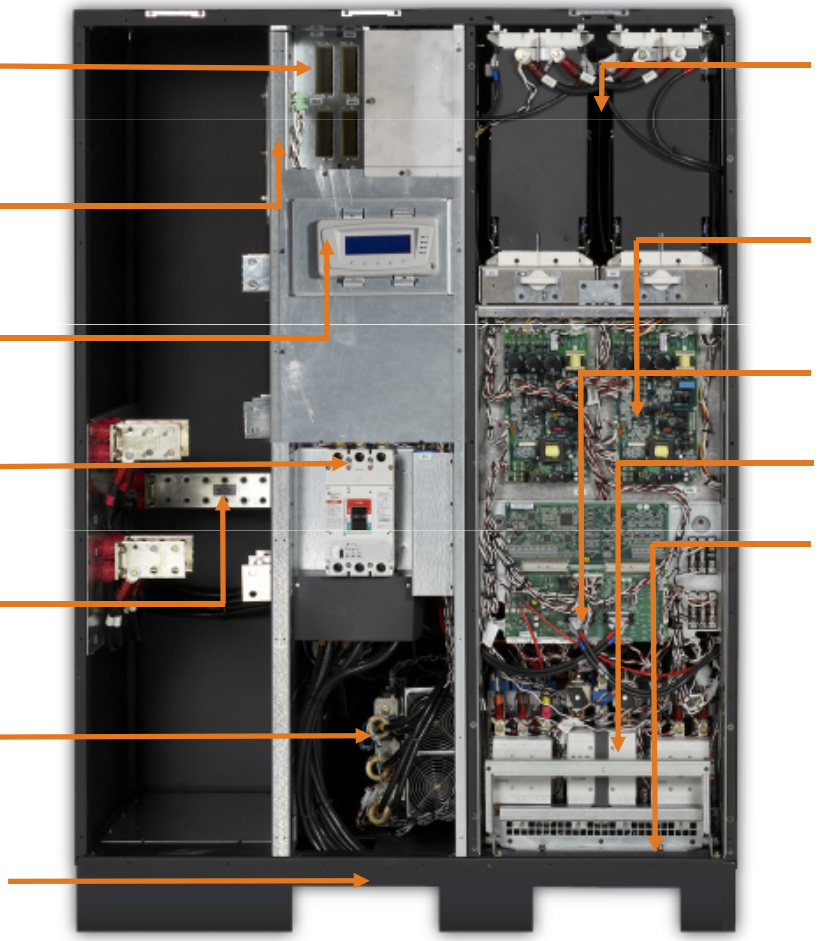
Transformerless Topology Differentiators



- Smaller system size and weight
- Efficient Operation
  - » No transformer power losses
  - » Maintains an optimally high DC link for the inverter
  - » Significant reduction in current handling for inverter components
- PWM Rectifier provides high input PF and low current THD over wide line and load range
  - » Doesn't require large input harmonics filters
  - » Reduce inrush current and improved generator compatibility
- Uses IGBT converters of identical make-up
  - » Standardizes on power circuits, components, support and service
- Green and Sustainable
  - » Reduction in iron, copper, and varnish usage
- Battery converter interfaces battery to inverter DC link
- No galvanic isolation, input to load, battery to mains

Inside the transformerless, modular UPS

- X-Slot communications
- Power Xpert Web Card
- 8-line backlit LCD
- Input circuit breaker option
- Top- or bottom-entry
- Static bypass – continuous duty
- Base with inter-unit cabling



- Double-conversion topology converter/ inverter section
- Redundant power supplies
- Redundant fans
- Contactor output
- UPM easy service disconnect

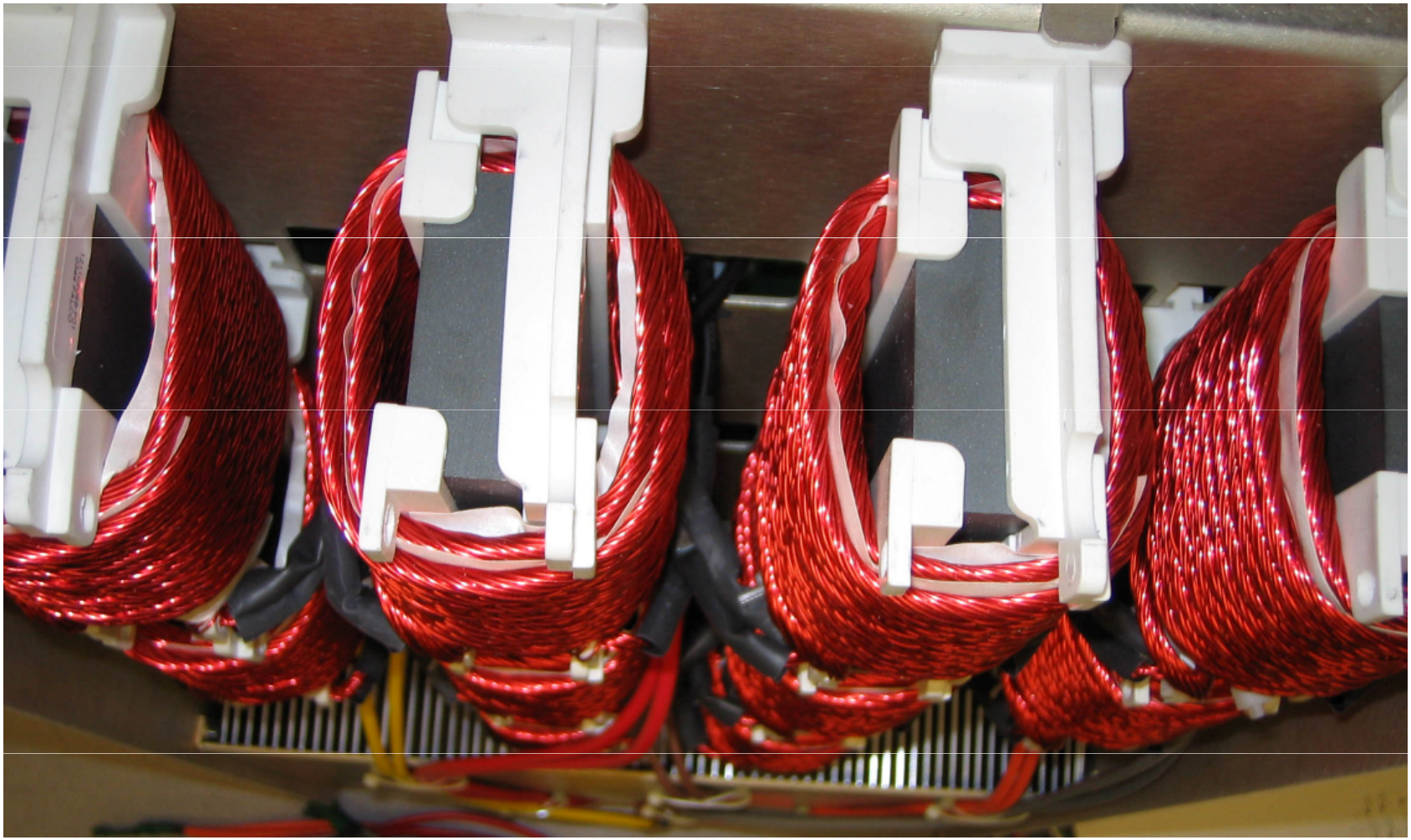
ISBM Section UPM Section

Hybrid Inductor Design in Transformerless UPS Allows Significant Size and Weight Reduction 275 kVA Examples Below

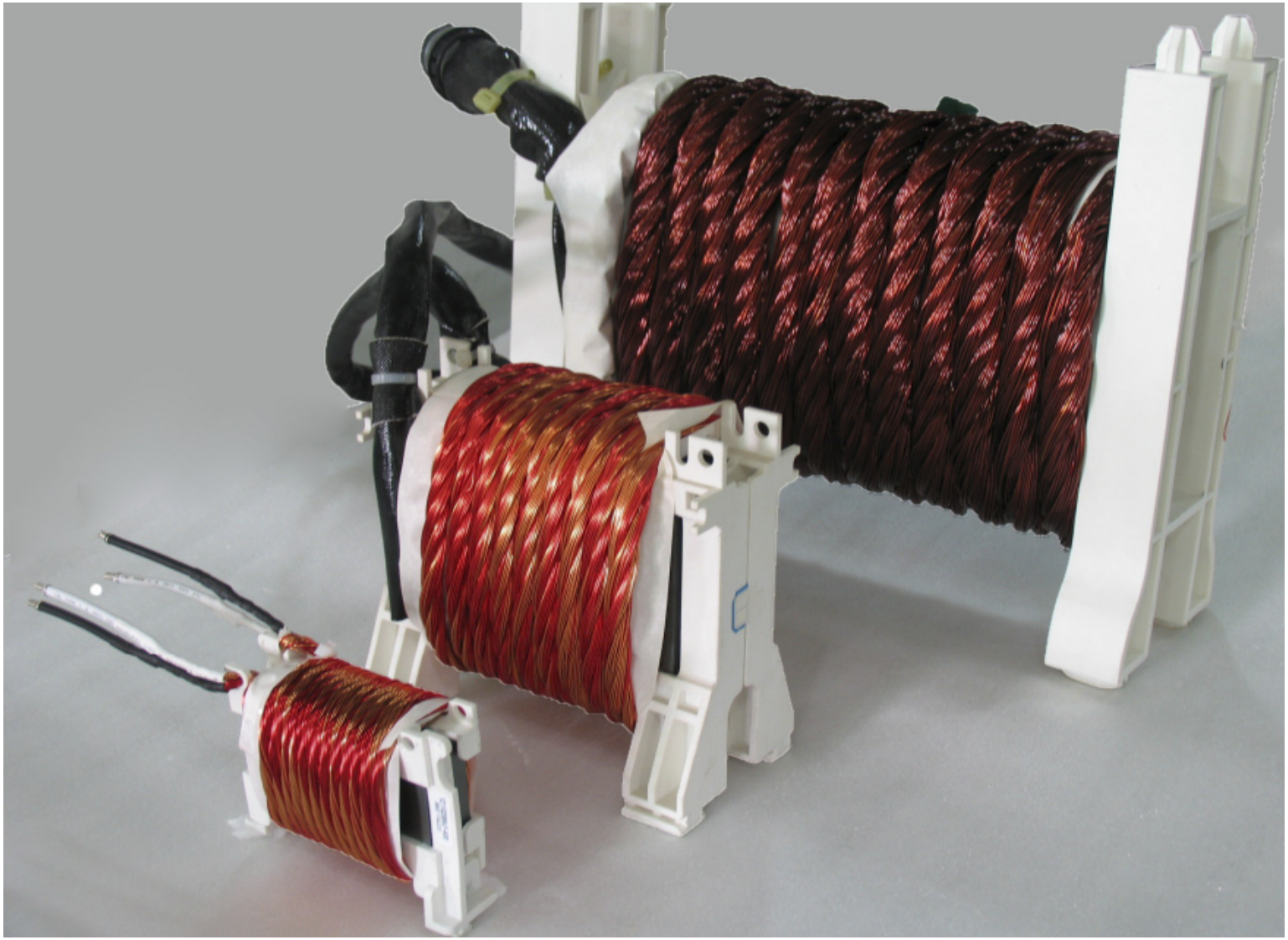
Transformer-free mag pak

Transformer-based mag pak

Low Loss Hybrid and Air-core Inductor Designs Yield Cooling Reductions

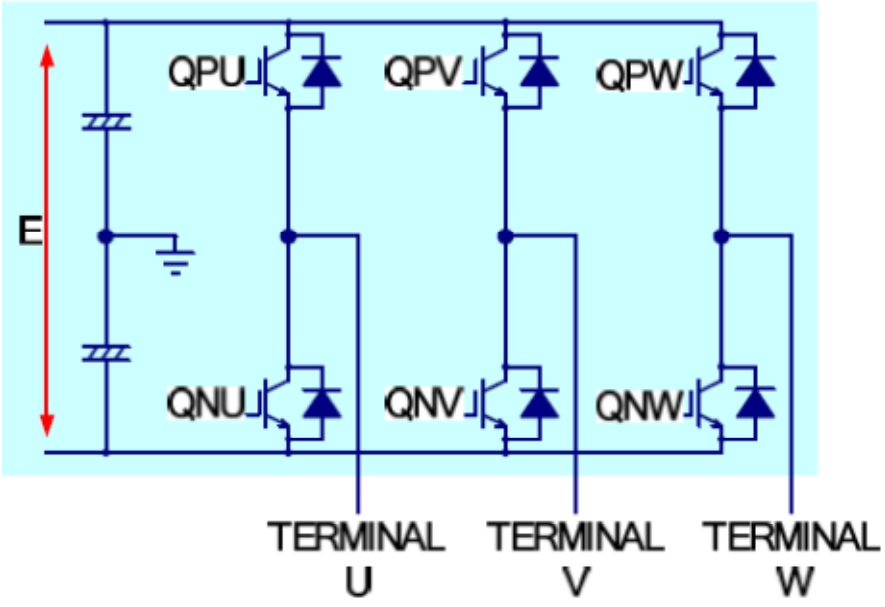


Hybrid & Air Core Inductors Reduce Cost



3-Level Designs for Higher Efficiency

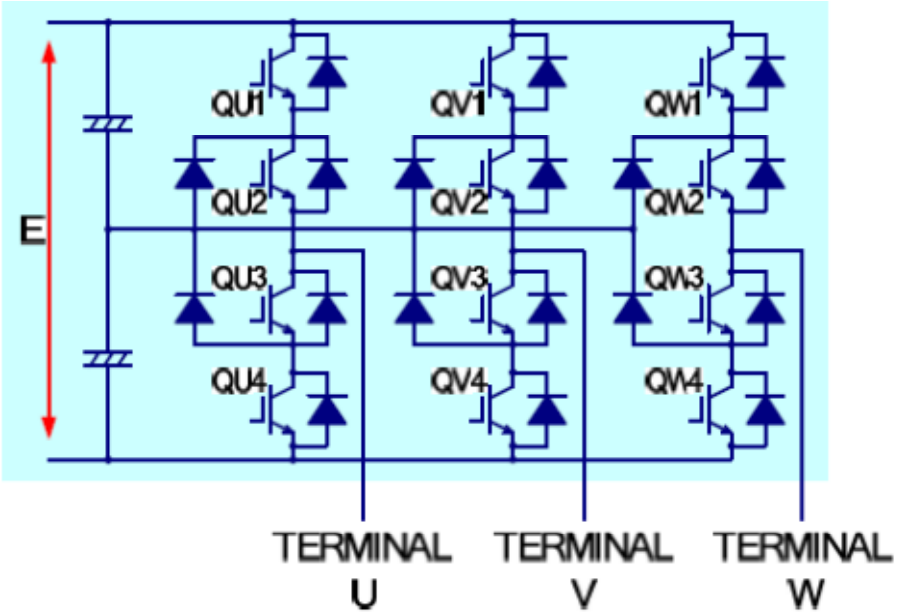
Conventional Inverter Bridge—95% Eff.



6 IGBT transistors (1200V)

6 Pumpback diodes

"Three Level" Inverter Bridge—97% Eff.



12 IGBT transistors (600V)

18 Power diodes

Leading Power Factor (Capacitive) Loads

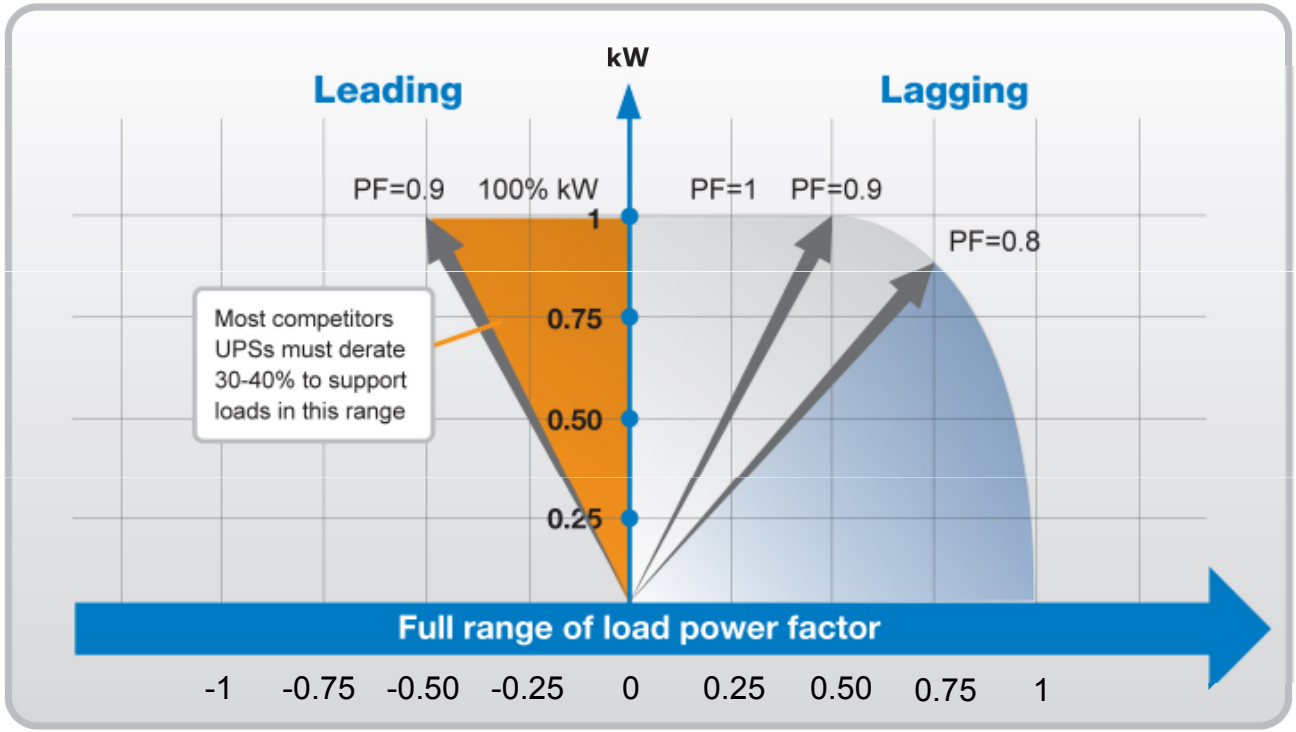
- What's the Problem?

- Data center loads are sometimes becoming leading power factor loads.
  - » Power supplies in the data center are being designed to meet stringent harmonic distortion limits and unity power factor – this result on increasing capacitive presence at the supply.
  - » Dual-cord and redundant configurations result in power supplies loaded well below 50%.
  - » Server power supplies are increasingly becoming a larger percentage of UPS loads.

Characteristics of the Load

- What's the Problem? (for the Geeks….)
  - Server power supplies have typically an active power factor correcting boost converter stage
  - Boost converter control loop is regulating input current to track the input voltage
  - PF Corrected loads are constant power with an apparent resistance that will vary with voltage and may oscillate if the response of the load power supply is similar to that of the UPS output filter.

Leading Power Factor in the Datacenter



Today's power factor corrected data center loads are becoming more "leading."

UPS should be tested with capacitive loads as low as 0.9PF

The Three Potential Problems

- Load capacitive current adds to output filter current… may require output KW de-rating for thermal reasons
- The input capacitance of PFC loads will move the filter pole to lower frequency compromising phase margin and stability of the control loop
- For high impedance (large filter) inverters there can be instability between inverter control loop and the PFC power supply boost regulator control loop

Technology for Stable Output

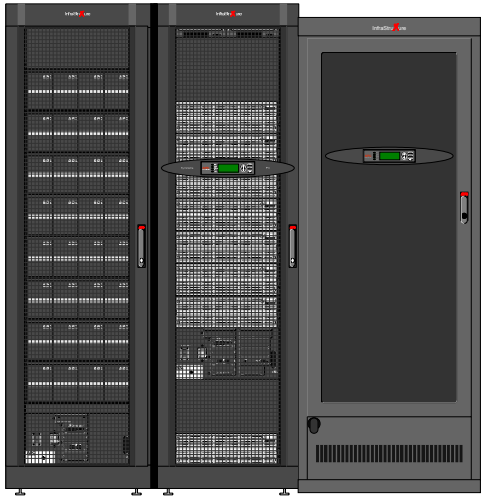
- Eaton inverter designs using pulse-width modulation (PWM) eliminates lower-order harmonics resulting in small output filter components
  - For conventional product, PWM switching frequency is 6.25KHz.
  - New products, effective switching frequency at output filter is 16.6KHz.
- Inverter design with low output impedance, allows large phase margin with good dynamic voltage regulation
- DSP-based inverter voltage control is well inside output filter resonant pole with lower gain at higher frequencies
- Previous generation product required higher gain to make up for large inverter filter impedance and provide acceptable voltage regulation

Technology for PFC loads

- Low output impedance assures stability of controls
- High-frequency PWM technology does not require complex filters – like harmonic traps with multiple resonances
- Faster response and lower source impedance to support inrush currents
- Low output voltage THD minimizes risk of PFC input filter resonant currents

UPS System Architecture

Modular-Scalable UPS systems



- N+X Redundancy
- Concurrent Maintenance
- Inherent Redundancy
- Module Level Control (VMMS)
- Common or separate batteries
- Flexibilities in paralleling-Pay as you grow

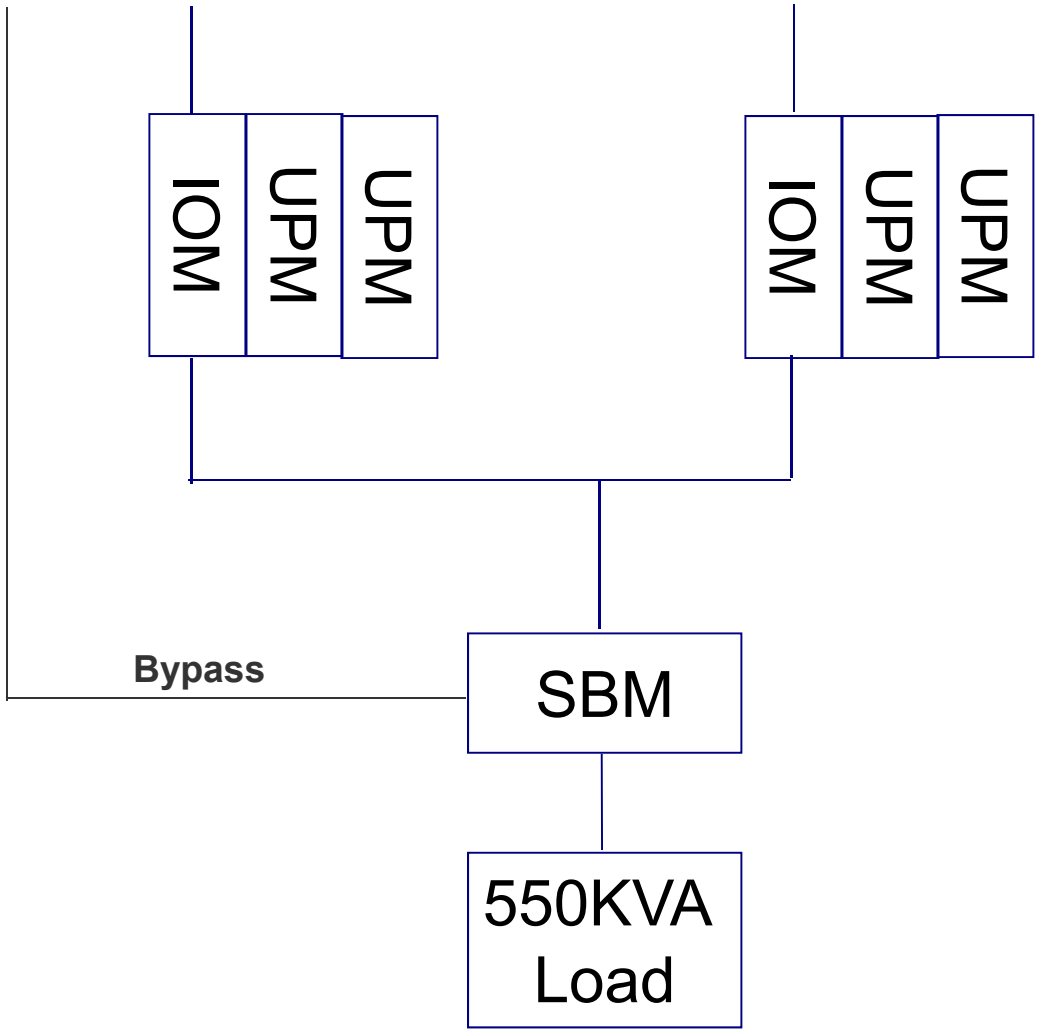
Flexible, Scalable, Upgradeable

On-site upgrade 275 kVA Redundant

On-site upgrade 550 kVA Redundant

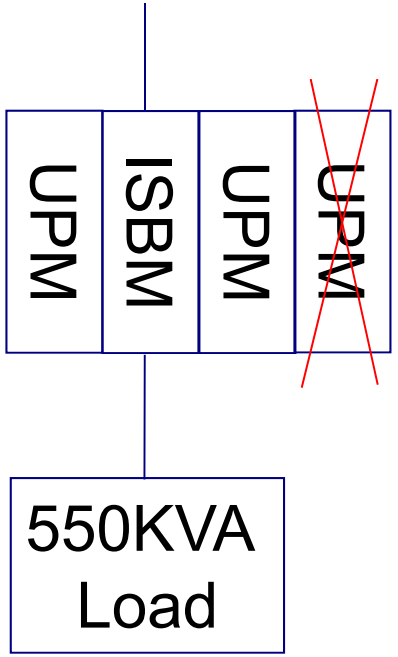
- Add another 275 kVA in the field for redundancy, or for capacity
  - » Simply choose an ISBM sized for future growth
  - » Leave space on the left side
- Enables flexibility for future changes in load demands, and new requirements for higher reliability

Paralleling the Modular UPS
550 kVA N+1 (Traditional)



Redundancy
System N+1
UPM +2

Paralleling the Modular UPS
550 kVA N+1 (Modular Architecture)



- **Smaller Footprint**
- **Lower Capex**
- **Lower Installed cost**
- **No SBM needed**
- **Still N+1 redundant**

Transformerless UPS
A History

- Early UPSs needed transformers in order to function!
- Input Transformer
  - Input voltage window limits for SCRs
  - Isolation for rectifier semiconductors and battery
  - Dual secondaries for 12-pulse rectifier, thus low THDi
  - Limit available fault current into the UPS
- Output Transformer
  - Step-up UPS output on low battery condition
  - Provide common mode isolation to critical load
  - Provide N-G bond physically close to the critical load?
  - Protect fragile inverter semiconductors during faults
  - Prevent DC offset during faults

Transformerless Efficiency

- Efficiency = Pout / (Pin + Ploss)
  - » Ploss is comprised of:
    - IGBT switching losses and conduction losses
    - Magnetics copper and core losses → transformer losses
  - » Switching losses are directly proportional
    - DC Link voltage
    - Switching frequency
- For the Transformerless UPS
  - » Modulating the N leg reduces harmonic content and allows for a reduction in switching frequency
  - » Adding a zero sequence to all of the PWM vectors causes the DC link to closely track the required three phase voltage space and effectively lowering the required DC Link
  - » Eliminating the transformer removes one more source of losses

UPS Fault Tolerance

- UPS is evaluated for performance under different external fault situations: battery faults, input source faults, output (load) faults, as well as its response to internal fault conditions
- Fault Tolerance - expected behavior
  - No load loss
  - No single point of failure
- Types of fault tolerant behavior
  - Unit remains on-line
  - Unit transfers to bypass
  - Unit announces/alarms condition

Easy Capacity Load Testing

- This test provides an enhanced startup and commissioning offering. It can take the place of some traditional load bank tests to save customers time and money during startup and commissioning.
- This load test ensures validation of performance of an installed UPS and can simulate various operations and power transfers.

No load banks to rent
No load connections needed
No wasted energy

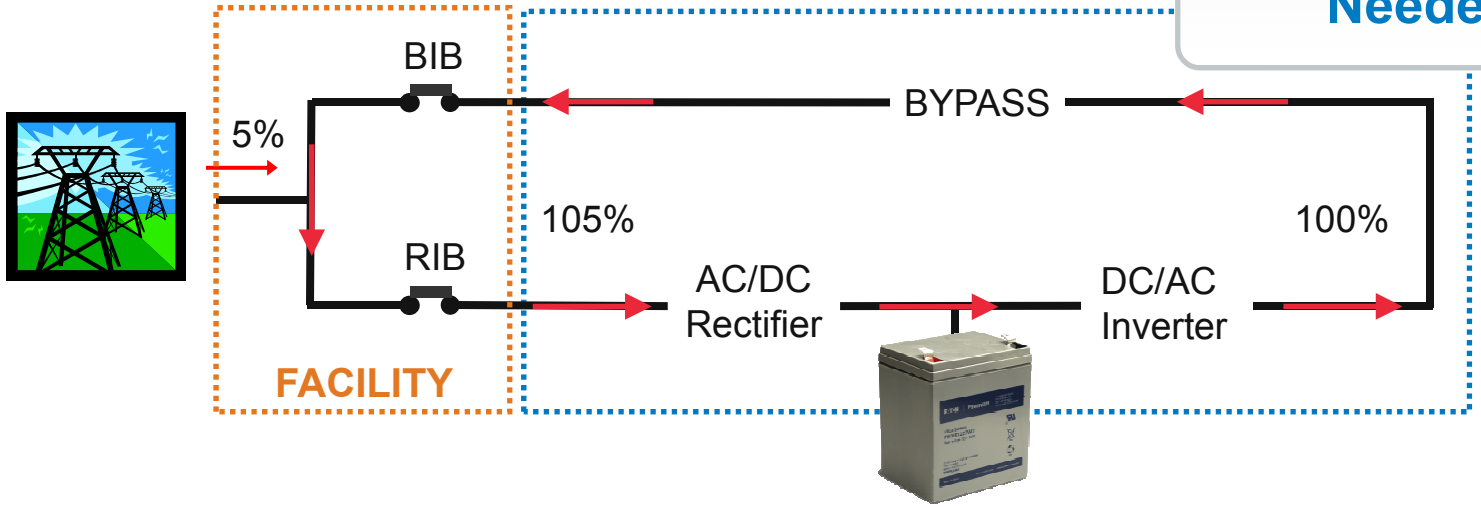
Load test capability saves customers time and money

Easy Capacity Load Testing

A field technician applies full load, tests & calibrates:

- Rectifier
- Inverter
- Battery – with option to perform full battery discharge test
- BIB
- RIB
- Static bypass switch
- Fuses
- Contactors
- Conductors

No Output Connection & Load Bank Needed



Additional thermal imaging tests are possible on UPS, input cables and switchgear

Energy Saving Options with Modular UPS Systems

Challenges For Customers

Energy costs and regulatory compliance will continue to place organizations at risk

Social, economic and regulatory pressures to reduce carbon emissions and energy costs globally

Increasing Energy Costs

» Through 2014, Energy costs will emerge as the second highest operating cost (behind labor) in 70% of the Data Center facilities worldwide *(source: Gartner)*

Sustainability

» 80% of CEO's view sustainability as impacting brand value *(source: 2008, McKinsey)*

» 31% say they want to reduce their environmental impact *(source: 2008, McKinsey)*

» IT accounts for 2% of the global CO2 emissions, as much as the airline industry *(source: 2008, IBM, UK)*

Regulations

» 82% of executives expect some form of climate change regulation within 5 years *(source: 2008, McKinsey)*

» European Union Code of Conduct for Data Centers

» UK Carbon Reduction Commitment (2010)

Module Management Systems

How to maximize efficiency with lighter loads in double conversion mode, *especially in multi-UPS and redundant system configurations?*

Solution #1 (+)

Concentrate load on certain UPS's to maximize UPS load level and overall system efficiency

» Some energy savings

- Limited to multiple-UPS systems (with several UPS in parallel)
- Still not optimal

Solution #2 (+++)

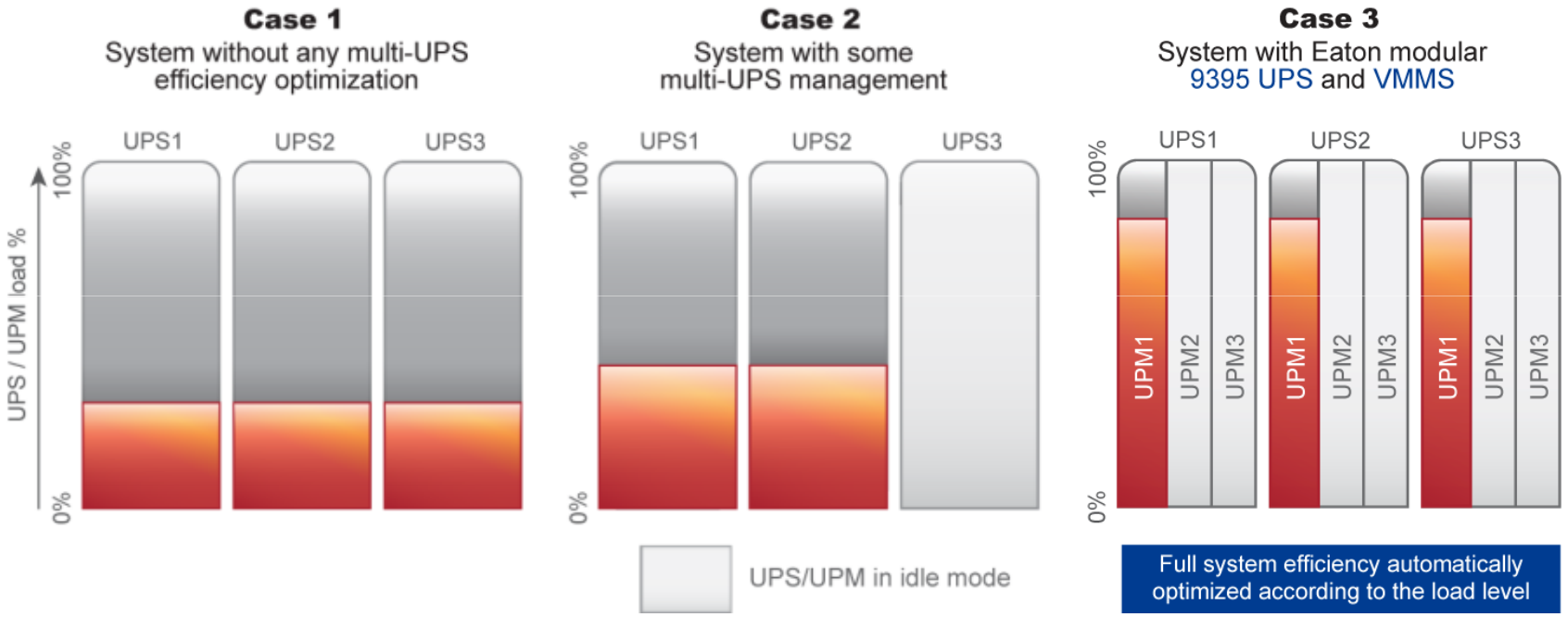
» Automatically optimize efficiency at UPM level

- Concentrate the load on certain UPM's to maximize overall system efficiency

» Only possible with modular UPS

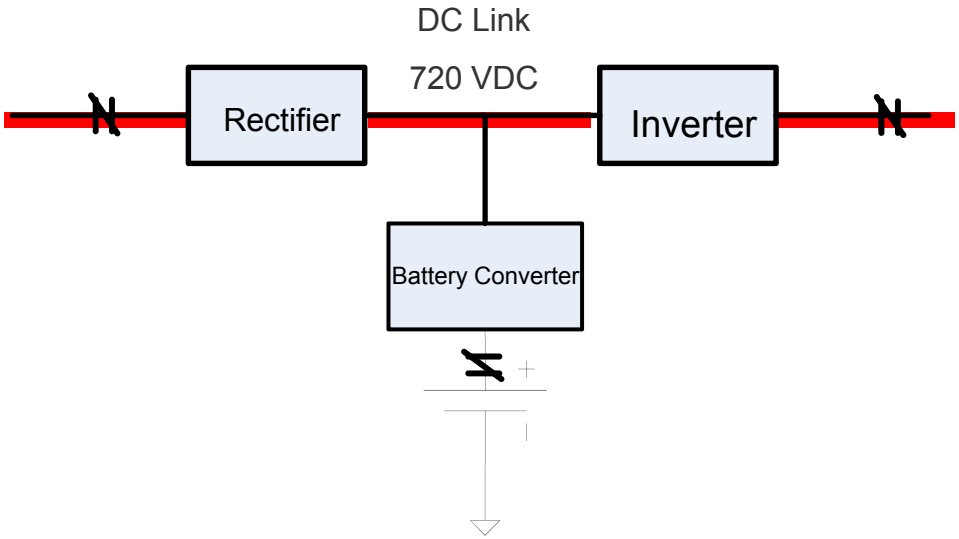
- Not limited to multiple-UPS systems
- Achieve even higher optimization thanks to UPM's modularity

Module Management Principle



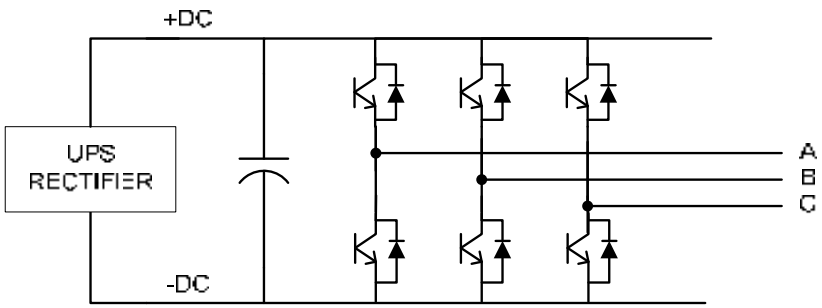
Flash On! Flash Off!

- How to start a UPS instantaneously? (no time to ramp up)
  - Leave contactors closed—eliminates all mechanical activity
  - Generate transistor gating at logic level. Gate in sync with system output.
  - Use pumpback diodes in rectifier and inverter bridges to support DC link voltage, and keep filter caps charged
  - Get rid of output transformer, so no need to magnetize
- Under the above conditions, the UPS inverter goes from “suspend mode” to full output power in 600 microseconds

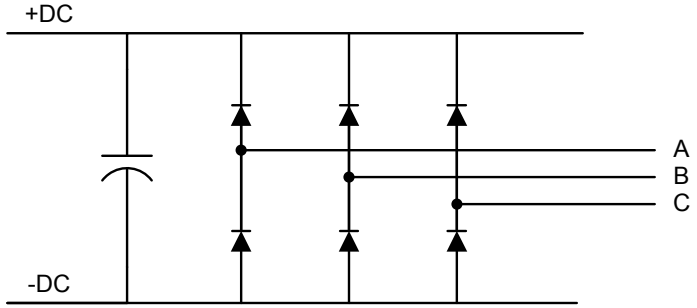


Fast Start VMMS/ESS Technology

INVERTER ON



INVERTER IN SUSPENDED MODE

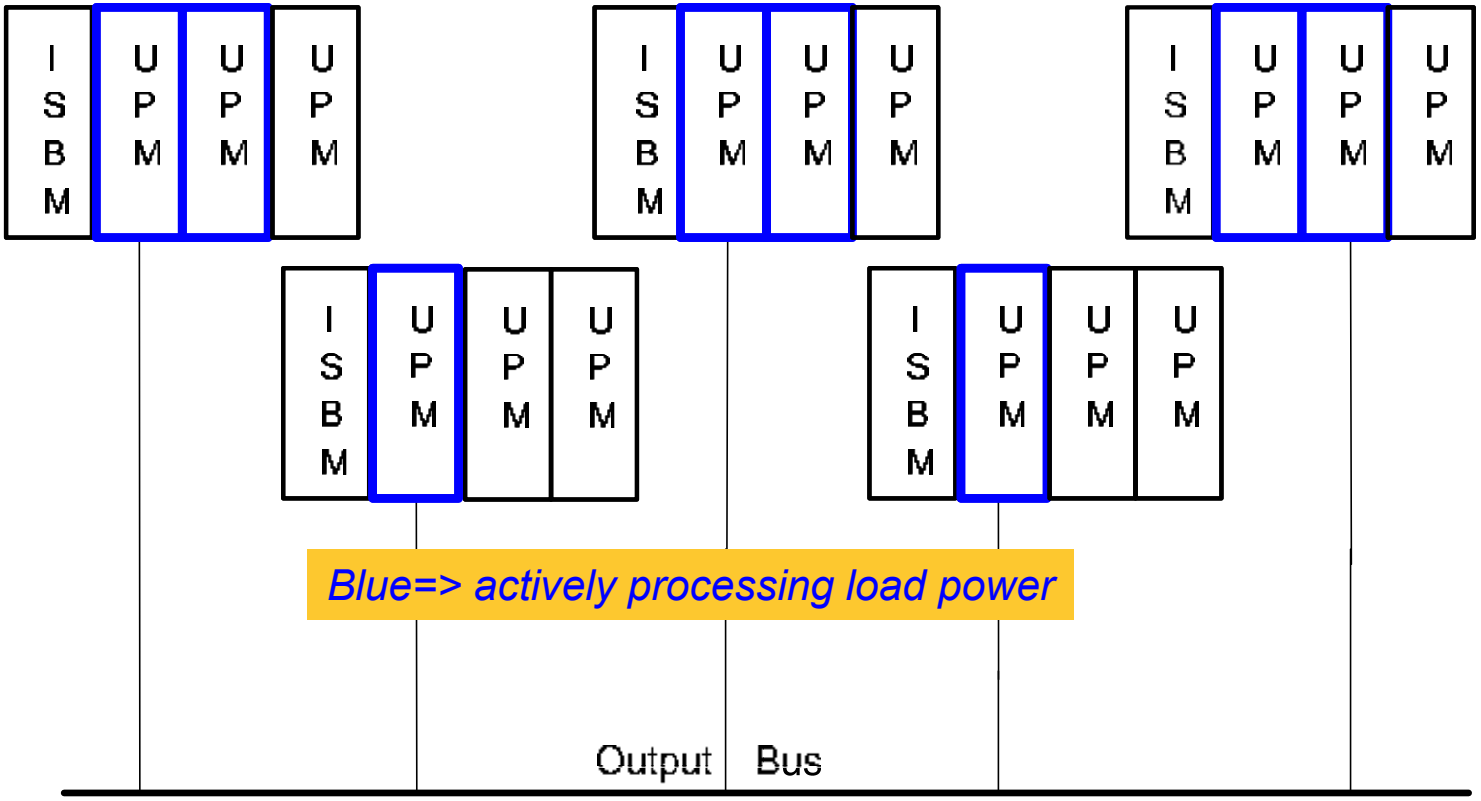


Same Circuit with transistors off.

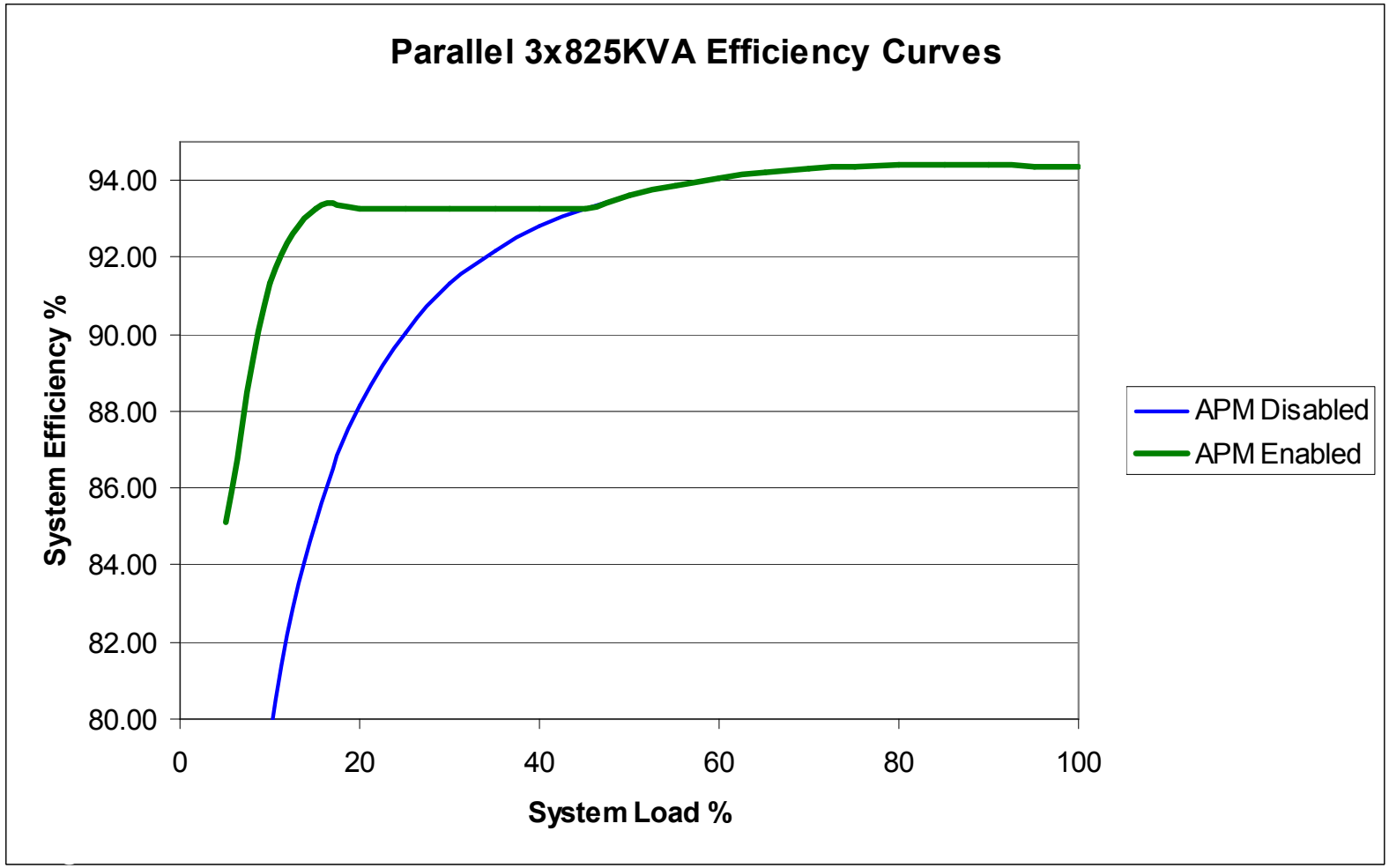
- ***The pumpback diodes rectify the critical bus output and create appox. 700vdc on the pos and neg dc rails.***
- ***The pumpback diodes act as a 3phase bridge rectifier.***

Pumpback Diode — A diode in the Inverter assembly that pumps excess energy back into the DC link during transistor turn off or transfers on and off line.

Parallel UPS with Module Management enabled

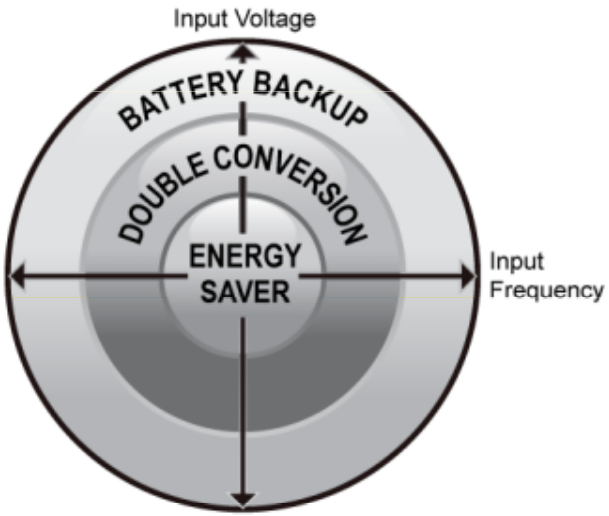


Enhances efficiency in multi-module system

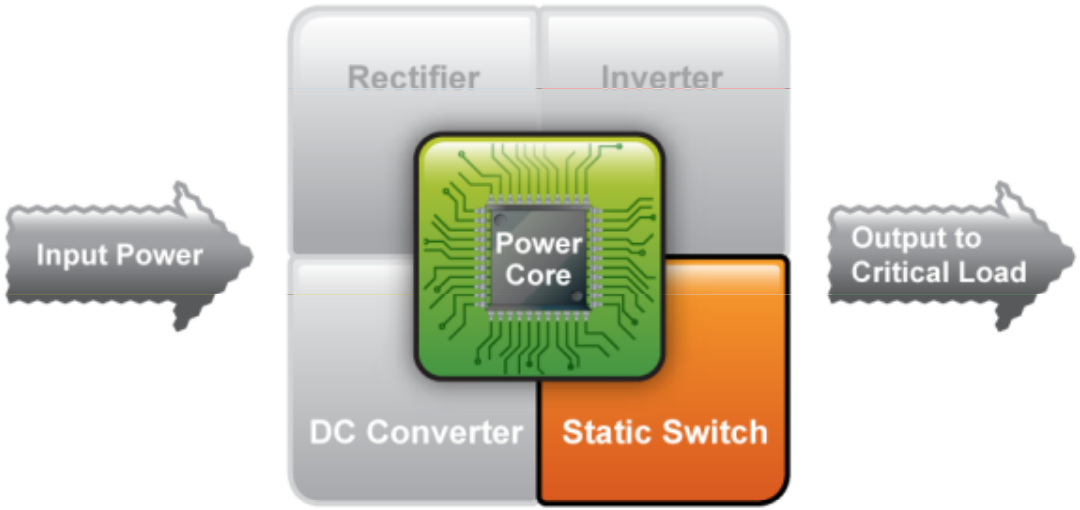


ESS=Engage subsystems in real time, based on input power quality

Input Power Quality



Active Modules

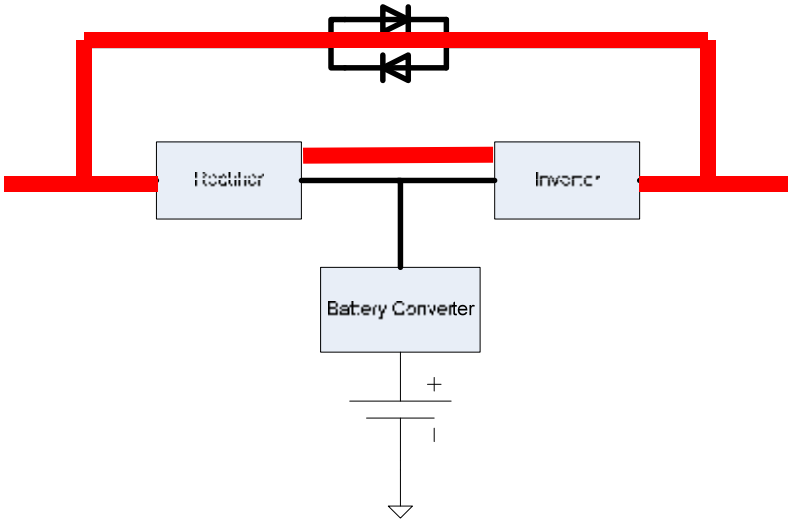


Energy Saver/Eco Modes

High Efficiency Mode

In high efficiency mode the load is supported from the bypass. All power converters are off and are in the “ready” state (in case a forward transfer is needed). During this mode, the output contactor is closed and the DC link is maintained thru the diode bridges. If the utility exceeds the output rating, the unit will transfer to standard mode of operation until the utility returns within limits.

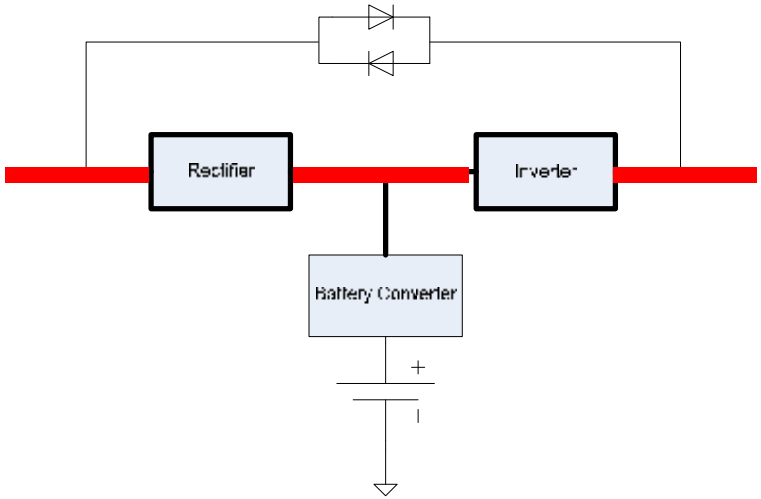
Output regulation online (voltage / frequency) will ramp to match utility when transitioning between HE mode and online mode.



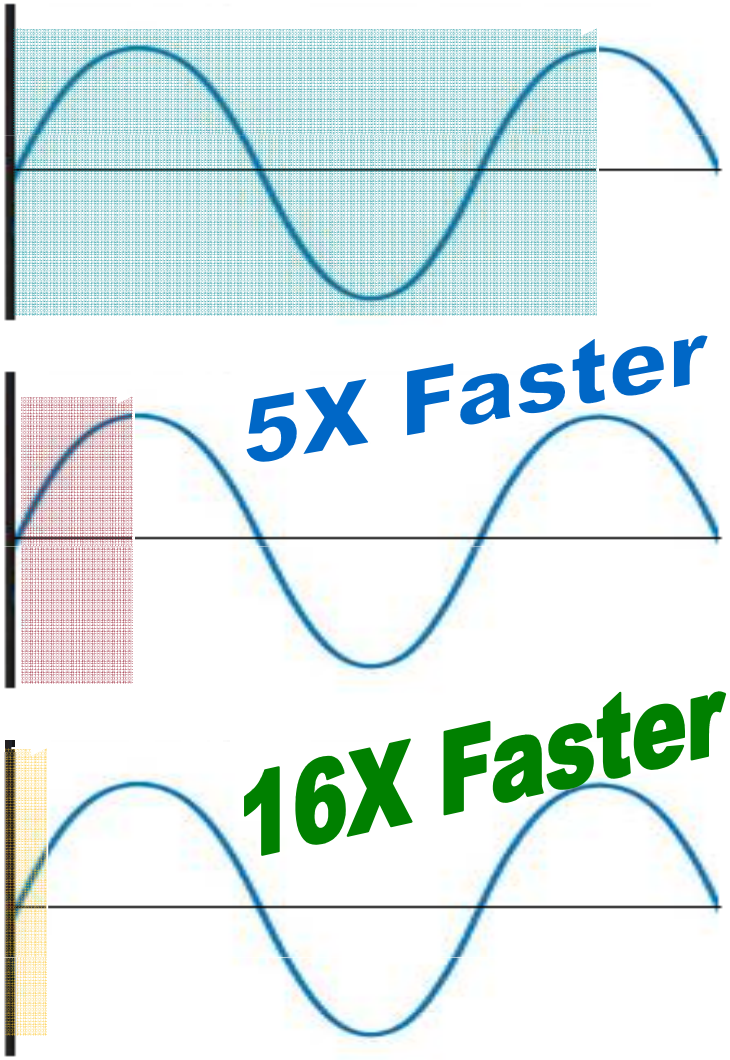
Automatic mode selection

High Alert Mode

In high alert mode the unit transfers from high efficiency mode to online (standard) mode for one hour (*EEP configurable*). At the completion of the hour, the unit defaults back to high efficiency mode. If the high alert command is received during the one hour, the one hour timer will be restarted.



Energy Saver System is Fast



Computer system tolerance.
20 mSec…..1/50th of a second

Digital Static Transfer Switch (STS).

4 mSec…..1/250th of a second

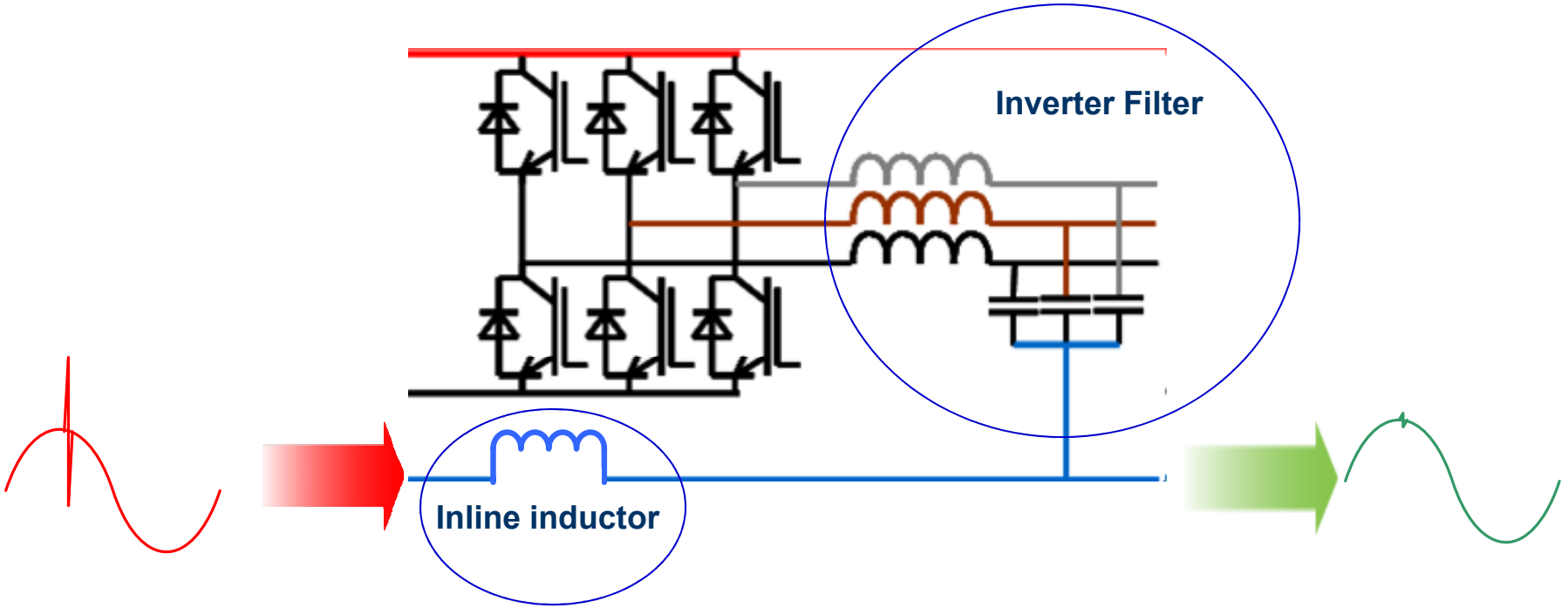
Energy Saver System.

1.2 mSec total…1/830th of a second

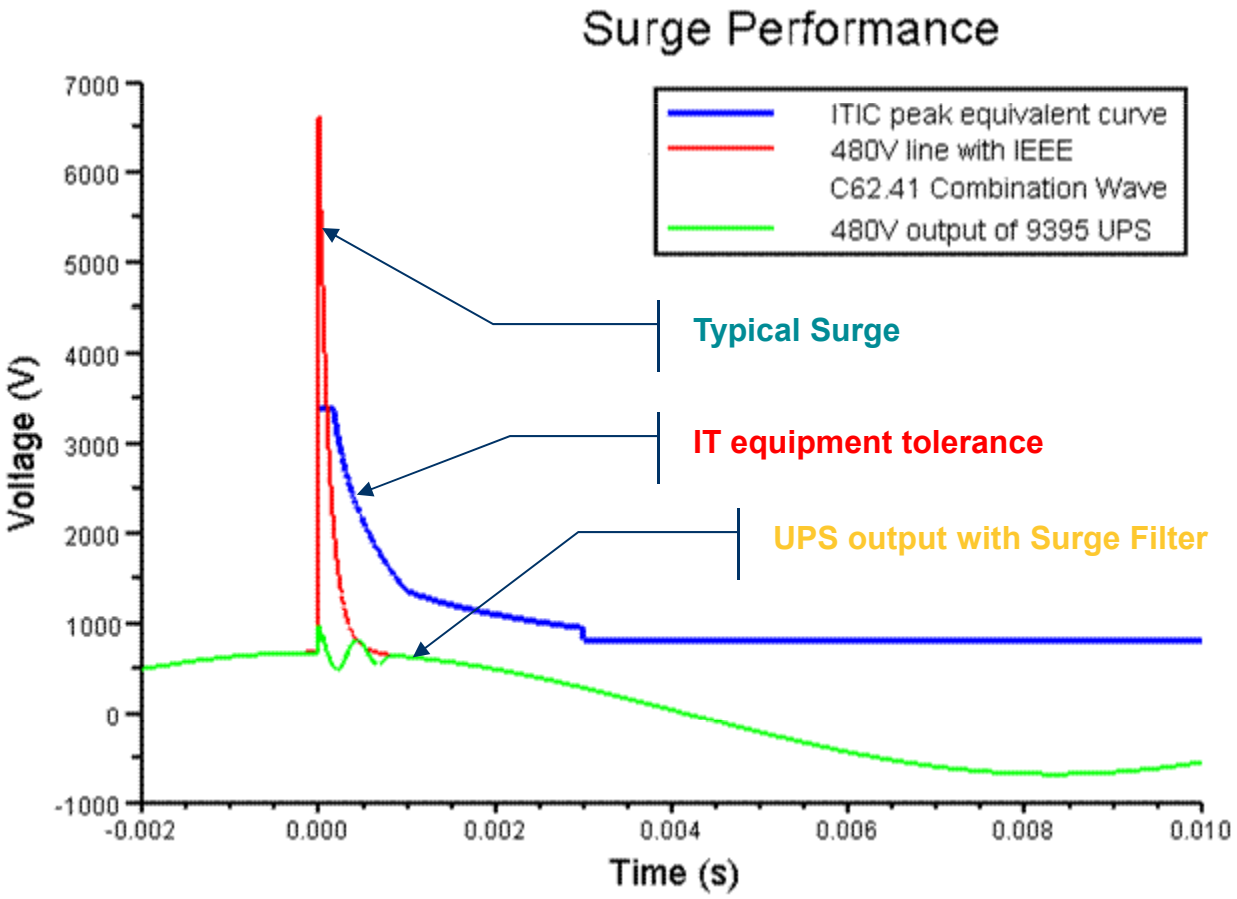
(Inverter is engaged in 620 micro-seconds!)

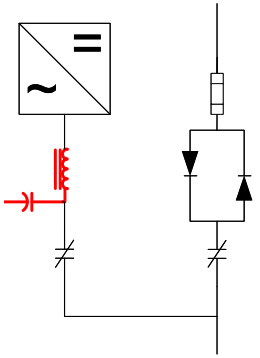
What about power line transients?

- In either ESS or VMMS mode the inverter filter is continuously “on-line” – it works with an inline inductor to filter out any abnormal line transients. Need proof?

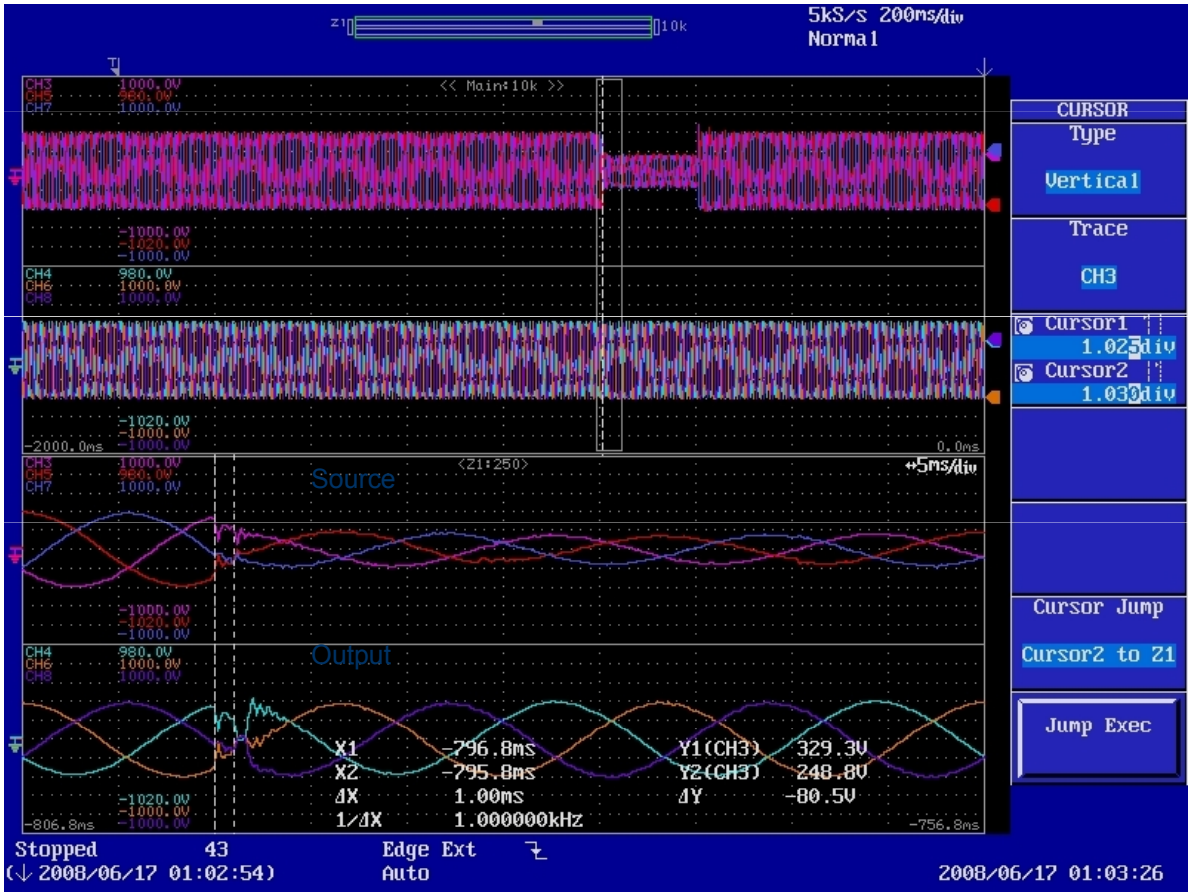


ESS Technology





Field Testing - Three Phase Outages Continued



Test Setup

- Source Channels -> 3,5,&7
- Output/Load Channels -> 4,6,&8
- Load -> 225KVA ΔY Transformer with 100KW Resistive Load
- Unit -> 275KVA IR (Internal Redundant) with Separate Batteries

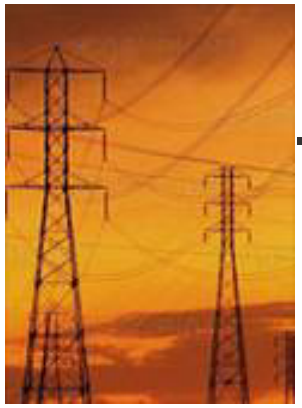
Test Description

- 40 cycle 40% dropout sequence (All Phases)

Test Result

- 1.6ms Transfer Time (1ms detection time plus 600us SCR clearing time).

Possibilities with Dual Bus Configuration



50% of Load

ESS 99%
Efficiency

"A"

Energy Saver on "A"

"B"

VMMS > 94%
Efficiency

50% of Load

Module Management on "B"

- **> 3%** efficiency improvement over existing double conversion only approach
  - Energy Saver 99% efficiency for 50 % of the system load
  - Module Management >93% efficiency for 50% of the system load
- Double Conversion backup for 100% of system load
- For dual source – no need for downstream static switch

Energy Saver System – The Bottom Line – 250kW

Summary Table

Critical Load	50 kW	125 kW	250 kW	500 kW	700 kW
Electric Costs *(energy + demand) per kW hr*	$0.11	$0.11	$0.11	$0.11	$0.11
Legacy UPS efficiency	92.5%	92.5%	93%	93%	93%
Eaton ESS UPS efficiency	**99%**	**99%**	**99%**	**99%**	**99%**
3-Year energy savings	145 MW hr	363 MW hr	670 MW hr	1340 MW hr	1876 MW hr
3-Year CO_2 savings	104 metric tons	261 metric tons	481 metric tons	962 metric tons	1347 metric tons
Cars off the road	6 cars	16 cars	29 cars	59 cars	82 cars
3-Year electric cost savings	**$15,972**	**$39.929**	**$73,715**	**$147,431**	**$206,403**

- **The energy savings from ESS typically recovers 100% of the UPS cost over a 2 - 3 year period**
- **Every 250kW with ESS is equivalent to pulling 29 cars off the road.**