Transformerless UPS Concepts and Capabilities for Large System UPS

Ed Spears

Mission Critical Webcast

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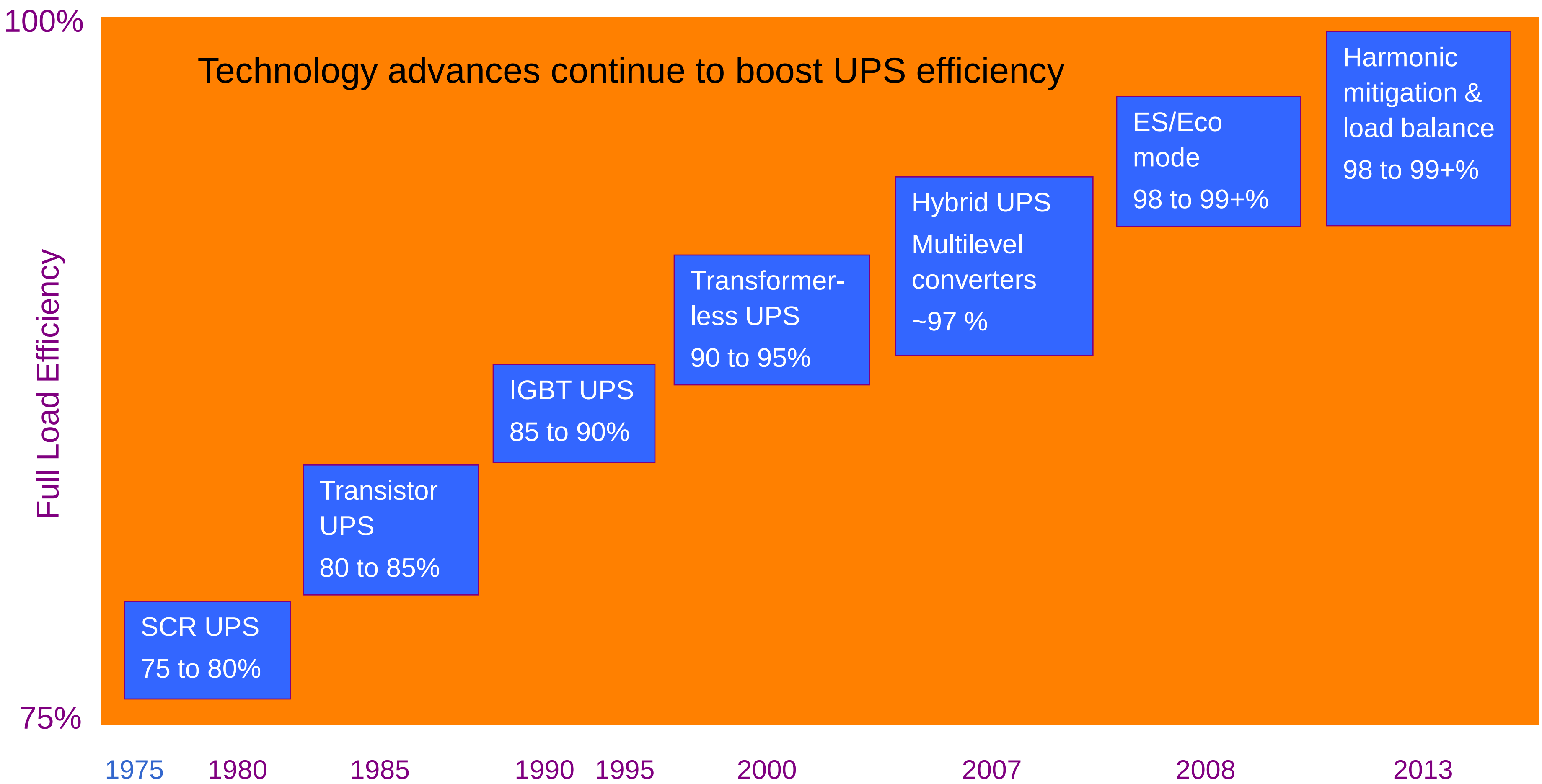
First, A Little History……

Technology and Efficiency over the Years



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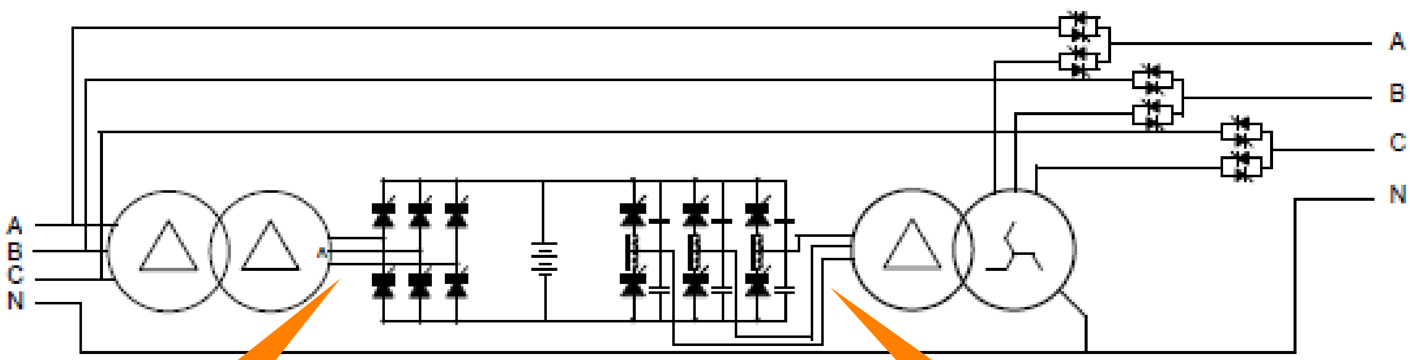
Transformerless Advantages

- Smaller system size and weight
  - Transformers are big contributors to these key factors
- PWM Rectifier provides high input PF and low THD over wide line and load range
  - Doesn’t require large input harmonics filters
- Efficient Operation
  - No transformer power losses and optimized DC Link voltage
- Uses IGBT converters, all of identical make-up
  - Standardizes on power circuits, components, and support
- Maintains an optimally high DC buss for the inverter
  - Significant reduction in current handling for inverter components
- Reduce inrush current and improved generator compatibility
- Technology current
  - IGBT performance/cost has steadily improved over the past 10 years
- Green and Sustainable
  - Reduction in iron, copper, and varnish usage

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



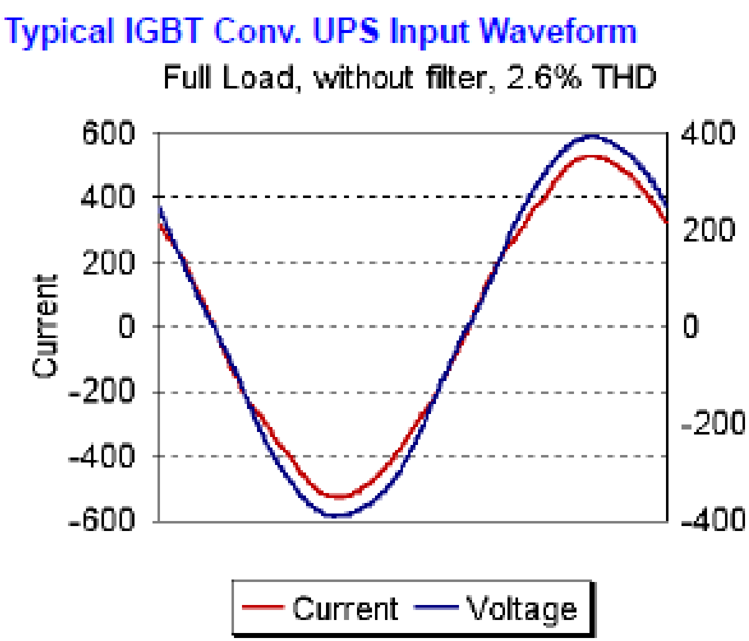
Input Transformer and 6-Pulse Rectifier

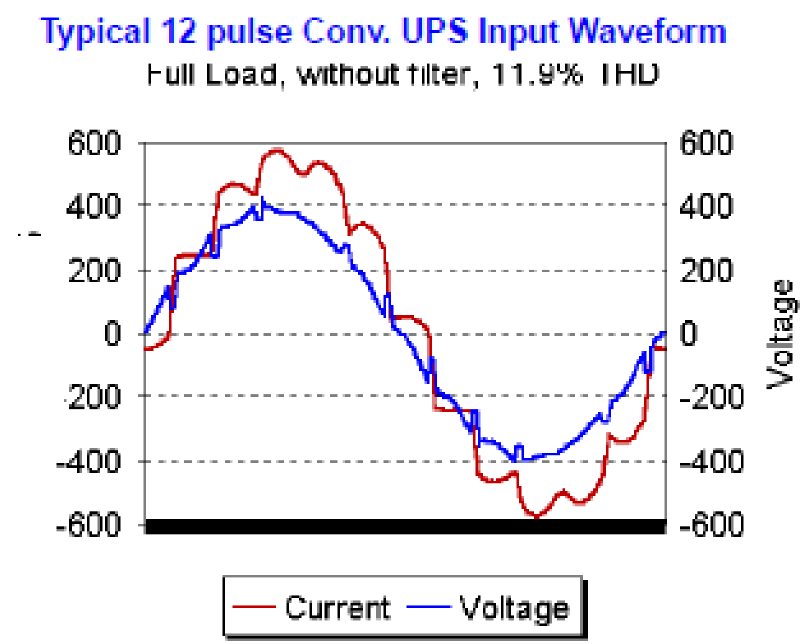
Force-commutated Inverter and Output Transformer

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





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Transformerless UPS
Allows Significant Size and Weight Reduction

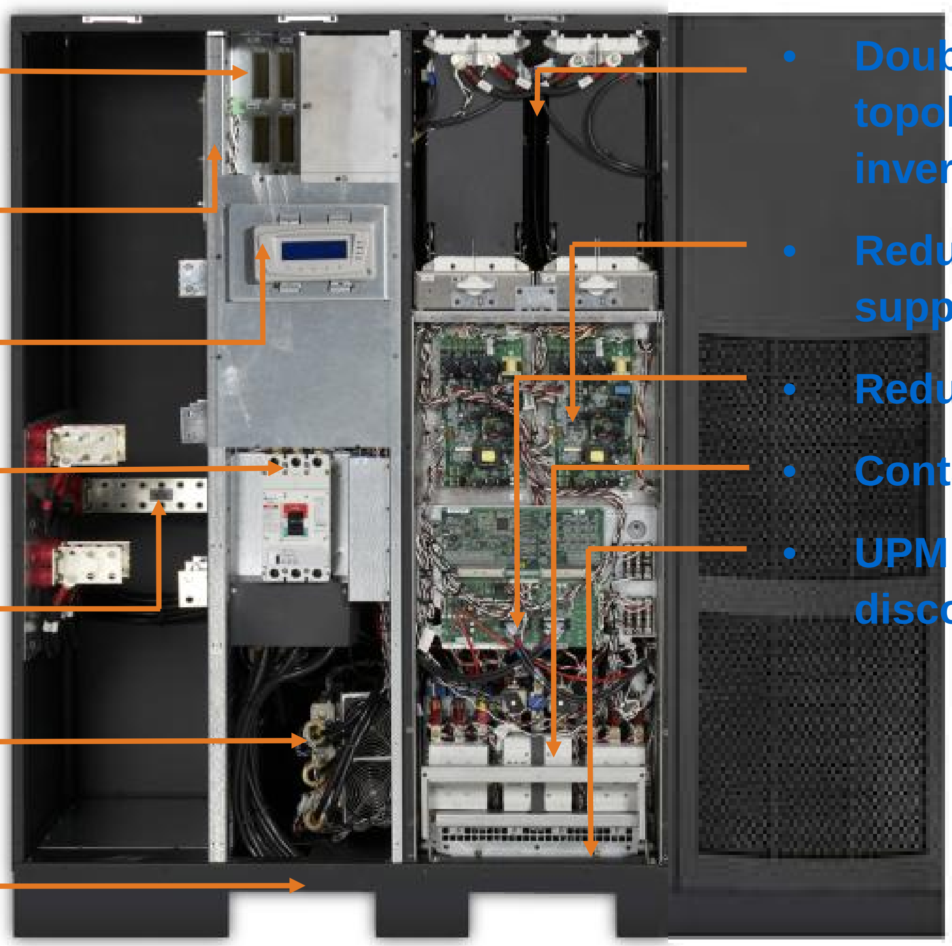
(Below – 275 & 300KVA Examples)

Transformer-free mag pak

Transformer-based mag pak

Inside the Transformerless 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 UPM Section

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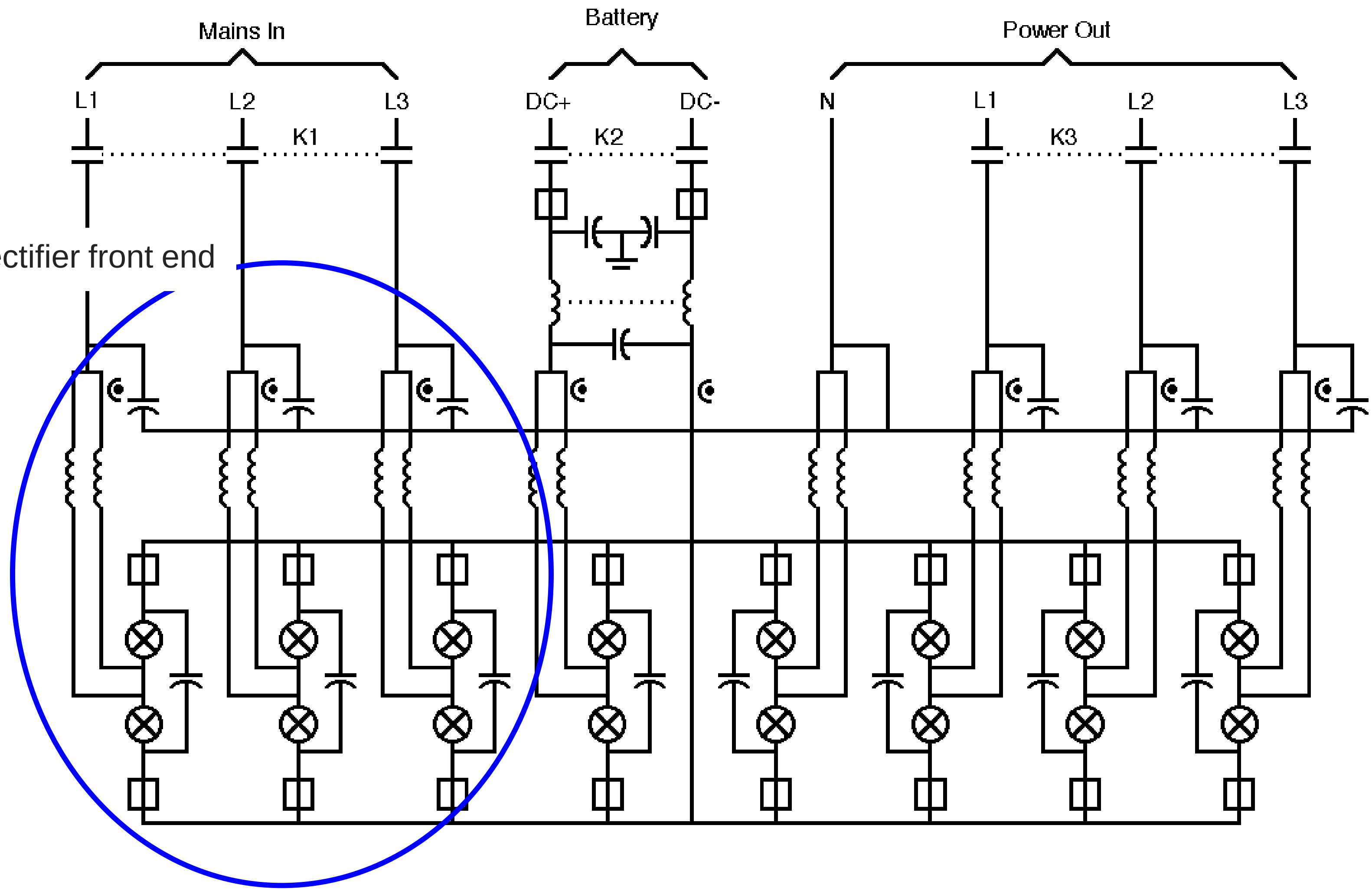
Transformerless Disadvantages

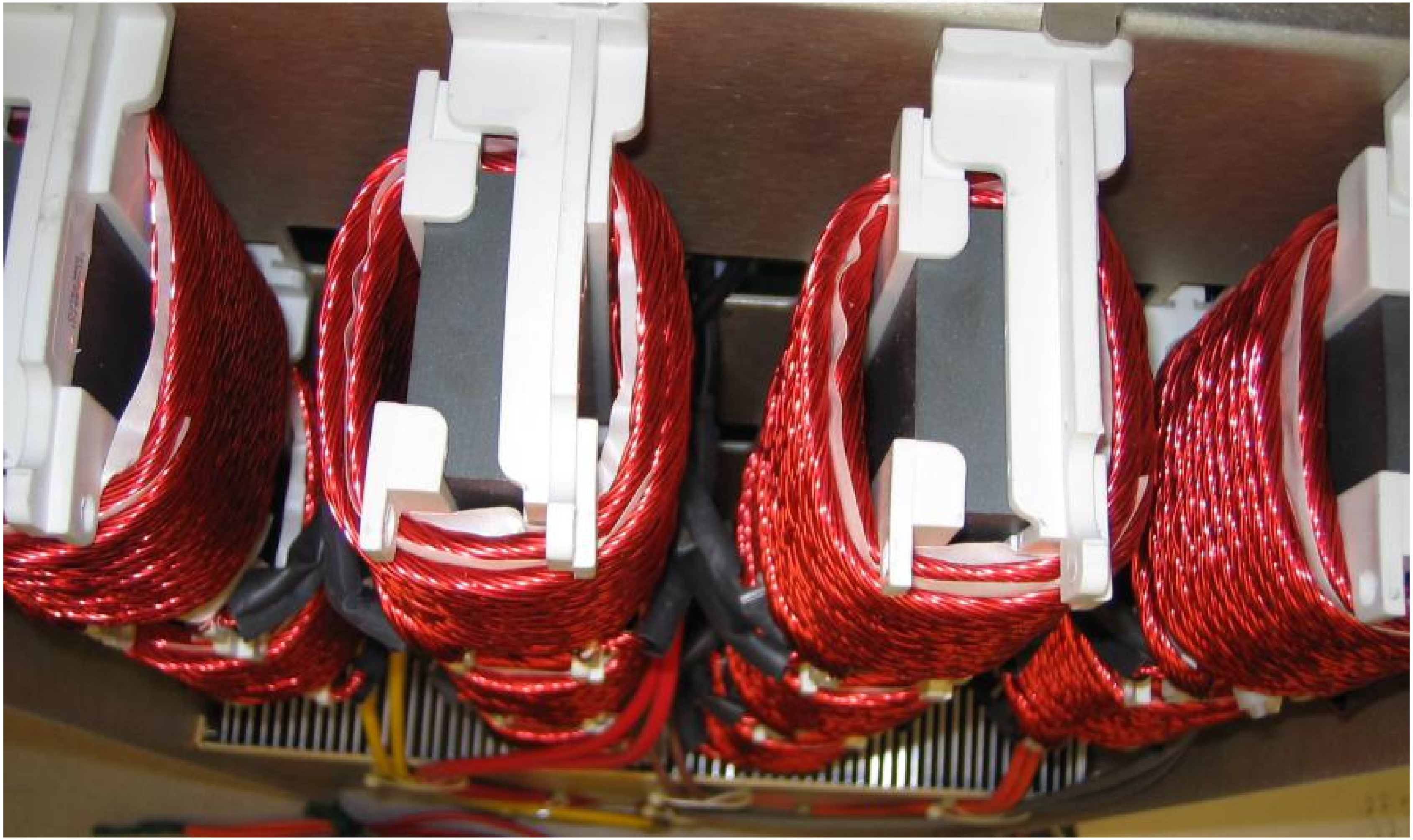
- No galvanic isolation
  - Battery is not isolated
  - No transformer based common mode noise isolation
- Requires specialized Hi Z battery fault detection equipment
- Higher DC Link voltage (when compared to SCR front end)
- Neutral phase leg required for L-N loads (WYE output)

Transformerless Topology
Simplified Schematic Diagram

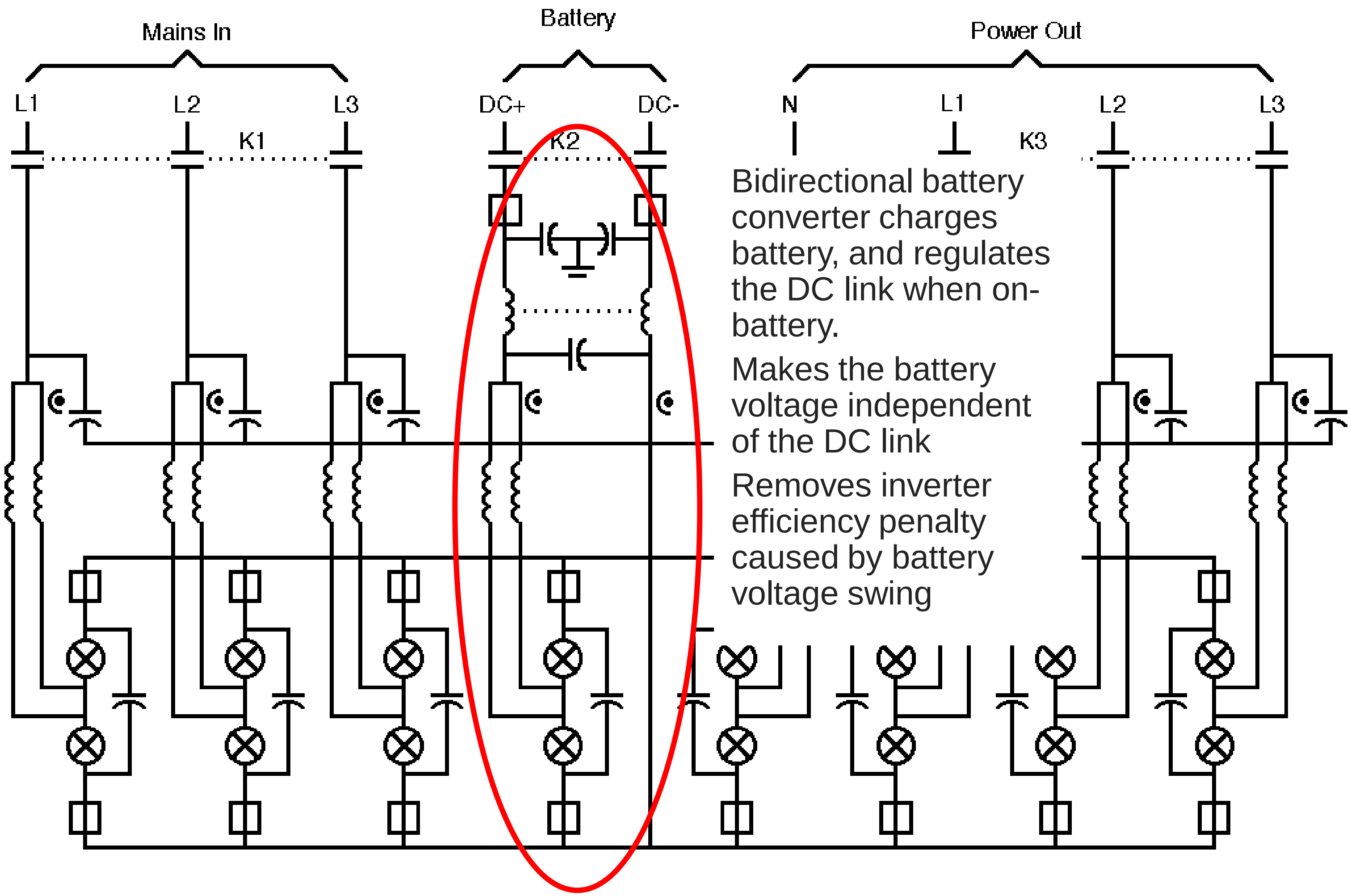
IGBT rectifier front end



Hybrid and Air-core Inductor Designs—Less Space, Weight, Plus Cooler operation



Transformerless Topology
DC-DC Converter



Bidirectional battery converter charges battery, and regulates the DC link when on-battery.

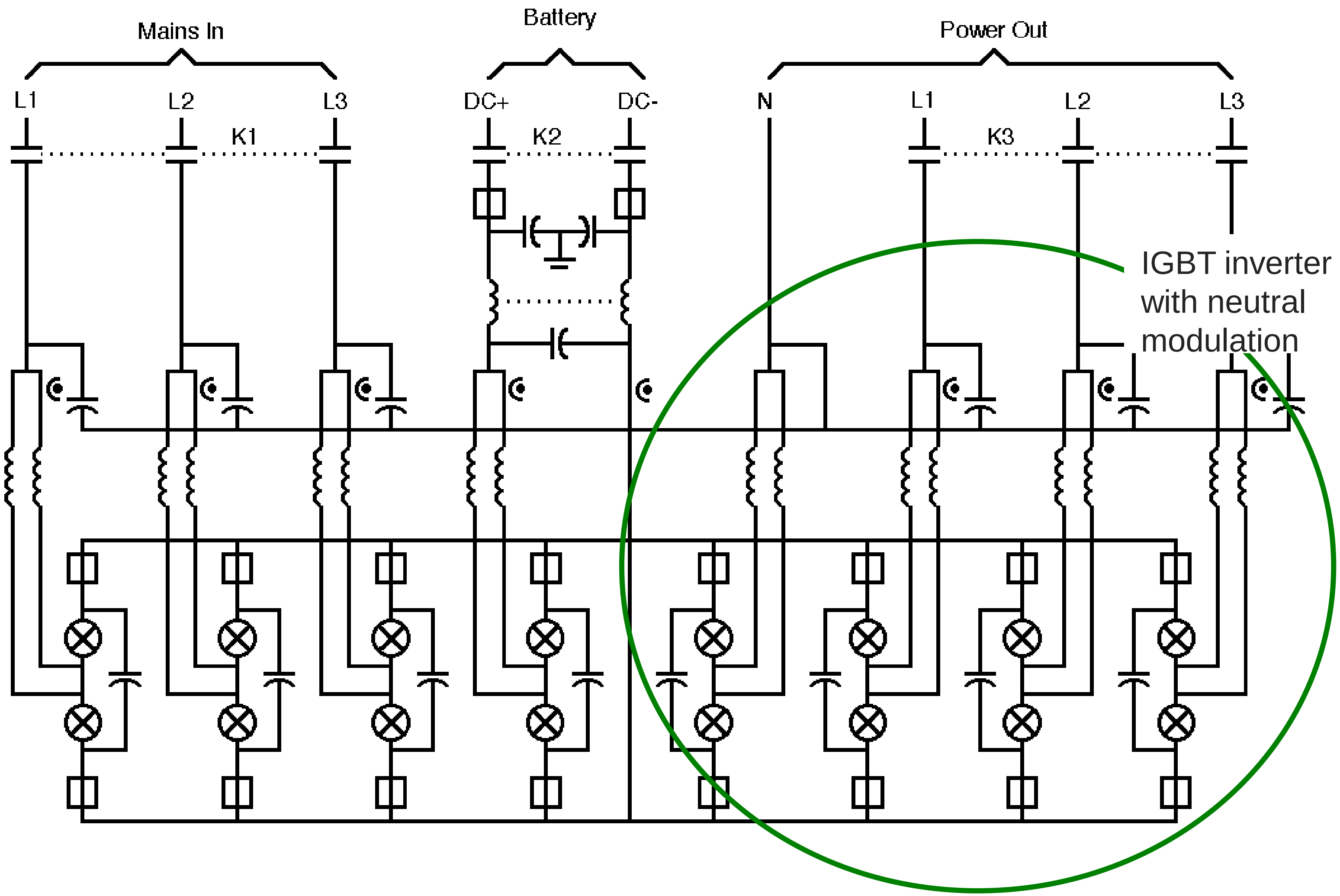
Makes the battery voltage independent of the DC link

Removes inverter efficiency penalty caused by battery voltage swing

The Battery Converter and Why

- Removes inverter efficiency penalty (current penalty) caused by battery voltage swing
- Makes the battery voltage independent of the DC buss voltage
  - Accommodates a broader range of nominal battery voltage configurations
- Provides system flexibility with many other DC sources including flywheels, ultra-caps, PV, etc.

Transformerless Topology
3 or 4-wire Inverter



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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

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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

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More on Eaton Transformerless Topology

- The myth
  - *The lack of an output transformer decreases the overall reliability of the system.*
  - *The transformer helps the inverter handle faults, protecting it from high fault currents*
  - *Similarly, the transformer protects loads from inverter faults, preventing them from having DC voltage applied to them when an inverter fails*
- The Truth
- Low-frequency inverters, driven by low-bandwidth analog or rudimentary microprocessor controls, do benefit from the increased impedance presented by either a large inductor or a transformer in the output of the inverter, as slow response controls requires the current's rate of rise to be slowed down in the event of a fault
- Transformerless topology has its foundation on:
  - High-frequency PWM power conversion
  - High-bandwidth advanced DSP controls, with sampling rates above 33 KHz (once every 30 microseconds)
- High-bandwidth controls do not get any benefit from additional impedance on the output of the inverter – on the contrary, they rely on <u>instantaneous</u> information to maintain best performance conditions

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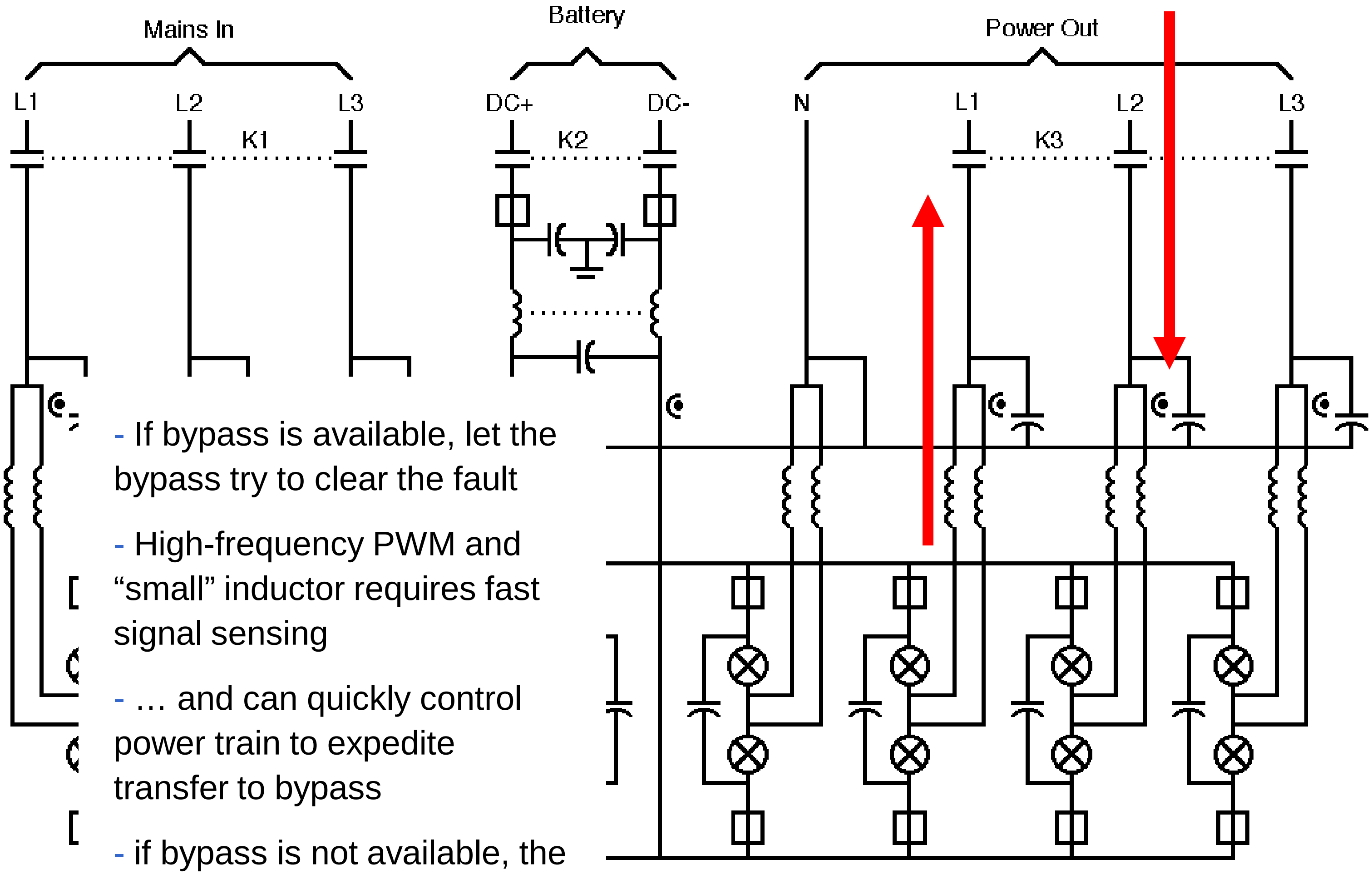
Handling output faults



- If bypass is available, let the bypass try to clear the fault
- High-frequency PWM and “small” inductor requires fast signal sensing
- … and can quickly control power train to expedite transfer to bypass
- if bypass is not available, the inverter supplies 300ms of limited fault current

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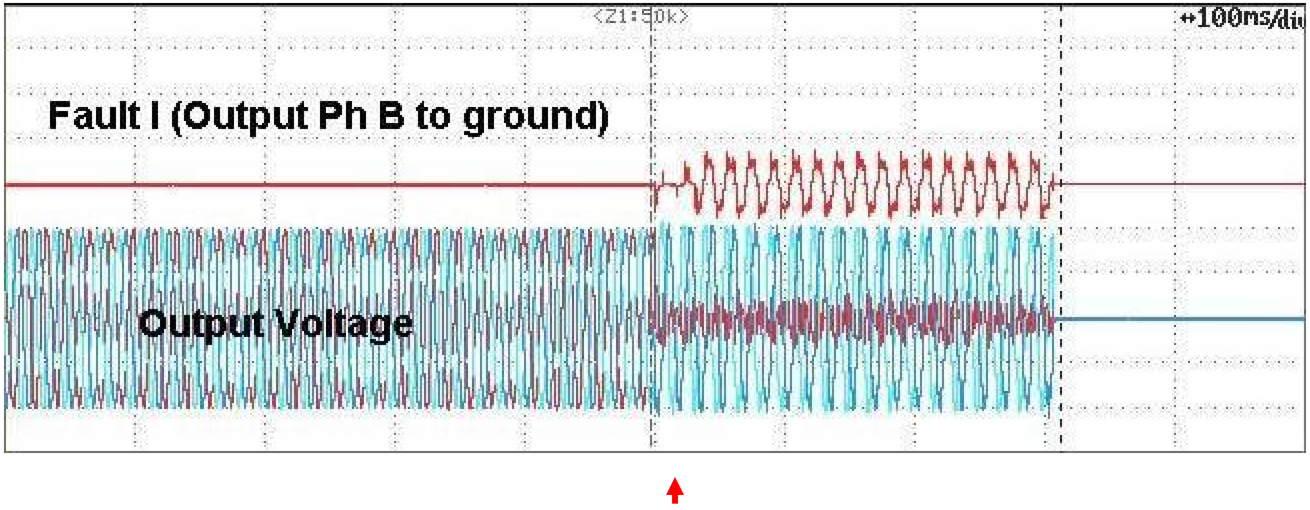
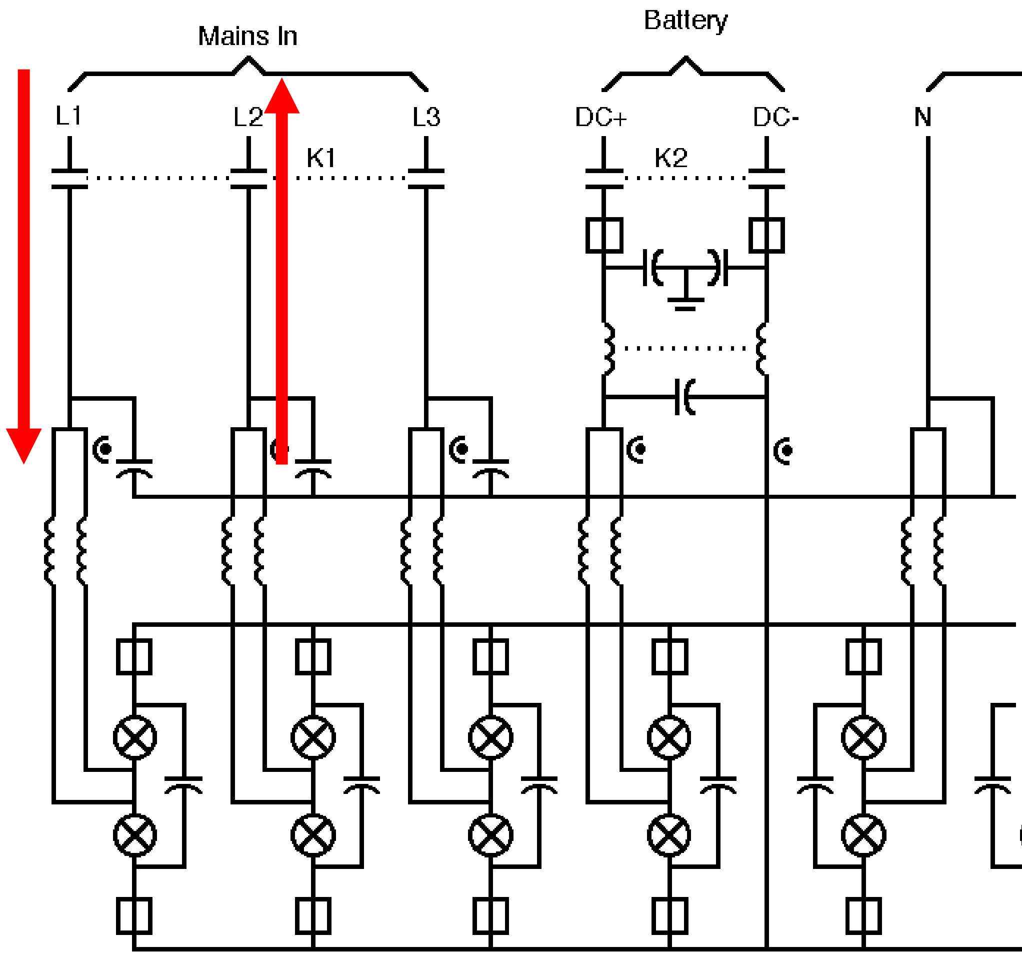
Output Fault Test

- Single 9395 1100KVA 480V UPS
  - 480Vin/480 Vout
  - Common Battery
    - (8) 1085 Cabinets 475W/240 Cell
  - 98% Load
  - Bypass Not Avail (therefore no bypass intervention, all inverter)
  - Fault applied output Ph B to ground

- Test Results: Unit services short for 300mS without damage or without tripping breakers
  - Waveform: voltages are 200V/div and fault current is 4000A/div



Handling input faults…

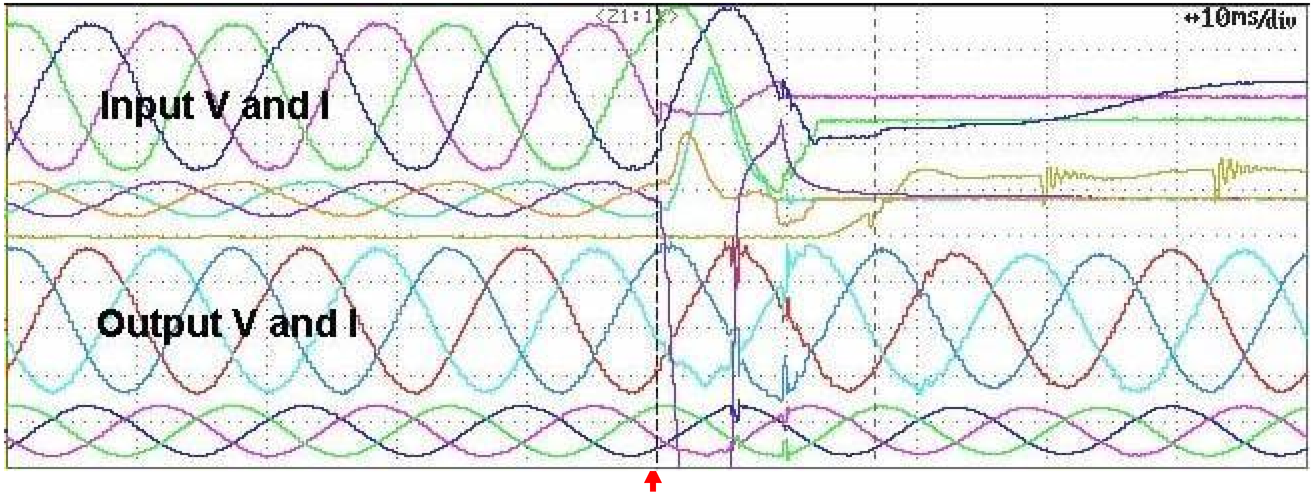


- Similar to output faults, high-frequency PWM and “small” inductor requires fast signal sensing
- … and can quickly control power train to expedite transfer to battery mode

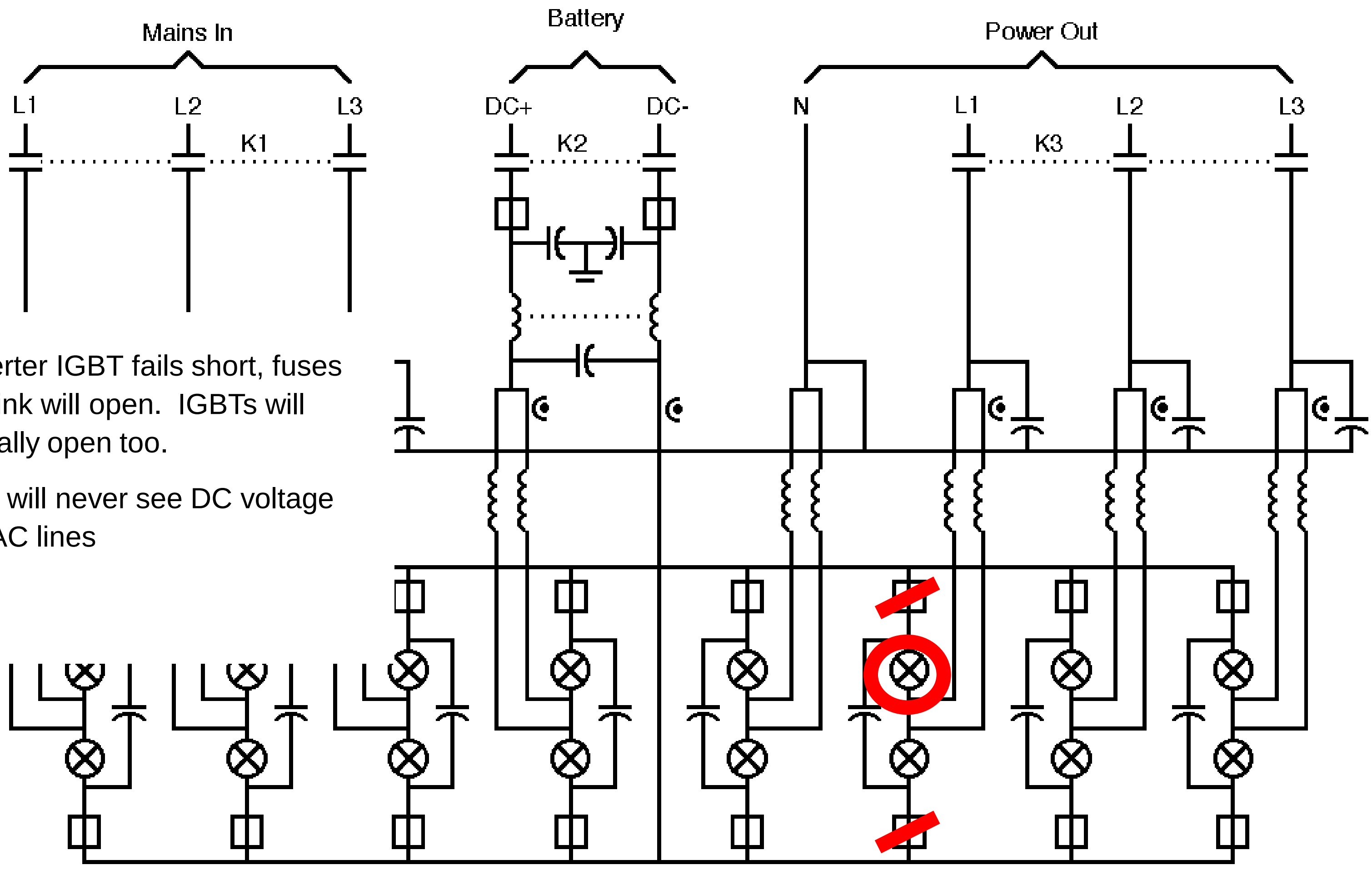
Input Fault Test

- Single 9395 275KVA 480V UPS
  - 480Vin, 480Vout
  - Battery
    - (2) 1085 Cabinets 475W/240 Cell
  - 100% Load
  - Fault applied at UUT input Ph B to ground

- Test Results: Input breaker trips (part of test setup) and unit drops to battery
  - Waveform: voltages are 250V/div and fault current is 1200A/div



Protecting the Mission Critical Load…

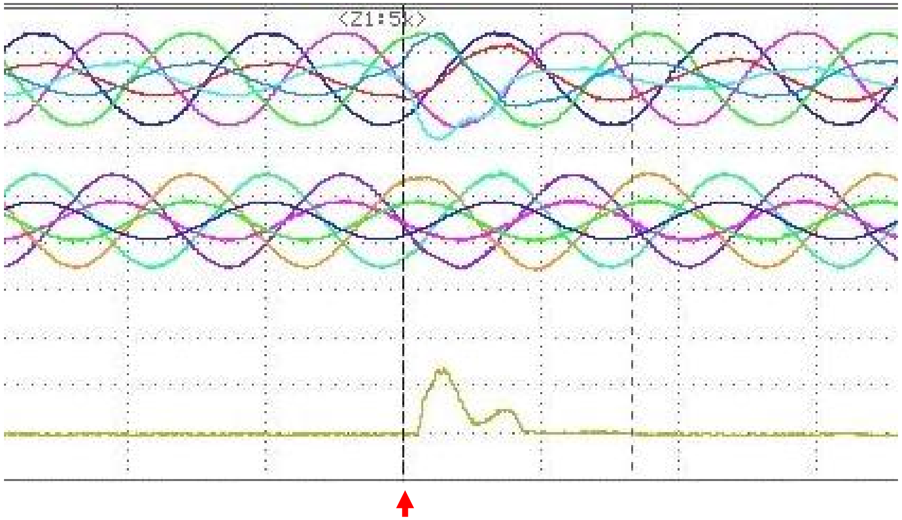


- If inverter IGBT fails short, fuses in DC link will open. IGBTs will eventually open too.
- Load will never see DC voltage at the AC lines

IGBT Internal Fault Test

- Single 9395 825KVA 480V UPS
  - 480Vin/480 Vout
  - Common Battery - (8) 1085 Cabinets 475W/240 Cell
  - 100% Load
  - Short circuit applied collector to emitter, Rectifier IGBT, Q1, phase B on UPM1

- Test Results: Unit transfers to battery. Alarm “Check Rectifier PM1” is enunciated.
  - Waveform: voltages are 400V/div and fault current is 1000A/div
  - IGBTS Q1 and Q3 failed
  - Fuses F1 and F4 open



Battery Isolation

- Battery galvanic isolation in the UPS can provide a false sense of security, and *should not be depended on* as a safety feature
  - Battery terminals should be treated with the same caution and respect given to any AC terminal in the system
- If a UPS only has an input transformer, then the battery is not floating
  - An output transformer is required to isolate the battery from the energized output bus
- Concerns about safe Service associated with hot battery terminals should be addressed by:
  - Using plastic or rubber battery terminal covers
  - Service procedures or guidelines that require all battery maintenance to include the precaution of opening battery circuit breakers
  - Measures that are much less expensive than transformers
- The absence of battery isolation is not detrimental to the UPS completing its stated mission: to protect the critical bus

Battery Isolation

Common Mode Noise Isolation

- Data center and communications equipment today is immune to common mode noise due to improved power supply designs
  - It’s a good idea to confirm if galvanic isolation is “really” needed by the critical load
- Common mode noise isolation as a requirement
  - This requirement is limited to some medical and industrial/processing equipment
  - Often times a downstream PDU or IDC can be used to support this requirement
  - PDU can be located closer to the critical load where the noise isolation is most important

What other cool stuff can we do, once the transformer is eliminated?

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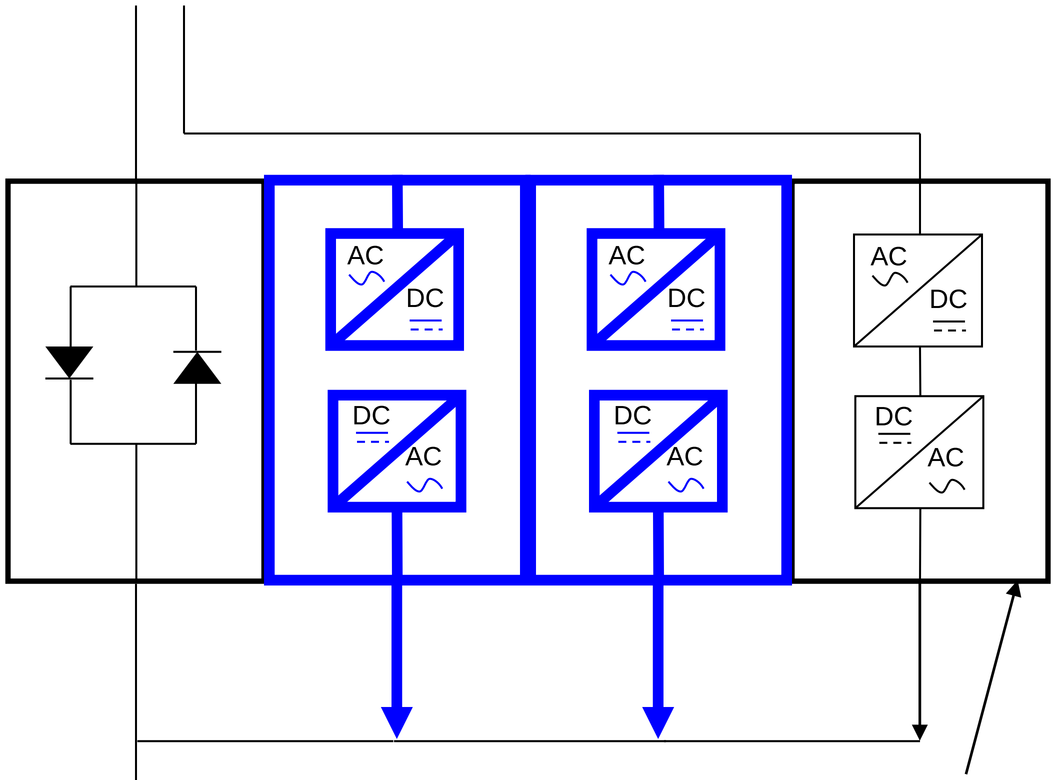
Variable Module Management System (VMMS)



- UPM not required to power load
- Remains Hot Tied to Critical Bus
- Assumes load in < 2ms when required

Load < 440KVA

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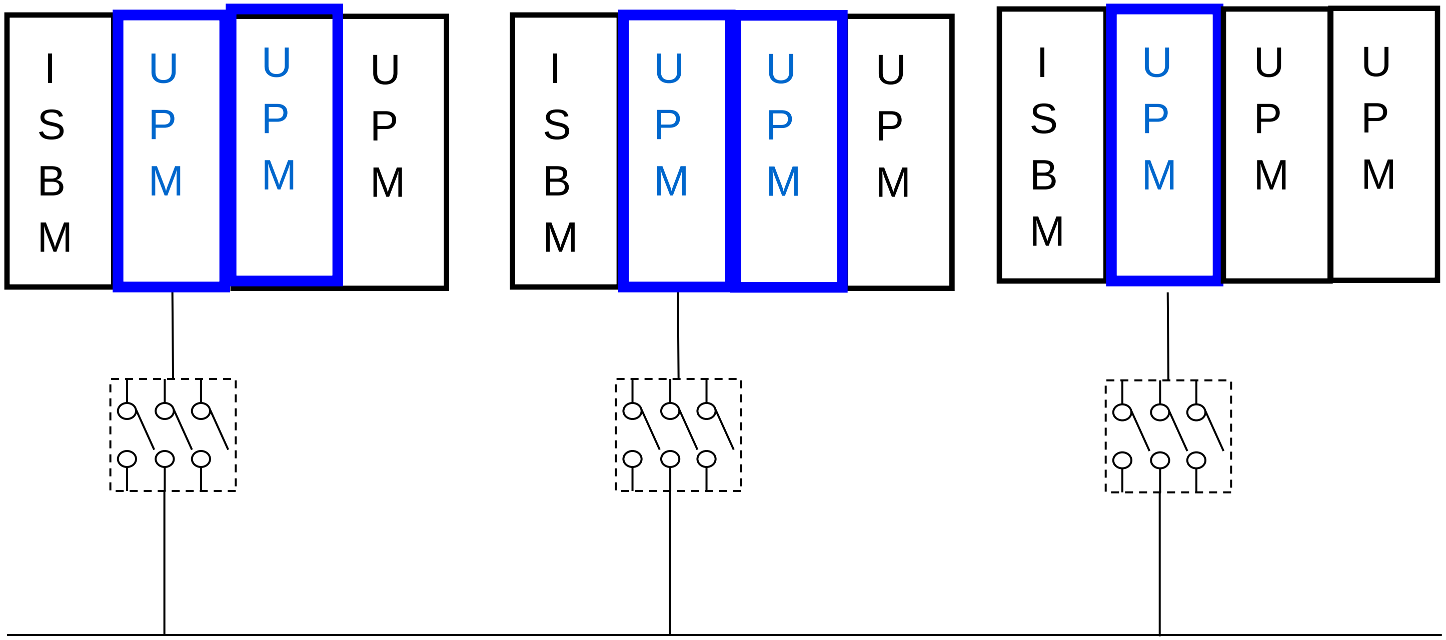
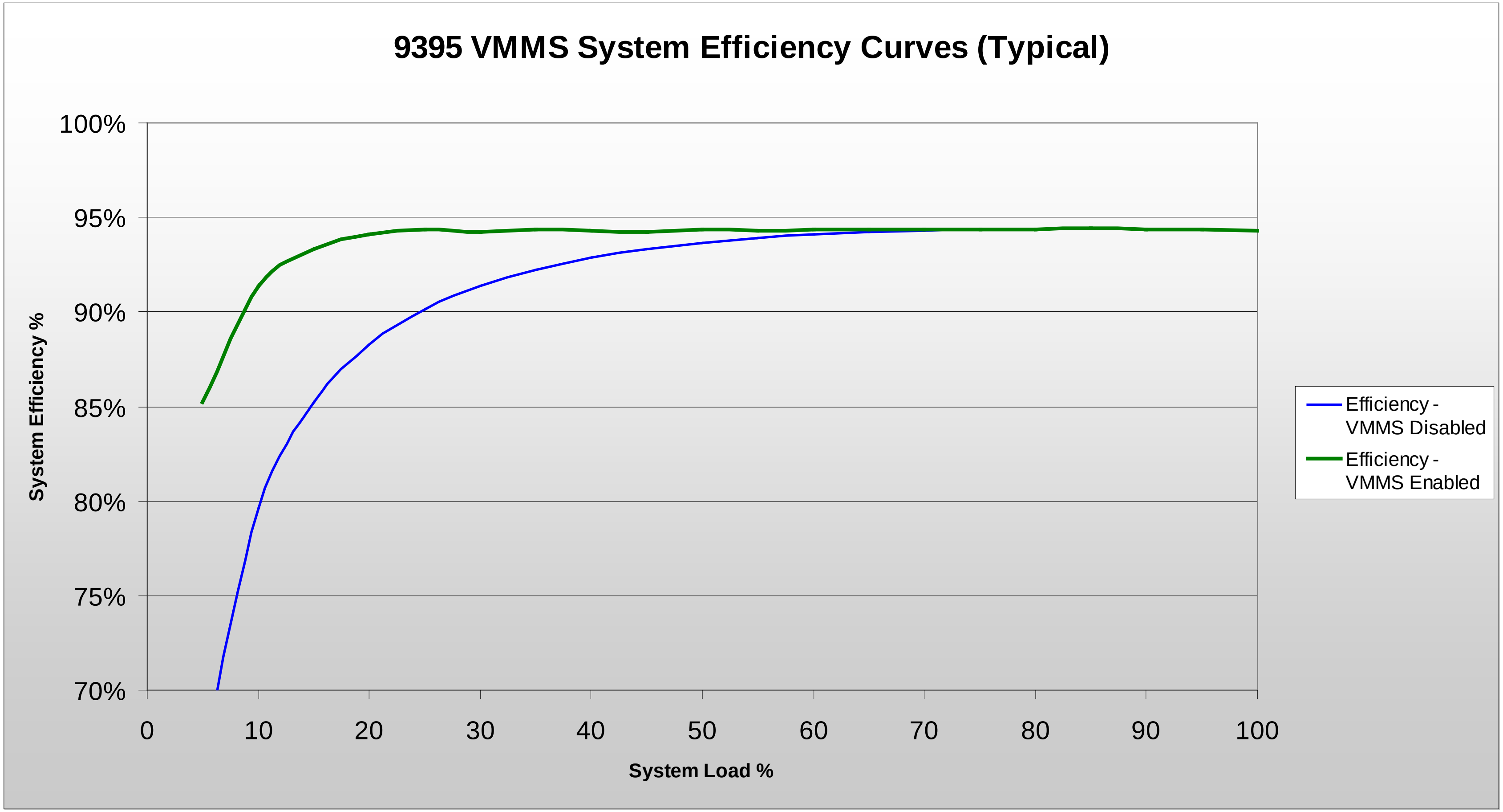
3 X 825KVA Parallel System with VMMS

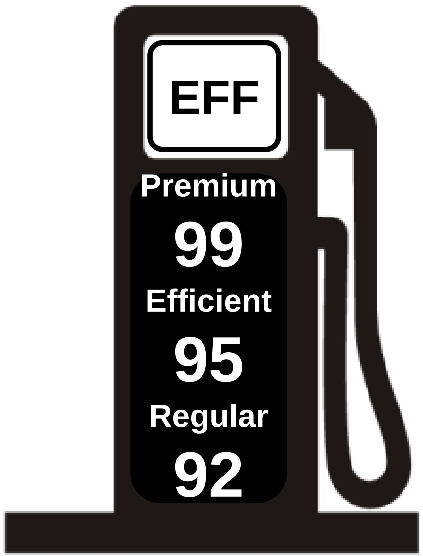


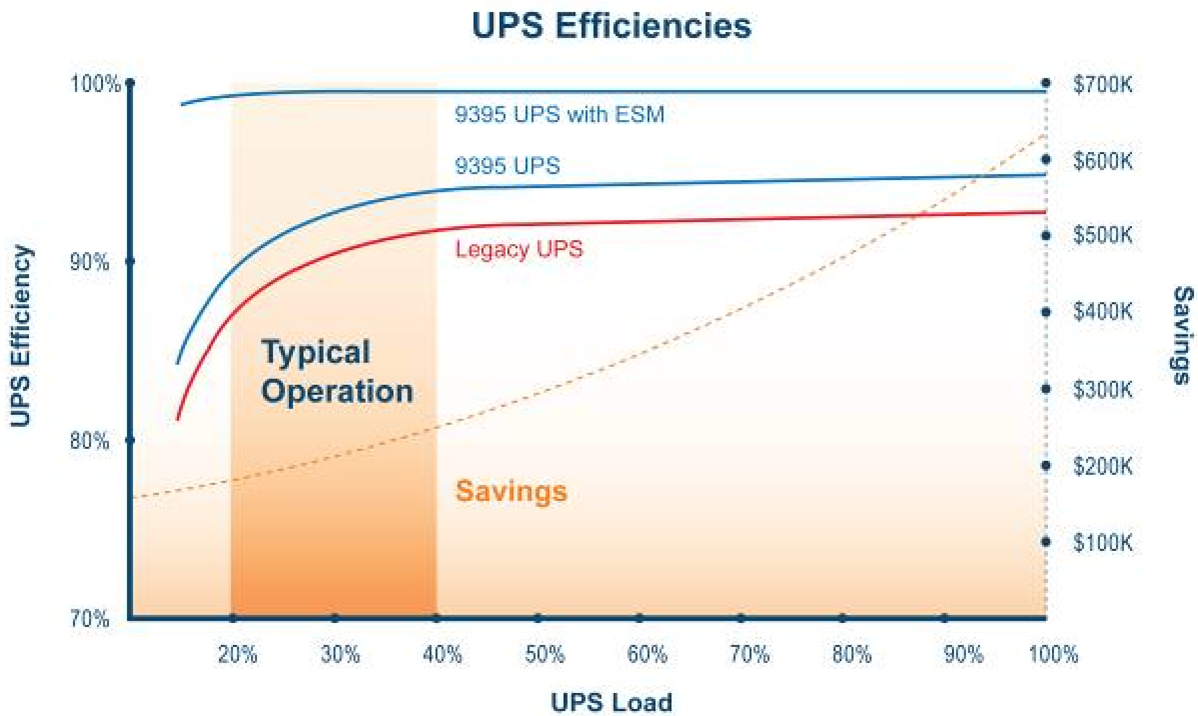
- Maintain UPM Loading of 80% to maximize efficiency
- UPM’s in VMMS-Mode are available to assume load in less then 2ms to respond to load changes.

3X825 Parallel System Efficiency



Energy Saver System
Maximum Efficiency Tracking





Savings based on 1MW at $0.1/Kw-hr

- Highest availability with 99% efficiency for a wide load range
- 85% reduction in losses compared to legacy transformer-based UPS
- Continuous power tracking and proprietary DSP algorithms combined with transformerless topology ensures critical loads are always protected

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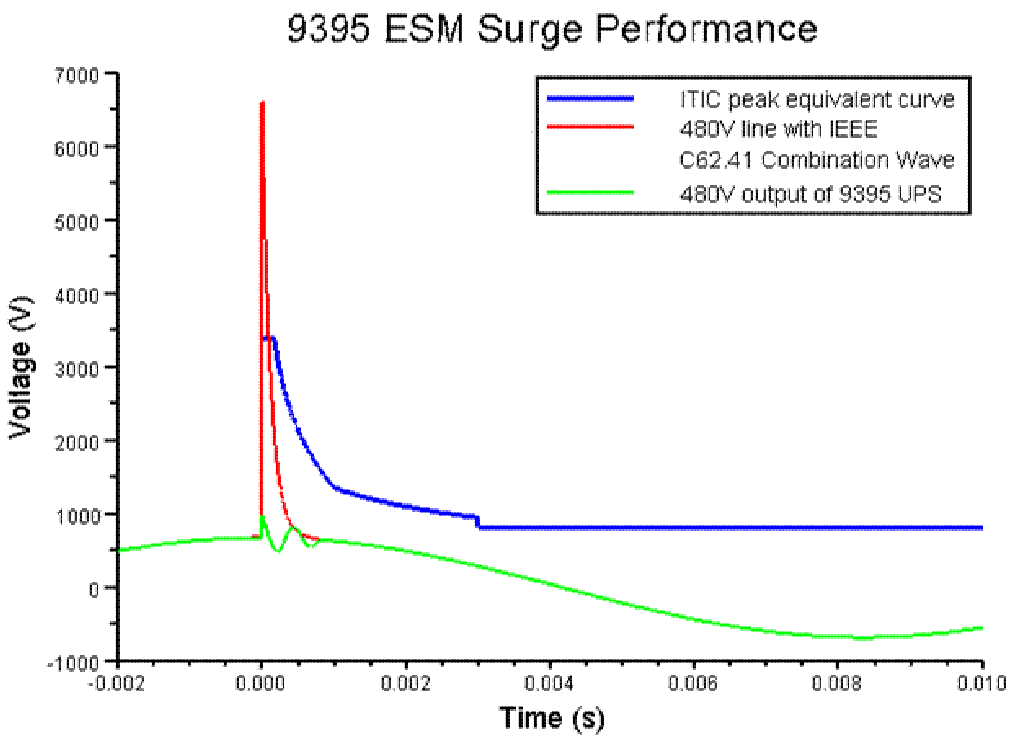
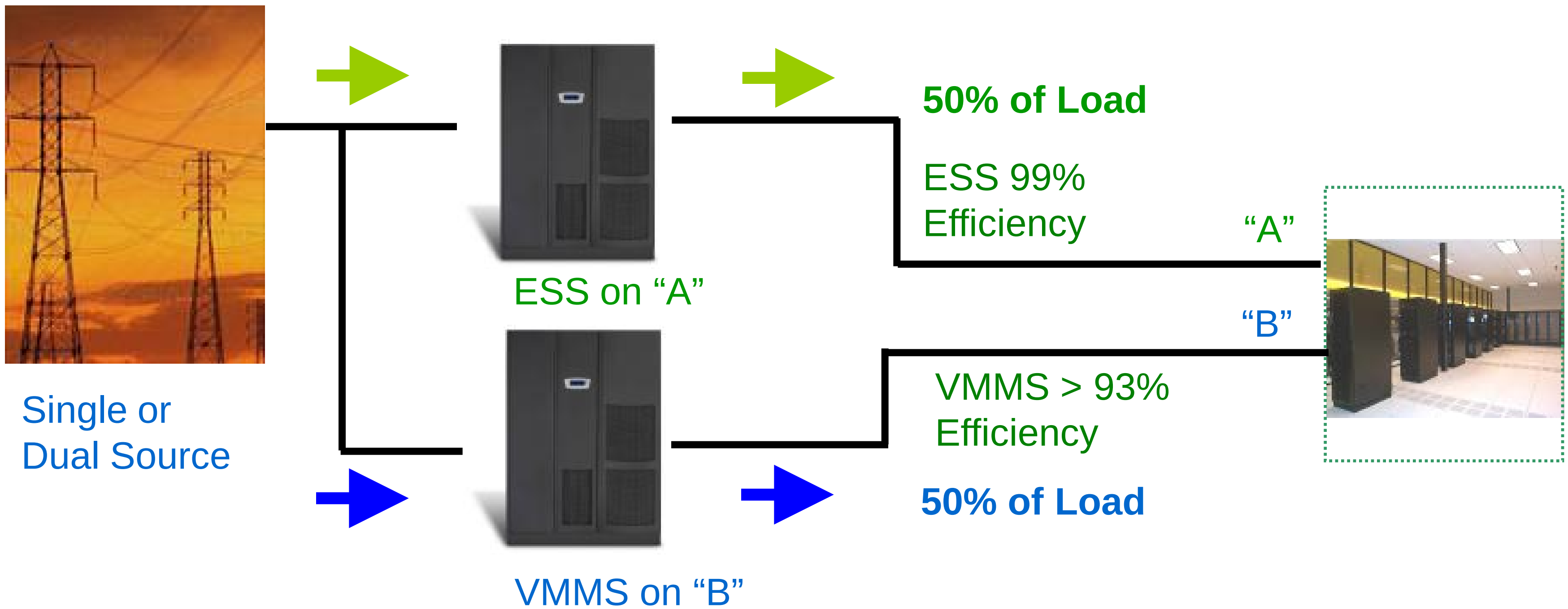
ESS Surge Response



ESS keeps the rectifier and inverter filters tied to the critical load bus, while the storage capacitors and power train semiconductors act as a peak tracking clamp

- minimizing spikes and noise
- attenuating line surges

ESS with VMMS Double Conversion



- **> 3%** efficiency improvement over existing double conversion only approach
  - ESS 99% efficiency for 50 % of the system load
  - VMMS >93% efficiency for 50% of the system load
- Double Conversion backup for 100% of system load

Questions

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