Transformerless UPS Concepts and Capabilities for Large System UPS

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Mission Critical Webcast
First, A Little History……
Technology and Efficiency over the Years

Technology advances continue to boost UPS efficiency

- **1975**: SCR UPS (75 to 80%)
- **1980**: Transistor UPS (80 to 85%)
- **1985**: IGBT UPS (85 to 90%)
- **1990**: Transformer-less UPS (90 to 95%)
- **1995**: Hybrid UPS (98 to 99+%) + Multilevel converters (~97%)
- **2000**: ES/Eco mode (98 to 99+%)
- **2007**: Harmonic mitigation & load balance (98 to 99+%)
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….”

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
Transformerless UPS  
Allows Significant Size and Weight Reduction  

(Below – 275 & 300KVA Examples)
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
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

IGBT inverter with neutral modulation
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
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 instantaneous information to maintain best performance conditions
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
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.
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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?
Variable Module Management System (VMMS)

Load < 440KVA

- UPM not required to power load
- Remains Hot Tied to Critical Bus
- Assumes load in < 2ms when required
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 than 2ms to respond to load changes.
3X825 Parallel System Efficiency

9395 VMMS System Efficiency Curves (Typical)
Energy Saver System
Maximum Efficiency Tracking

- 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

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