



High Voltage DC (HVDC) Inverter & Permanent Magnet (PM) Motor Input Performance Evaluation

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Overview



- Introduction
- Power Quality
- Configuration Overview
- Results
- Future Work

Revolutionary Vertical Lift Technology (RVLT)



Revolutionary Vertical Lift Technology (RVLT) Project

- Primary Focus:
 - Advanced Air Mobility (AAM)
 - On-Demand Air Mobility (ODM)
- Addressing industry gaps:
 - Tool Development
 - Standards Development
 - Model Validation





Power Quality

- A physical description of the electrical characteristics that allow the system to function properly without significant loss of performance or life. The physical description includes:
 - Steady State Voltage
 - Load/Line Step Transient Voltage
 - Ripple Performance
 - Stability
 - Abnormal Surge
 - Among More



Power Quality

- Why does it matter?
 - Properly defined Power Quality allows power distribution systems to operate within boundaries to reduce component failures
 - System Stability
 - Fault Recovery
 - Designing system/components to a Power Quality Standard can move one towards a 'plug and play' approach to design and integration

Advanced Reconfigurable Electrified Aircraft Lab (AREAL)

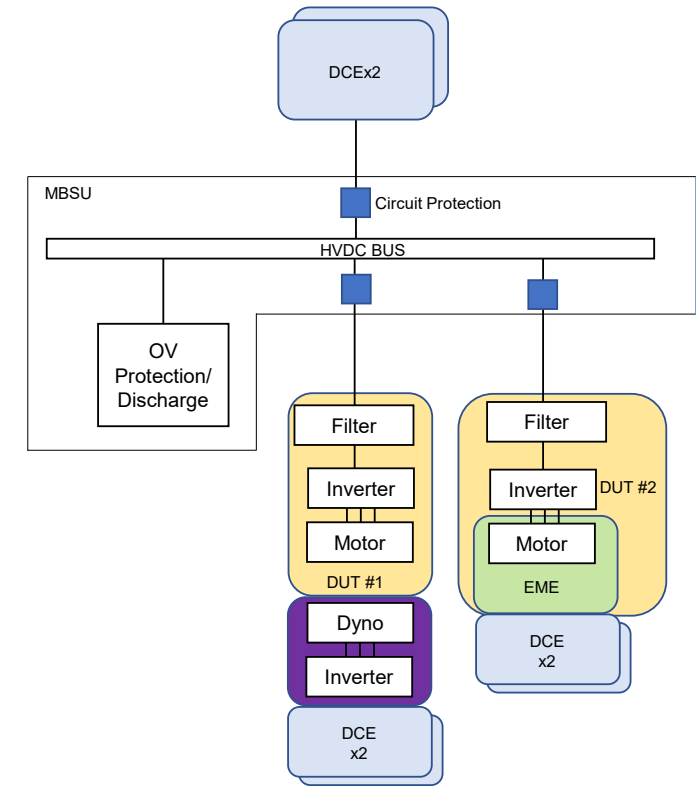


Capabilities

- Up to 1 kVDC
- 200 kW Nominal Source Capacity
- Source/Load Emulation
- Power Quality Investigation
- Fault capability

Testing

- Nominal, Abnormal, and Fault Operation Conditions
- Models, Procedures, and Requirements Validation





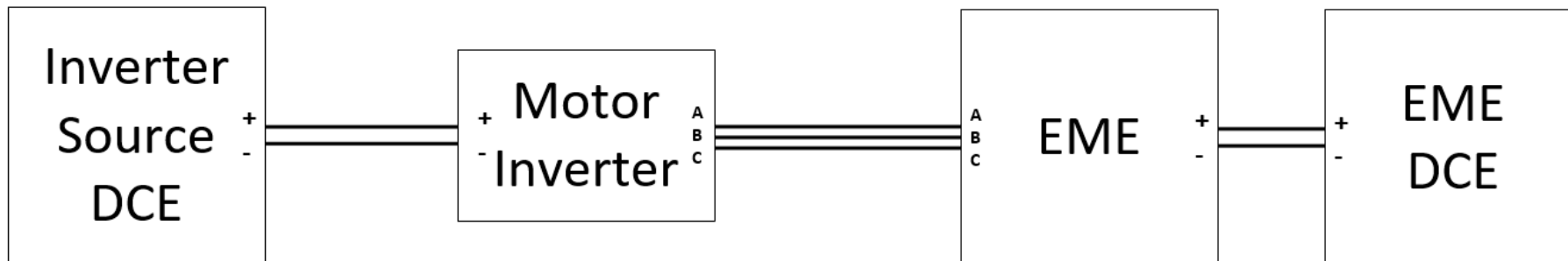
UE Testing Setup Overview

Equipment:

- D&V Electronics DCE (325 Vdc) and EME
- High Voltage Inverter
- Emulated 60 kW Motor
- Speedgoat Real Time Target Machines
- Yokogawa DL850E Scopecorder



AREAL Lab UE Testing Setup



UE Testing Summary

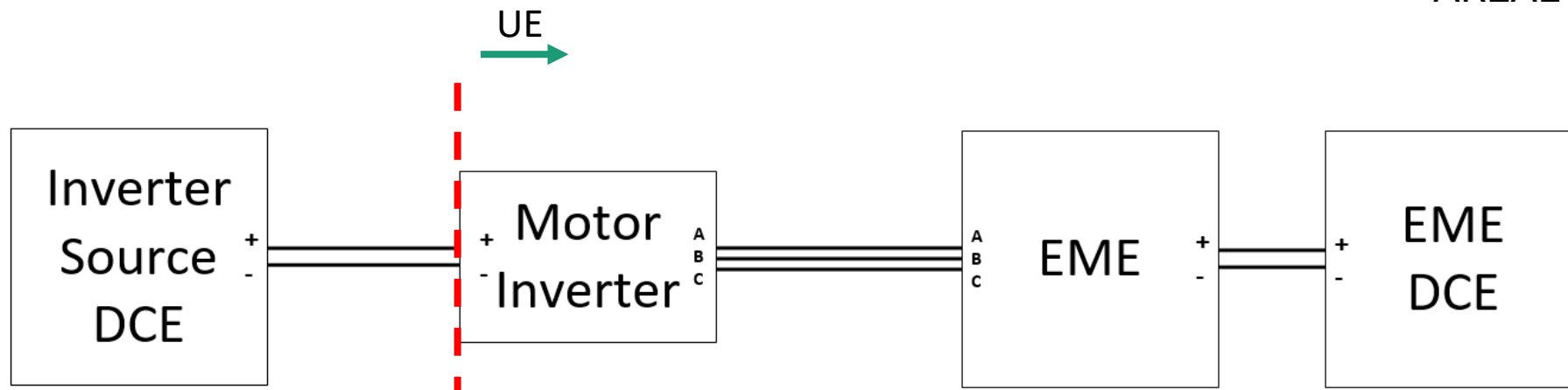
- UE tested against draft performance limits for the draft SAE AS7499 Aircraft

High Voltage DC Power Quality Standard

- Steady-State
- Input Impedance
- Ripple Performance
- Inrush
- Line-Step Transient
- Overvoltage Surge



AREAL Lab UE Testing Setup





Steady-State Performance

Objective:

- Verify Utilization Equipment (UE) operates within the draft AS7499 standard steady-state voltage limits at various torques and speed conditions.

Test Points:

- Speeds: 839 RPM, 1678 RPM, 2517 RPM, and 3770 RPM
- Torques: 17 Nm, 34 Nm, 51 Nm, 112 Nm, 160 Nm, and others depending on UE Voltage.

AS7499 Limit (p.u.)	UE Voltage
1.0	325V
1.04	338V
0.93	302V
1.14	370V
0.77	250V

Draft Steady-State Voltage Limits



Steady State Performance



Steady-State Voltage Scope Capture

Test Condition:

- 250 VDC
- 3770 RPM
- 27 Nm
- Field-Weakening

Results:

- No loss in performance was identified for the upper voltage limits.
- Degradation in torque capability was identified at lower voltage limits due to field-weakening.

Input Impedance

Objective:

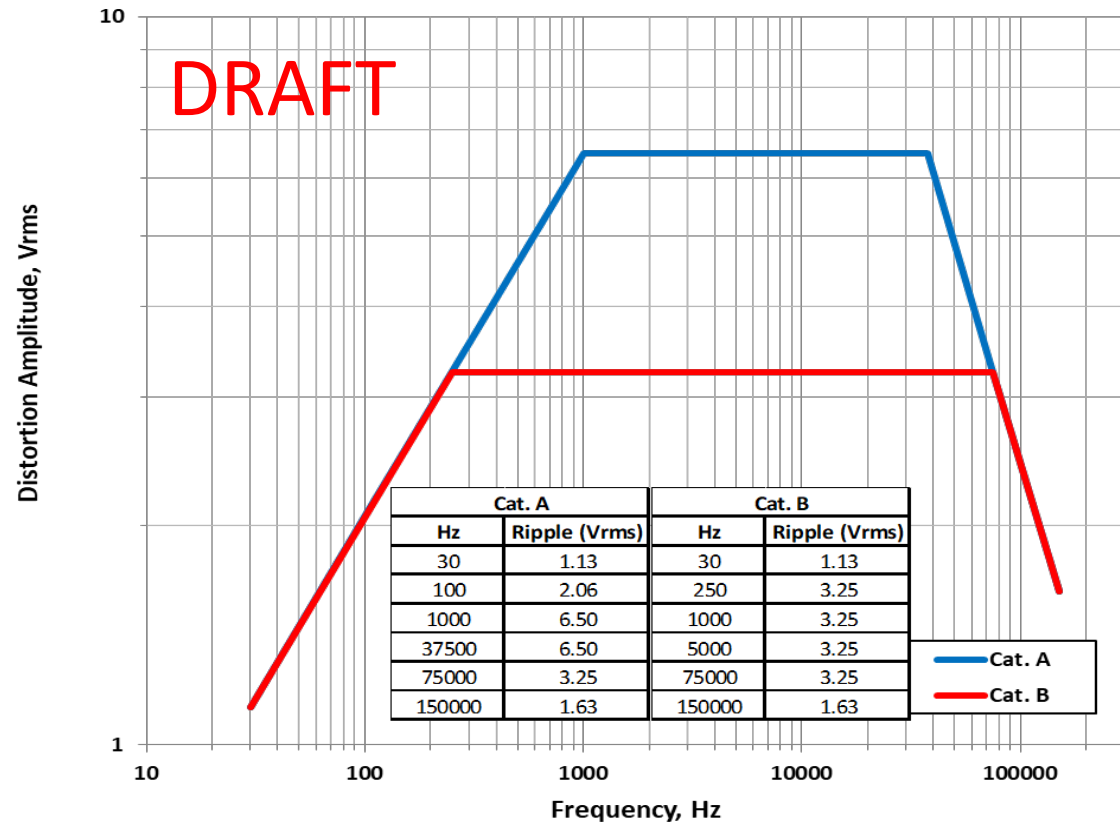
- Characterize the input impedance of the UE under various torque-speed operating points at the nominal, low, and high voltages prescribed for steady-state within the draft AS7499 standard.

Results:

- Constant Power below ~ 10 Hz
- Interesting response in the 30 Hz to 1k Hz frequency range
 - moves toward real/capacitive
- Consistent LC resonant point identified at ~ 8 kHz



Ripple Performance



Draft Ripple Voltage Spectrum Scaled to 325Vdc

Objective:

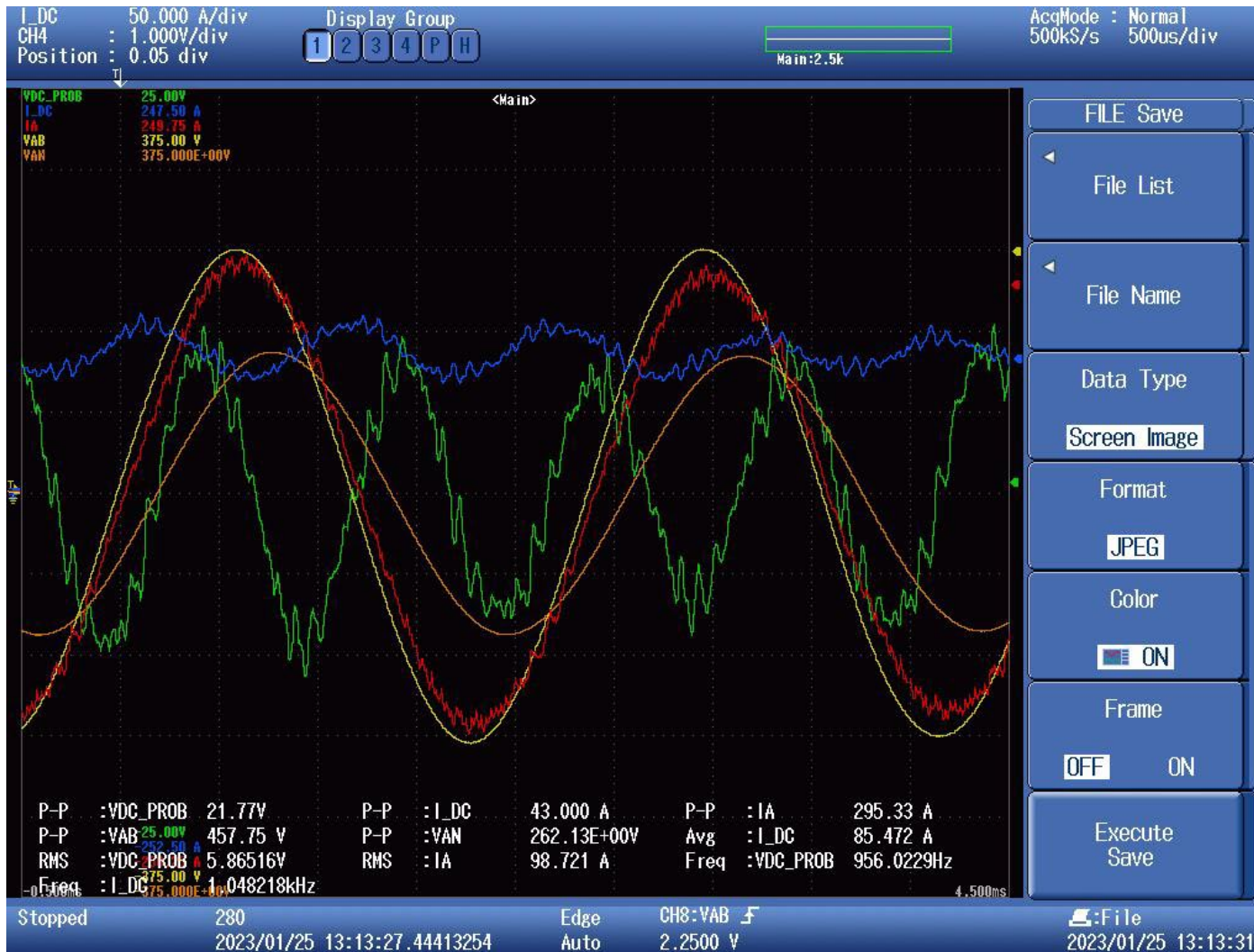
- Verify proper operation of the UE when subjected to the draft AS7499 ripple voltage spectrum limits at various torques and speed conditions.

Test Points

Speed	Torque
839 RPM	51 Nm
2517 RPM	90 Nm
2517 RPM	95 Nm



Ripple Performance



Ripple Voltage Spectrum Scope Capture

Test Condition:

- 325 VDC
- 1 kHz Ripple Injection
- 2517 RPM
- 90Nm

Results:

- Inverter was able to maintain torque regulation throughout the entire spectrum.
- In some low-speed cases, supply current swinging negative for a portion of the waveform caused by the ripple.
- Ripple Current was unacceptable about the LC resonant frequency
- Damped Input Filter will be integrated for next round of UE testing.



Inrush Capability

Objective:

- Verify UE is capable of self-limiting inrush/surge transients within the recommended limits per AS7499 draft:
 - 0.012 ampere-seconds/ampere for loads drawing rated current $I_{dc} \leq 10$ A
 - $(0.00252 + 0.096/A)$ ampere-seconds/ampere for loads drawing rated current from $10 \text{ A} < I_{dc} \leq 200$ A.
 - To be coordinated with system integrator for loads drawing rated current $I_{dc} > 200$ A

Results:

- Inverters inrush capability shows compliance with the recommended limits but fails on the overall peak.

Inrush/Surge Current Peak and Capability Test Points

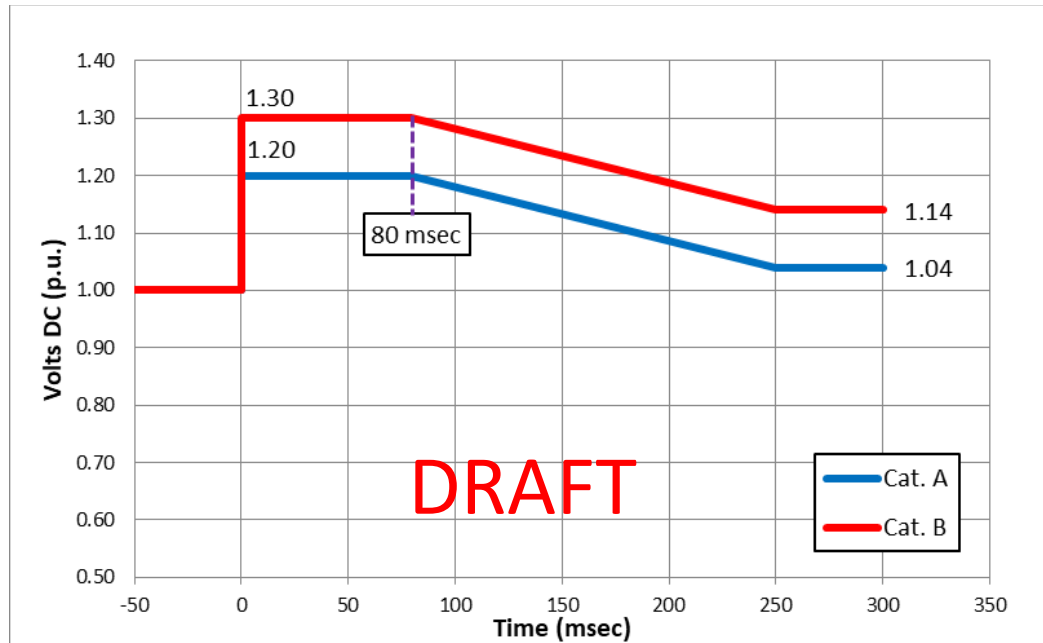
DCE Current Limit	Initial Voltage	Final Voltage	Q (A-sec)	C (μF)	Peak Inrush (A)
200 A	0.5 V	325 V	0.087 (Pass)	268 (Pass)	448 (Fail)
200 A	0.5 V	370 V	0.097 (Pass)	262 (Pass)	449 (Fail)



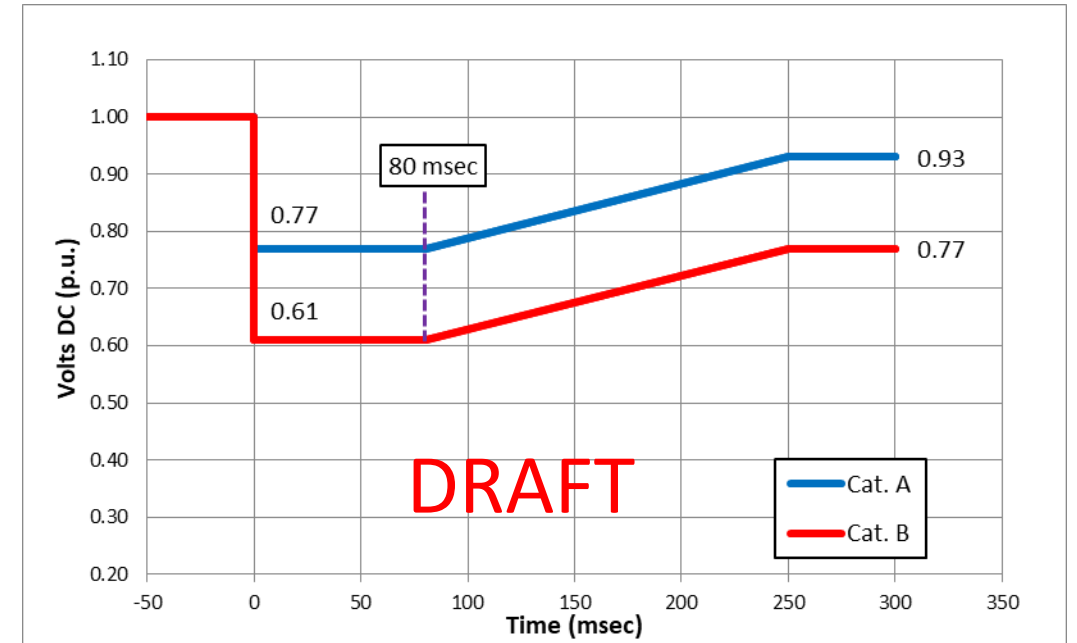
Supply Voltage Stepped to 370V, Current Limited to 200A



Line Step Transient Voltage



Draft Line Step-Up Voltage Transient



Draft Line Step-Down Voltage Transient
Test Points

Objective:

- Verify UE meets the draft AS7499 performance standard and maintains proper operation under the transient voltage envelopes.

Speed	Torque
839 RPM	17 Nm
1678 RPM	112 Nm
2517 RPM	51 Nm
3770 RPM	23 Nm



Line Step Transient Voltage



Results:

- No loss in performance was identified due to the line-step up transient portion of the voltage profile.
- Potential for degradation in torque capability was identified during the line step-down voltage transient due to field-weakening.

Overvoltage Surge

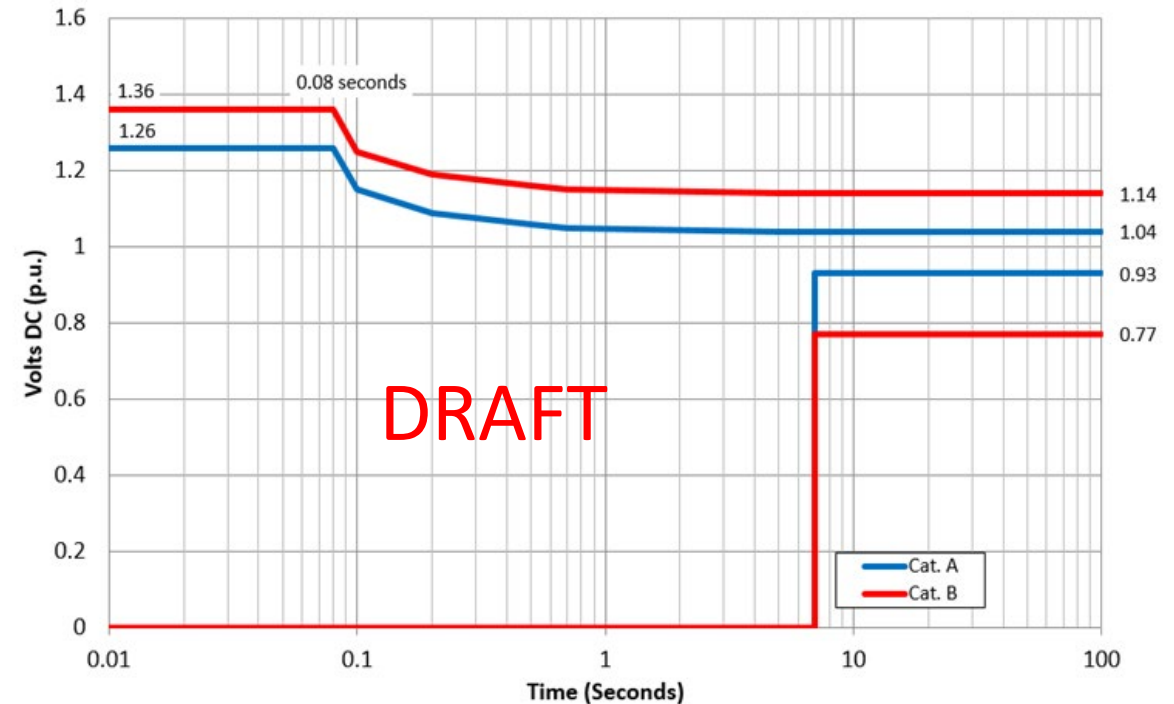


Objective:

- Verify UE is capable of surviving an overvoltage surge due to a fault at the load interface to within power quality as prescribed in draft AS7499 standard.

Condition	AS7499 Limit (p.u.)	UE Voltage
Nominal	1.0	325 V
Abnormal Regulated	1.26	410 V
Abnormal Unregulated	1.36	442 V

Draft Abnormal Overvoltage Limits



Draft Abnormal Voltage Limits for Overvoltage and Undervoltage



- 325 VDC Nominal Voltage
- 1678 RPM
- 112 Nm
- 442 VDC Voltage Limit

- Inverter was able to maintain torque regulation throughout the entire profile.

Conclusion



Conclusion

- Tested Inverter/Emulated Motor at 325 Vdc with only a capacitive element at the input.
- Steady-State Performance, and Overvoltage Surge met the testing limits
- Inrush Capability showed compliance with the recommended limits but fail on the overall peak inrush
- Characterized Input Impedance from 1 Hz to 150 kHz
- Ripple Performance was unacceptable about the LC resonant frequency
- Undervoltage Surge was not able to be tested with the testing setup used for this preliminary results
- Feeding results to SAE Standards Committee



Future Work

Future Work

- Incorporate modifications and establish method to test Undervoltage Surge limits within the draft AS7499 standard
- Incorporate Damped Input Filter to UE Setup
- Perform Power Quality testing per draft AS7499 with added Damped Input Filter with the UE setup to better meet draft AS7499 requirements.
- Furthermore, investigate low frequency performance during Input Impedance evaluation, understand the effects on UE performance and tuning from 30 Hz to 1 kHz, and explore difference in the effects of control model (Speed and Torque).

Acknowledgments



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Questions