



Revolutionary Vertical Lift Technology (RVLT) Project Infrastructure Motivation and Capabilities

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Electrical Systems Working Group (ESWG) Meeting
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Revolutionary Vertical Lift Technology (RVLT) Project

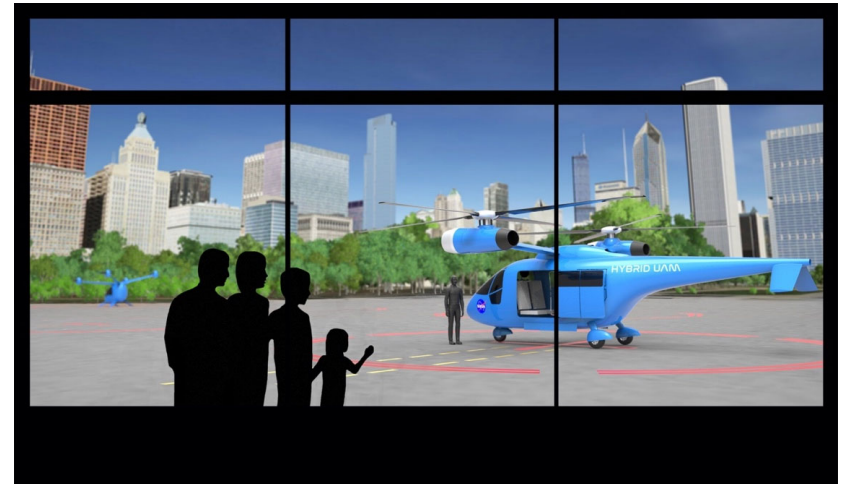


Vision

Create a future where VTOL configurations operate quietly, safely, efficiently, affordably, and routinely as an integral part of everyday life.

Scope

- Technologies that address noise, safety, environment, and efficiency
- Non-conventional light and medium vertical lift configurations



Develop and Validate Tools, Technologies and Concepts to Improve Future Vertical Lift Vehicles

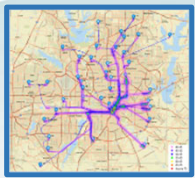
NASA's RVLTL Project Provides Tools and Design Practices for UAM eVTOL Vehicles



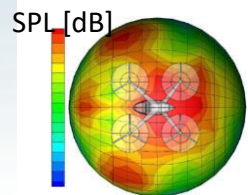
Noise Research



Human Response to UAM Noise



UAM Acoustic Impacts



Predictive Tools for UAM Noise

Safety Research



Crashworthiness & Occupant Protection



Handling Qualities



Electric Powertrain Reliability

Share technical insights and lessons learned



SDOs

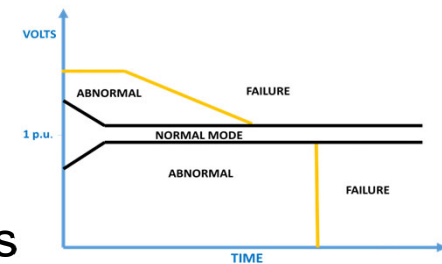


Delivering Tools and Technologies to the eVTOL Community



Tying DC Power Quality to Reliability

- **What is Power Quality and why does it matter?**
 - Physical description of power, namely voltage (DC)
 - Applicable during any operational period (Normal, Abnormal, Emergency)
 - Voltage: Steady-state, transient, ripple
 - Stability, fault conditions, & much more
- Improves reliability
 - Reduces component failures by defining operational boundaries
 - Ensures stable operation
 - Defines/drives proper fault recovery
- Drives one towards 'plug and play' approach to design and integration
 - Not completely obtainable, but moves one closer
 - Helps guide lower-level standards (e.g. components, connectors, etc.)





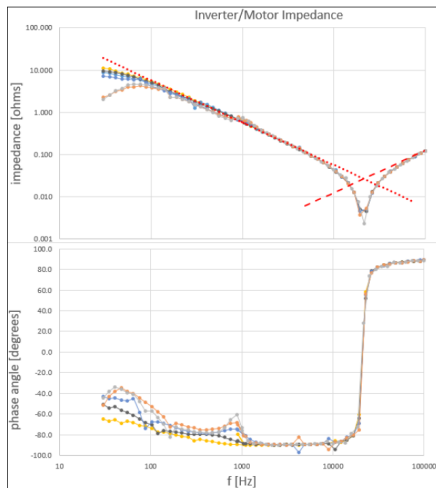
Needs

- **Existing Standards, Guidelines, Test Methods for HVDC Power System Integration & Power Quality don't exist***
 - Limited to 270 V on the high end
 - High Voltage Standards, Testing/ Test Methods are limited to Terrestrial Applications or are in development*
- **Limited infrastructure available which is flexible enough to test these systems**
 - Current proposed designs are highly customized
 - Various architectures (regulated/unregulated, all- vs. hybrid- vs. turbo- electric, + vs. +/-)
 - No standardized voltage class (e.g. 270 V)
 - Plug and play is difficult
- **Lack of test data to inform community, software tools, analysis**

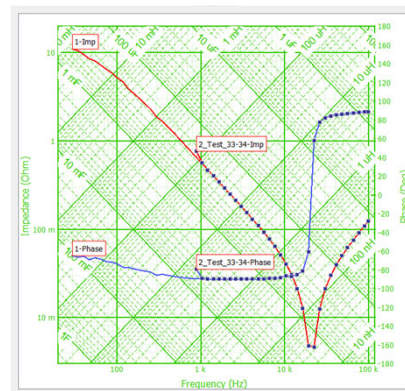
Scaled Power EIEctrified Drivetrain (SPEED)



Simulation Results



Physical Sys. Results



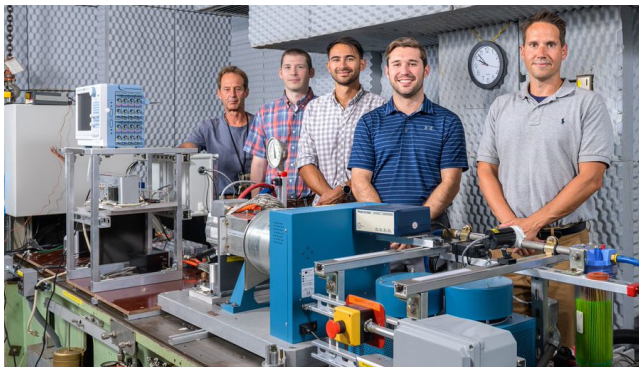
Testbed for investigating power system interactions at low power

Capabilities

- 400 VDC and 12,000 RPM
- Up to 7 kW (dyno limit)
- Mechanical, electrical, vibration data

Testing

- Motor/inverter characterization & integration
- Baseline testing of motors for AREAL testbed
- Software model validation
- Test motor, controls, power electronics
- Developed approach for impedance measurements



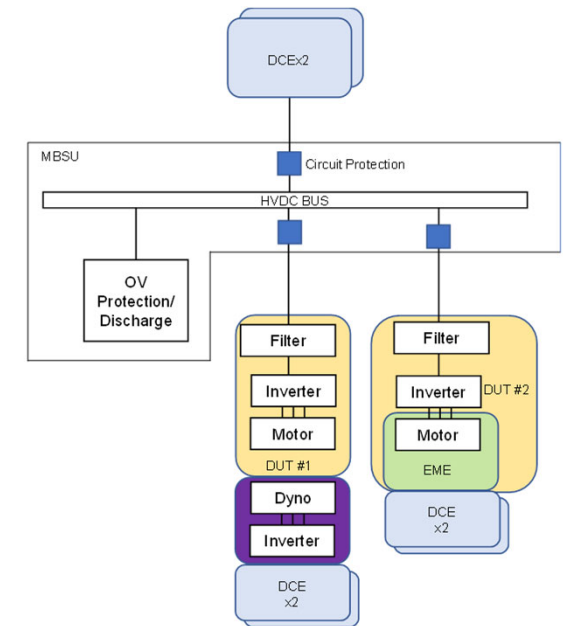


AREAL Overview

- **200kW Reconfigurable Lab**
 - Up to 1 kVDC

System Voltage (Vdc)	Short Circuit Capability (A)
500	400
800	250
1000	200

- **Highly flexible for various test needs**
 - System integration and PQ testing
 - EPS / UE performance evaluation
 - Models, procedures, requirements validation
- **Low- and high-speed data acquisition systems**
- **Utilizes mixture of real and emulated hardware**

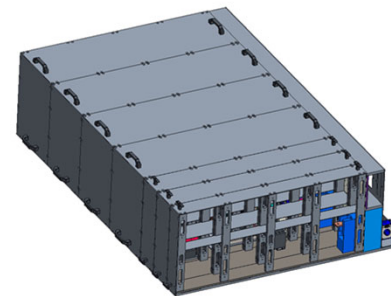


**System Configuration Example
for the AREAL**



AREAL EPS Hardware Overview

- **Six DC Emulators¹**
 - Four 100 kW, 500 V units; Two 100 kW, 800 V units
 - Small-signal bandwidth (>20 kHz)
 - Can be series and paralleled for increased capability
 - Controllable voltage, current, power, or impedance
 - Bidirectional capability
- **High voltage distribution**
 - Pre-charge distribution box
 - Main Bus Switching Unit (MBSU)
 - High voltage wiring
 - Protection
 - Overcurrent, overload, overvoltage



MBSU



D&V Electronics DC Emulator

Note 1: Product of D&V Electronics



AREAL UE Hardware Overview

- **Inverters**
 - Currently three commercial-off-the-shelf (COTS) units
 - ~800 Vdc, >100 kW peak
- **Motors**
 - Two axial-flux based COTS units
 - ~60 kW continuous or more
 - Drive stand for testing
- **Electric Motor Emulator (EME)¹**
 - Dynamically emulate permanent magnet or induction motors
 - Ability to include three-dimensional flux maps
 - Includes an AC Fault Injection Unit (FIU)¹ to emulate motor faults
 - 2 Channel, up to 275 kW per channel (550 kW total)



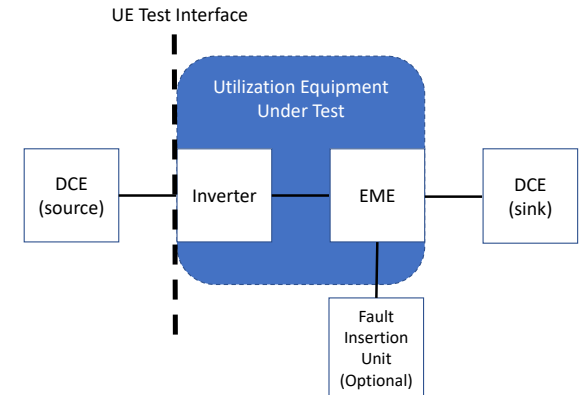
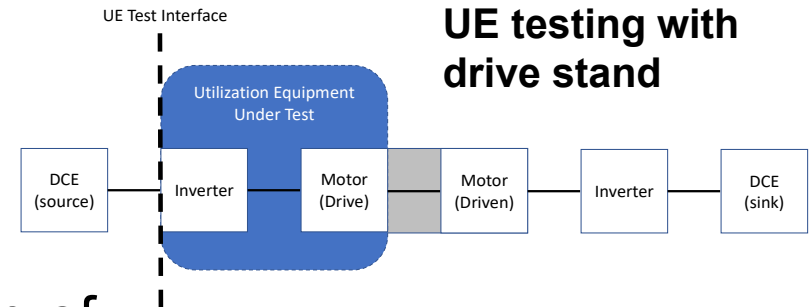
Electric Motor Emulator

Note 1: Product of D&V Electronics

UE Testing



- **Two primary test configurations**
 - Emulated
 - Physical
- **Physical**
 - Performance and characterization testing of inverter, motor, or combination of both
- **Emulated**
 - Test inverter with EME when motor not available
 - Characterize inverter stand-alone performance
 - Fault testing via AC FIU¹



Note 1: Commercial-off-the-shelf. Note 2: Product of D&V Electronics



UE Testing

Planned AREAL Power Quality Tests

Steady State Operation
Line Step Transient Voltage
Ripple Current
Ripple Voltage Spectrum
Large Signal Stability
Input Impedance
Small Signal Stability
Current Limiting Switchgear Compatibility

Inrush/Surge Current Transients
Reverse Current
Input Isolation
Abnormal Reverse Current
Overvoltage Surge
Undervoltage Surge
Emergency Operation

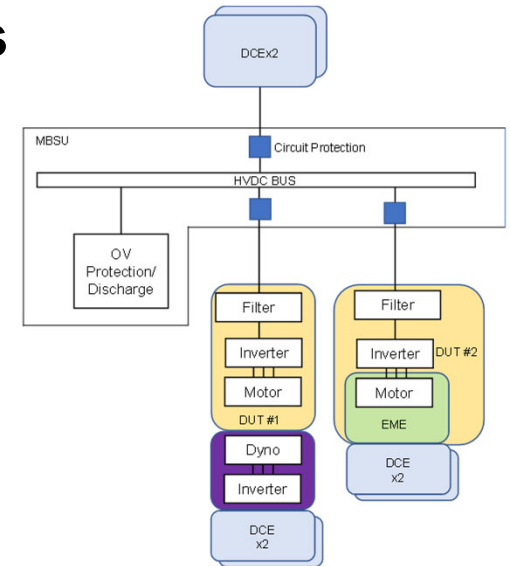
Motor Test Parameters via Physical UE Test Configuration

Electrical	Mechanical	Thermal
Stator Resistance, R_s	Moment of Inertia, J	Efficiency Maps
Stator Inductances: L_s (total), L_d (direct-axis), L_q (quadrature-axis)	Damping Constant, B	
Motor Voltage Constant, K_e . Motor Torque Constant K_t	Torque Speed Map	



EPS Testing

- **AREAL allows for multiple EPS test configurations**
 - Single-String
 - Multi-String
- **Different ground-configuration testing**
- **System characterization**
 - Measure end-to-end efficiency and performance over a chosen flight-profile
- **Power Quality testing**
 - Normal
 - Abnormal
 - Emergency

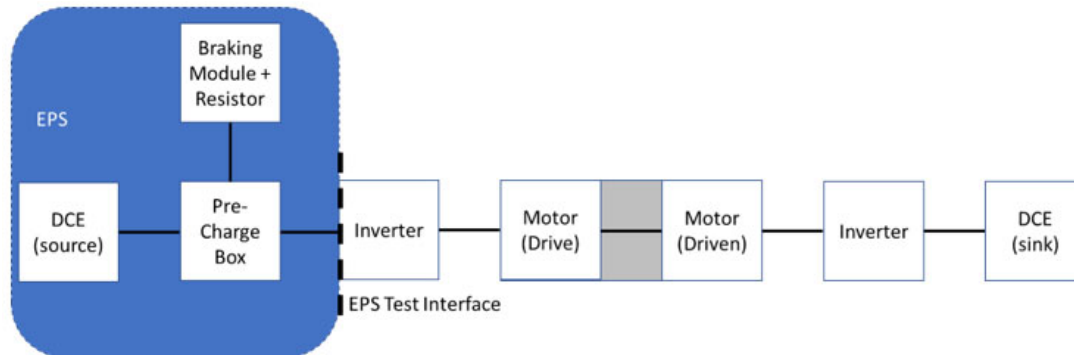


**System Configuration Example
for the AREAL**



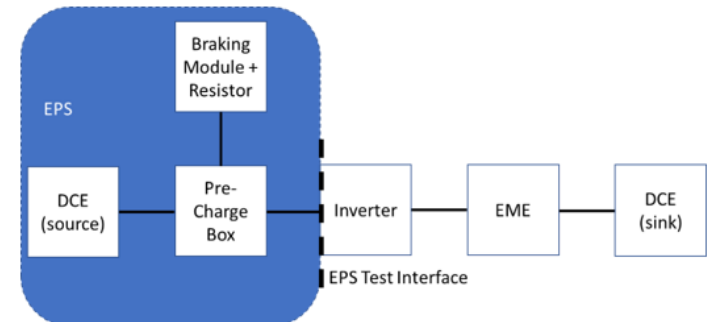
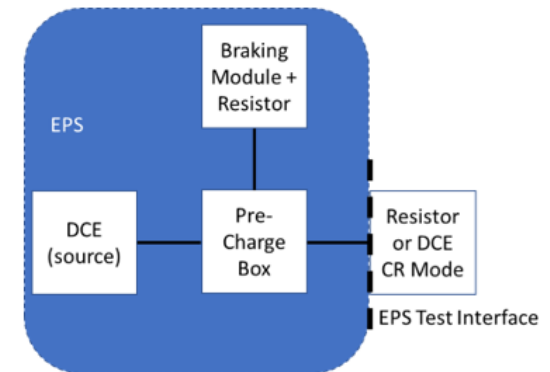
EPS Single-String Testing

- **Single-String configurations**
 - One-source One-load
 - Useful for stand-alone EPS testing/characterization
 - Representative of some power systems
 - Useful for isolated load testing against a source
- **Power Quality Testing**
 - Normal operation



EPS Testing with drive stand

Stand-alone source testing



EPS Testing with EME

Single-String Normal EPS Testing Capabilities



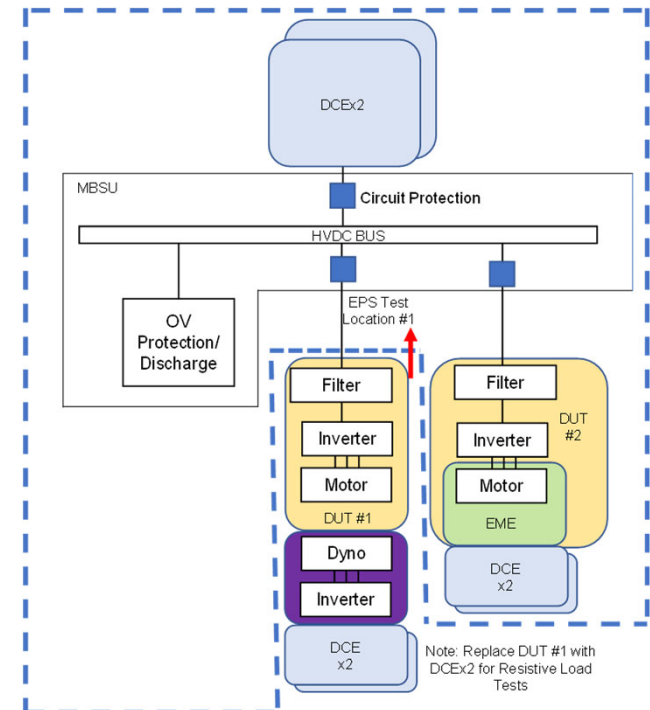
Grounding
Distribution Wiring
Electrical Isolation
Segregation
Reverse Current
Electromagnetic Compatibility
Steady State Voltage
Normal Load Step Transient Voltage
Pulsed Loads
Source Impedance
Small Signal Stability
External Power Source

Differential Mode Peak Ripple Voltage
Differential Mode Ripple Voltage Amplitude
Differential Mode Ripple Voltage Spectrum
Common Mode Peak Ripple Voltage
Common Mode Ripple Voltage Amplitude
Common Mode Ripple Voltage Spectrum
Inrush/Surge Current Capability
Peak Inrush/Surge Current Capability



Multi-String Testing

- **Multi-String configurations**
 - One source, multiple loads
 - Useful for complex EPS testing/characterization
 - Representative of some power systems
- **Power Quality testing**
 - Normal operation
 - Abnormal operation
 - Emergency operation

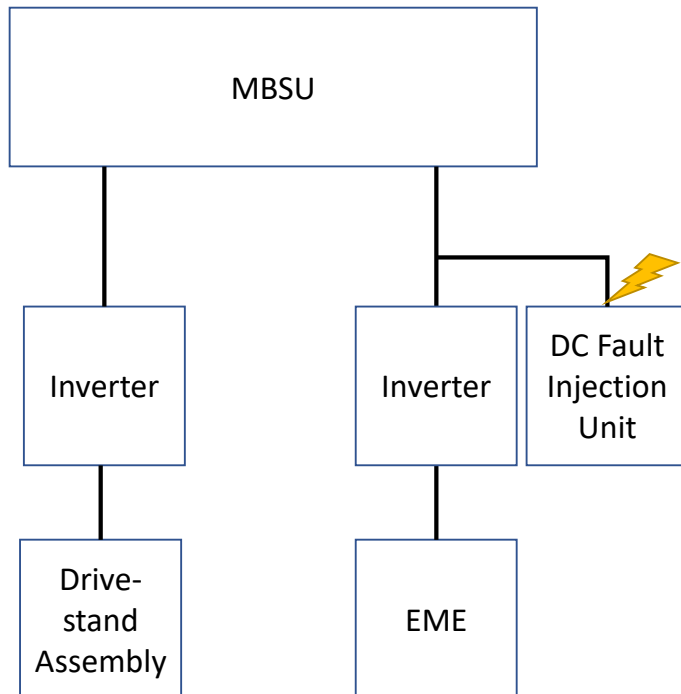


Example Multi-String test configuration

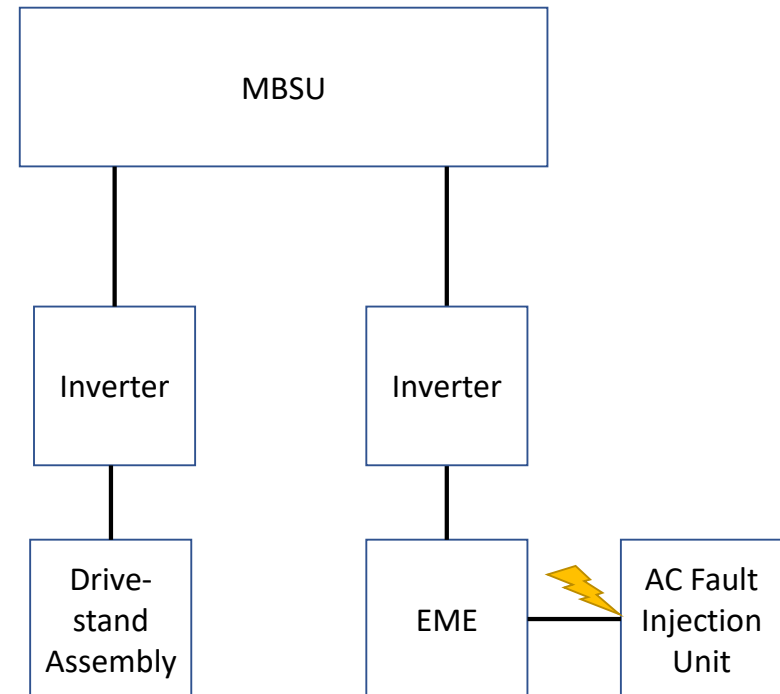


Multi-String Abnormal Test Configurations

DC Fault Testing



AC Fault Testing



Note: DC Fault Injection Unit is Custom Hardware by NASA



Multi-String EPS Test Capabilities

Normal EPS Test Capability

Grounding
Distribution Wiring
Electrical Isolation
Segregation
Reverse Current
Electromagnetic Compatibility
Steady State Voltage
Normal Load Step Transient Voltage
Pulsed Loads
Differential Mode Peak Ripple Voltage
Differential Mode Ripple Voltage Amplitude
Differential Mode Ripple Voltage Spectrum
Common Mode Peak Ripple Voltage
Common Mode Ripple Voltage Amplitude
Common Mode Ripple Voltage Spectrum
Inrush/Surge Current Capability
Peak Inrush/Surge Current Capability
Source Impedance
Small Signal Stability
External Power Source

Abnormal EPS Test Capability

Abnormal Reverse Current
Overvoltage Surge
Undervoltage Surge
High Impedance Faults
Low Impedance/High Current Faults
Arc Faults*
Fault Coordination
Fault Transfer*
Emergency Operation*

*Not within current scope of planned testing. To be added at a future date.



Conclusion and Future Work

- **Upcoming electrified aircraft are utilizing HVDC Power Systems**
- **Corresponding standards, tools, and test guidelines are in development**
 - Availability of items improves capability of the community to develop and test safe, reliable systems for eVTOL and other high voltage aircraft
 - Public test data is required to inform and validate these items
- **SPEED and AREAL were constructed to meet these test needs**
 - Flexible infrastructure to cover a wide range of power system integration activities and power quality tests
- **Future Work**
 - Expand testing to additional loads such as DC-DC converters
 - Incorporate additional electromagnetic test capabilities