NASA Advanced Reconfigurable Electrified Aircraft Laboratory (AREAL) High Voltage Utilization Equipment (UE) Power Quality Testing

Presenter: Brian Malone

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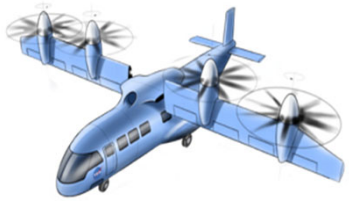


Authors: David J. Sadey, Xavier Collazo-Fernandez, Patrick A. Hanlon, Keith R. Hunker, Casey J. Theman, Linda M. Taylor, Paul M. Nowak, Brian P. Malone NASA-Glenn Research Center, Cleveland, OH

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Table of Contents

- Background
- AREAL Overview
  - UE Test Configurations
- Test Descriptions and Results
- Conclusion and Future Work

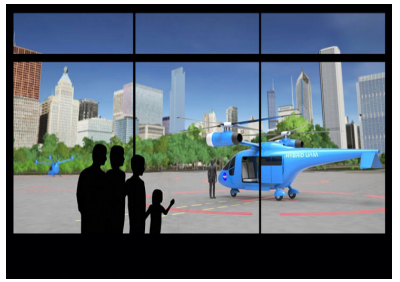




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Advanced Air Mobility Background

- Many electrified aircraft are in development
  - Vertical Takeoff and Landing
  - Small & Large Transport
- Many of these vehicles require voltages >>270Vdc
  - Standards and test guideline documents are still in development
  - Lack of public test data available to community
    - Data needed to inform and validate documents and models
      - Power quality test and performance data is a prime example

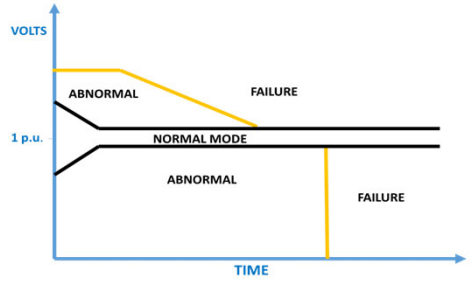


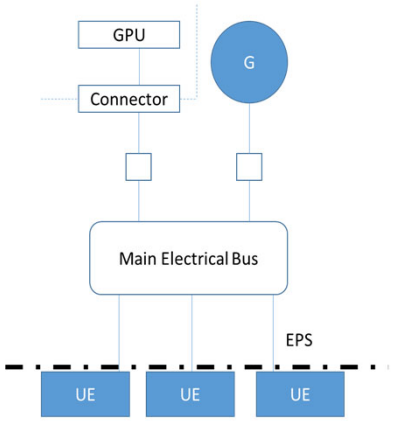


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DC Power Quality

- What is Power Quality (PQ) 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
  - Move towards ‘plug and play’ approach to design and integration
    - Helps guide lower level standards (e.g. components, connectors, etc.)

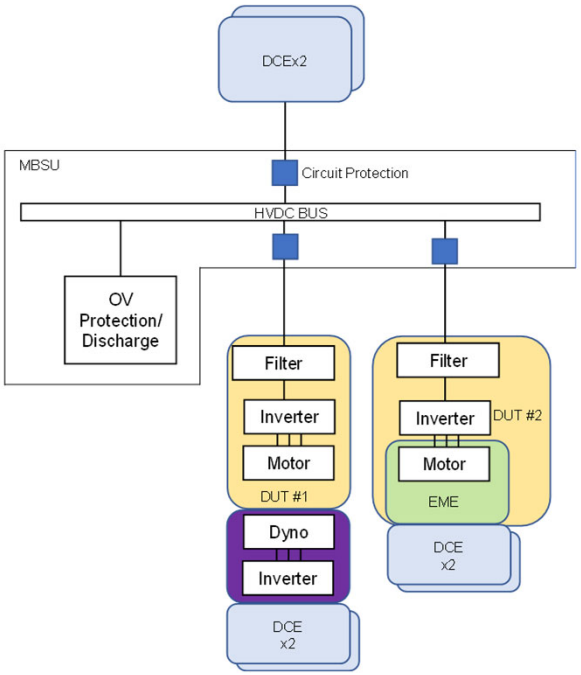




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Advanced Reconfigurable Electrified Aircraft Laboratory (AREAL) Overview

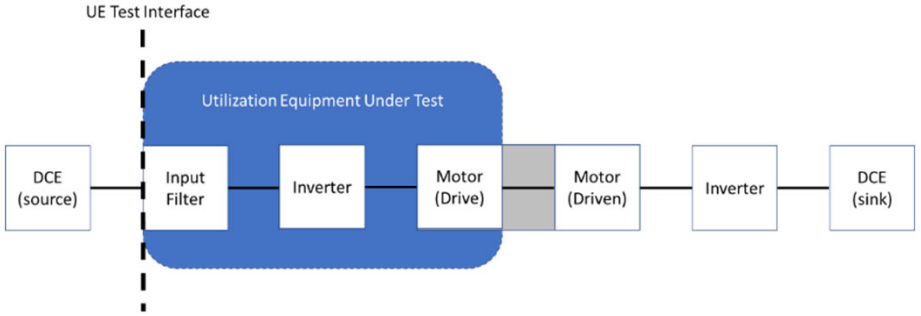
- 200kW Reconfigurable Lab
  - Up to 1kVDC
- Highly flexible for various test needs
  - Electric Power System (EPS) testing and evaluation
  - UE performance evaluation
  - Power Quality testing
  - Models and procedure development, requirements validation
- Low- and high-speed data acquisition systems
- Utilizes mixture of real and emulated hardware

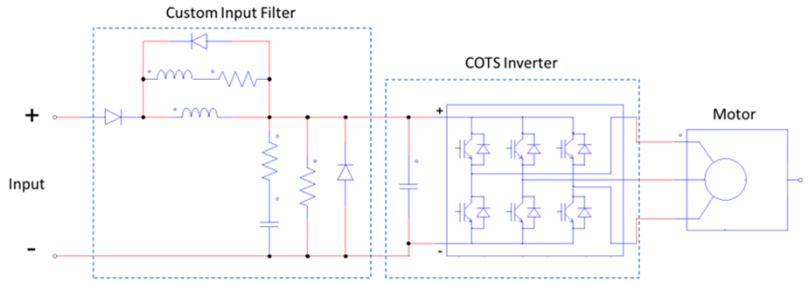


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AREAL HV UE Test Configurations

- Equipment:
  - D&V Electronics 800V DCE
  - High Voltage Inverter
  - 60kW motor pair
  - Custom Input Filter
  - Speedgoat Real Time Target Machines
  - Yokogawa DL950E Scopecorder





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UE Power Quality Testing

- Performed several PQ tests on physical and emulated UE test configurations

UE Tests	Normal/Abnormal Operation
Steady-State Operation	Normal
Line-Step Transient Voltage	Normal
Input Impedance	Normal
Overvoltage Surge	Abnormal
Undervoltage Surge	Abnormal

- Requirements were derived internally and based on inputs from ongoing standards work and inputs
- Nominal bus voltage 630Vdc

Steady-State Test Objective

- Objective: Verify UE operates to specification at each input voltage test point, across varying speeds/torques

Low	Nominal	High
485Vdc	630Vdc	718Vdc

Speed (RPM)	Torque (Nm)
1627	17
3253	34
4880	51
5300	90

Steady-State Test Results

- Results were as expected at 485Vdc
  - Field-weakening was present at 4880 and 5300 RPM
    - Integrators should be aware of reduced torque capability and closely look at performance during bus transients
- Results were as expected at 630Vdc and 718Vdc
  - No field-weakening present

Voltage (VDC)	Speed (RPM)	Torque (Nm)	Field-Weakening	Mod. Index	Id (A)	Iq (A)	Idc (A)	Pass/ Fail
485	1627	17	No	0.43	0	22.1	5.8	Pass
485	3253	34	No	0.82	0	44.3	21	Pass
485	4880	51	Yes	1.10	-36	66.5	56.6	Pass
485	5300	90	Yes	1.10	-104	117	118	Pass
630	1627	17	No	0.34	0	22.1	4.7	Pass
630	3253	34	No	0.63	0	44.3	16.1	Pass
630	4880	51	No	0.94	0	66.5	36.5	Pass
630	5300	90	No	1.08	0	117	74.1	Pass
718	1627	17	No	0.31	0	22.1	4.3	Pass
718	3253	34	No	0.56	0	44.3	14.4	Pass
718	4880	51	No	0.82	0	66.4	30.6	Pass
718	5300	90	No	0.96	0	117	63.7	Pass

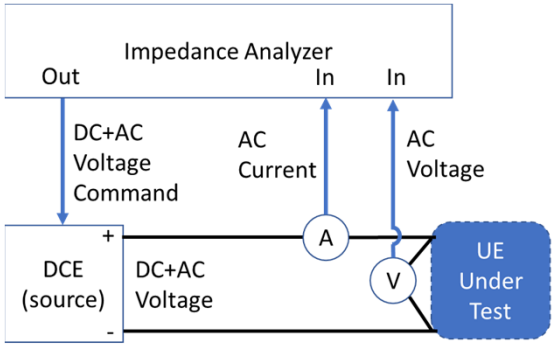
Input Impedance Test Objective

- Objective: Measure and record input impedances from 1Hz to 150kHz. Test conditions are same as steady-state.

Low	Nominal	High
485Vdc	630Vdc	718Vdc

- No internal impedance requirement was derived due to the lack of a corresponding source requirement.
- An input filter was included to increase damping of the corresponding UE.

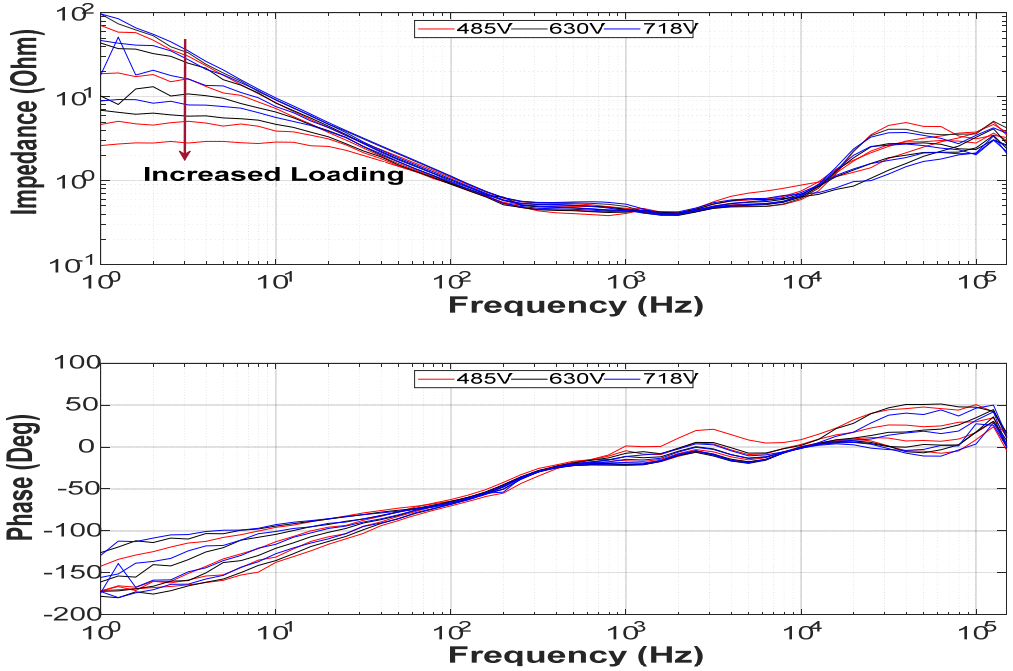
Speed (RPM)	Torque (Nm)
1627	17
3253	34
4880	51
5300	90



AC injection Configuration for Input impedance testing

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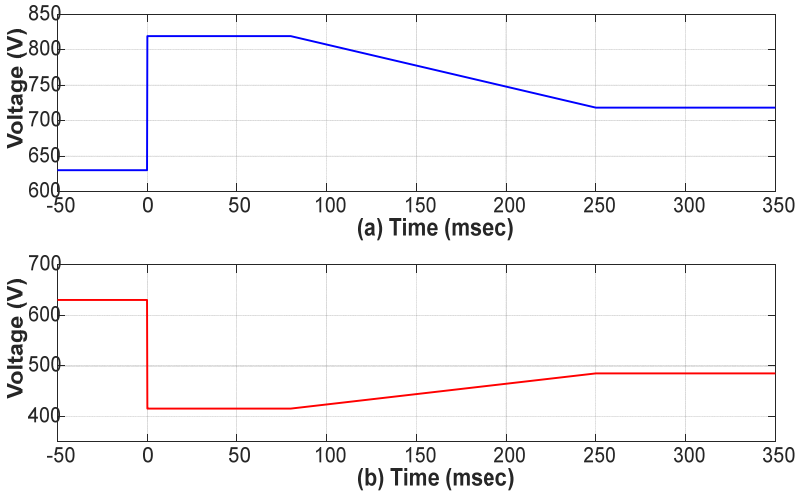
Input Impedance Test Results



- Constant power trend below ~30Hz

Line-Step Transient Test Objective

- Objective: Verify UE maintains stable operation and recovers to the expected performance level after the applied transients.



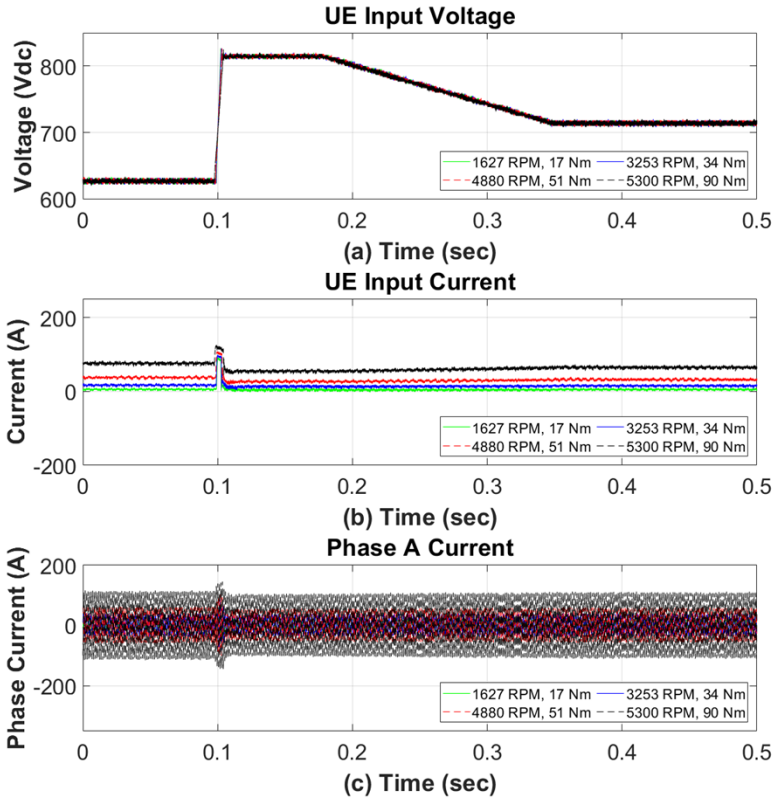
Line-Step Test	Speed (RPM)	Torque (Nm)
Up	1627	17
Up	3253	34
Up	4880	51
Up	5300	90
Down	1627	17
Down	3253	34
Down	4880	51
Down	5300	90

Line-Step Transient Test Result Summary

- Overall, UE remained stable and recovered to expected performance after the line-step up and down transients were applied.

Line-Step Test	Speed (RPM)	Torque (Nm)	Pass/Fail
Up	1627	17	Pass
Up	3253	34	Pass
Up	4880	51	Pass
Up	5300	90	Pass
Down	1627	17	Pass
Down	3253	34	Pass
Down	4880	51	Pass
Down	5300	90	Pass

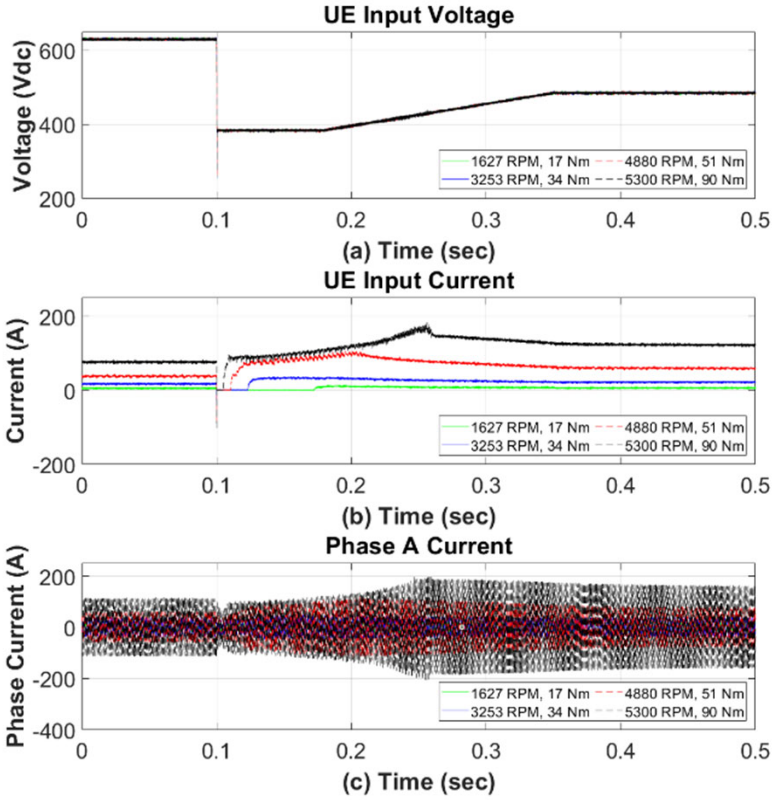
Line-Step Transient Test Results



Line-Step Up Transient Data

- Inverter rides through disturbance
- Input surge current observed
  - DC and AC
  - No impact on overall performance

Line-Step Transient Test Results

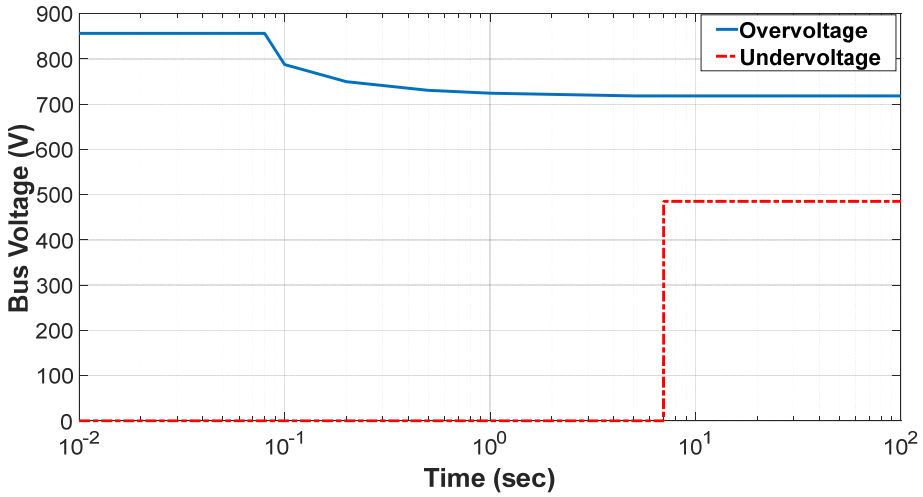


Line-Step Down Transient Data

- Inverter rides through disturbance
- Field-weakening can occur transiently
- Input surge current observed
  - DC and AC
  - No impact on overall performance
  - Blocking diode prevents reverse current

Overvoltage/Undervoltage Surge Test Objective

- Objective: Verify UE is not damaged and is able to maintain or restart operation after the subjected transients.



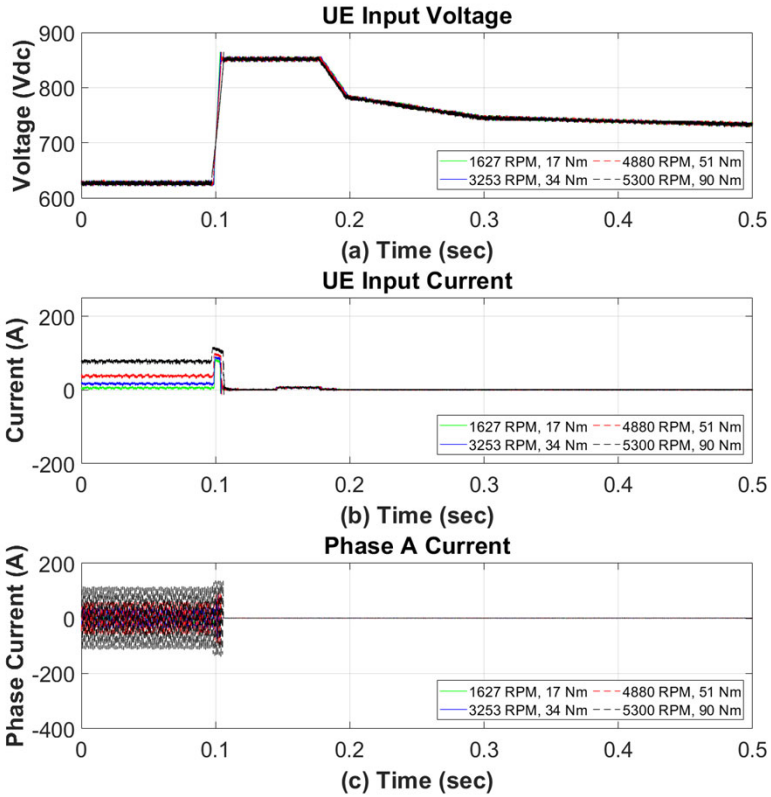
Surge Test	Speed (RPM)	Torque (Nm)
Overvoltage	1627	17
Overvoltage	3253	34
Overvoltage	4880	51
Overvoltage	5300	90
Undervoltage	1627	17
Undervoltage	3253	34
Undervoltage	4880	51
Undervoltage	5300	90

Overvoltage/Undervoltage Surge Test Results Summary

- No damage was observed during any test

Surge Test	Speed (RPM)	Torque (Nm)	Pass/Fail
Overvoltage	1627	17	Pass
Overvoltage	3253	34	Pass
Overvoltage	4880	51	Pass
Overvoltage	5300	90	Pass
Undervoltage	1627	17	Pass
Undervoltage	3253	34	Pass
Undervoltage	4880	51	Pass
Undervoltage	5300	90	Pass

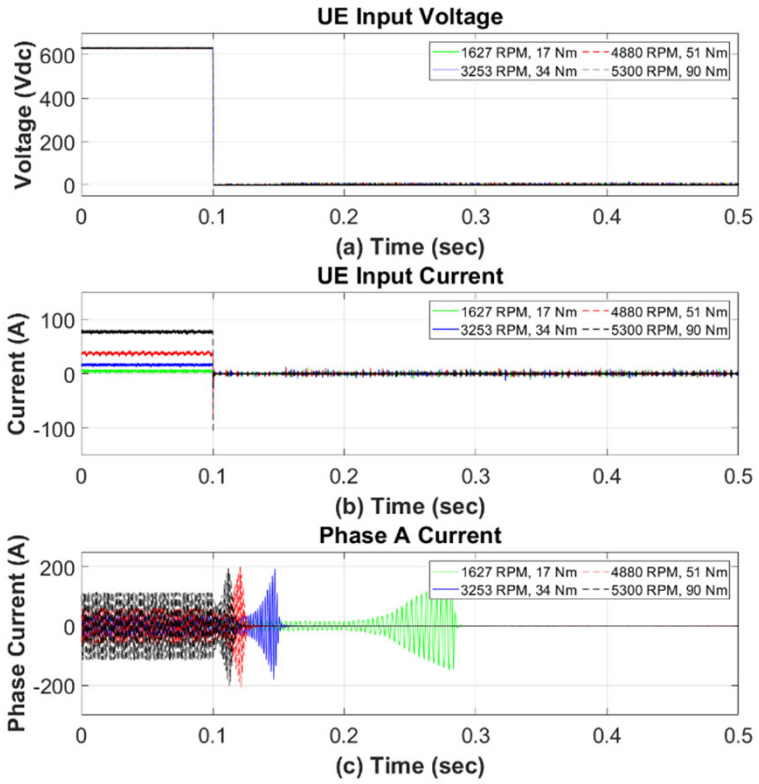
Overvoltage Test Results



Overvoltage Transient Data

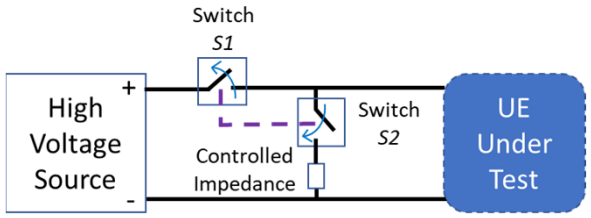
- UE rode through the overvoltage transient
- Surge observed in DC input and AC output currents
- No impact on output torque regulation post transient observed by operators

Undervoltage Test Results



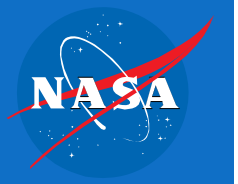
Undervoltage Transient Data

- UE was tripped at 50Vdc and was able to be restarted after the bus voltage recovered at the end of the transient.
- Blocking diode prevented reverse current
  - Reverse recovery current negligible
- Alternative test configuration can be implemented



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Conclusion and Future Work



- Performed HV power quality utilization equipment testing
  - Normal and abnormal tests
  - Custom Input Filter + Inverter + Motor
- Documented results
  - Identified test setups to subject equipment to draft power quality limits
    - Alternative setups also identified to improve test equality or if different equipment is available
  - Demonstrated and described operation of equipment against prescribed tests
    - No unexpected behavior observed during any normal or abnormal test
  - Setups, test methods, and results to be fed to standards requirement development
- Future work
  - Additional UE tests including full spectrum ripple susceptibility testing
  - Integrated system testing

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Questions

