Power Quality Analysis for a High Voltage Power System for Urban Air Mobility Application

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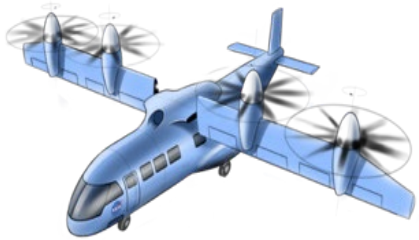
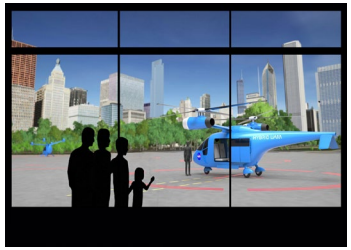


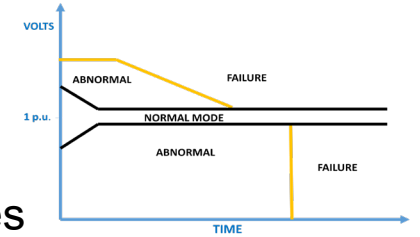
Urban Air Mobility Background

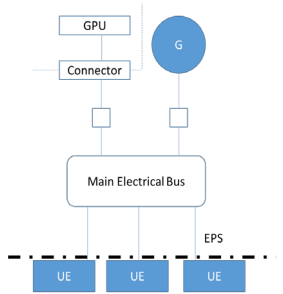
- **Many Electrified Aircraft are in development**
  - Vertical Lift and Takeoff
  - Small & Large Transport
- **Many of these vehicles require voltages >>270Vdc**
  - Minimal simulation & test data available to community
  - Standards are still in development
    - Power Quality is a prime example



DC Power Quality

- **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.)





Model Overview

- **Lift-Plus-Cruise Vehicle Model (Conceptual NASA Design)**
- **650V, <1MW Simulink® Power System Model for PQ Studies**
  - Generator, one cruise motor, four lift motors, and a power distribution unit (PDU) for each bus, with two busses total.
  - Each generator and motor has an integral rectifier and inverter and are scaled based on validated models
  - Utilizes directional overcurrent protection scheme

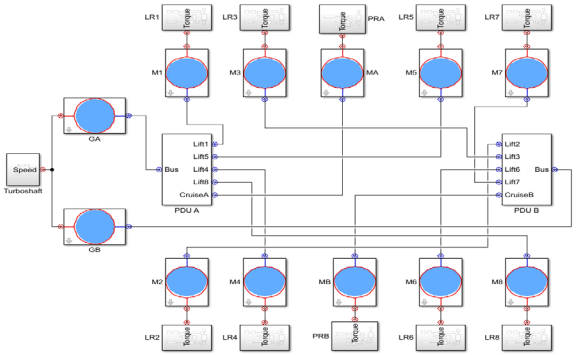
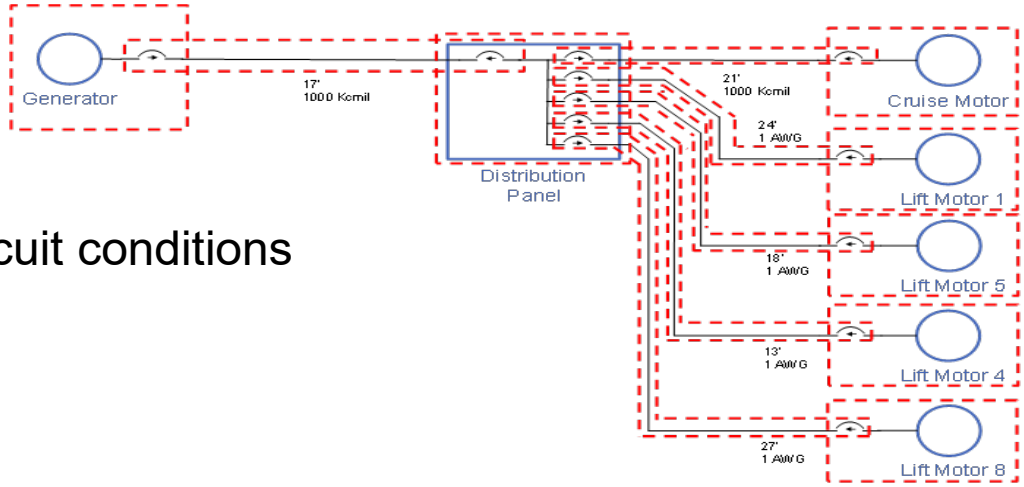


Table 1: Machine and associated Power Converter Parameters

	Generator	Lift Motor	Cruise Motor
Count on Aircraft	2	8	2
Machine Type	Wound-Rotor Synchronous	Permanent Magnet Synchronous	Permanent Magnet Synchronous
Rate Power (HP)	1000	98.6	423
Rated Torque (N m)	1978	668	2366
DC Voltage (V)	650	650	650
Rated DC Current (A)	1147	113	485
Speed (RPM)	3600	1050	1273
Control Objective	DC Voltage	Speed	Speed

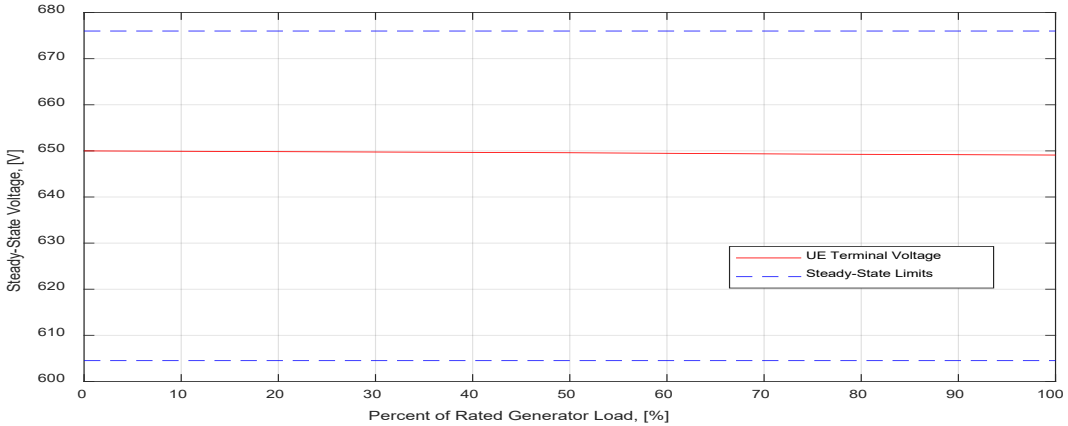
Power Quality Analysis Overview

- **System iteratively designed and tuned to meet an internal PQS specification**
- **Normal Operation**
  - Steady-State, Transient Voltage
  - Stability
- **Abnormal Operation**
  - Voltage response under short circuit conditions



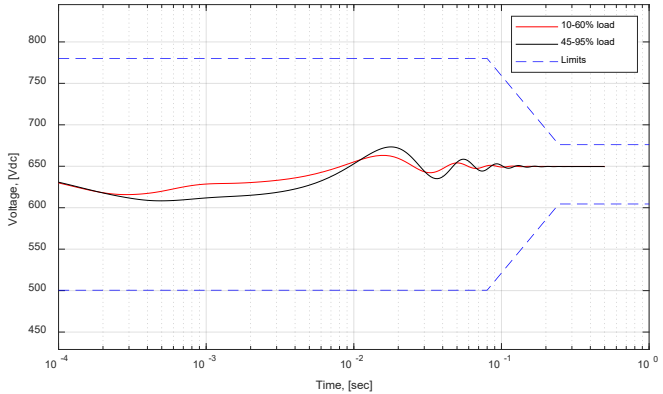
Steady State Voltage

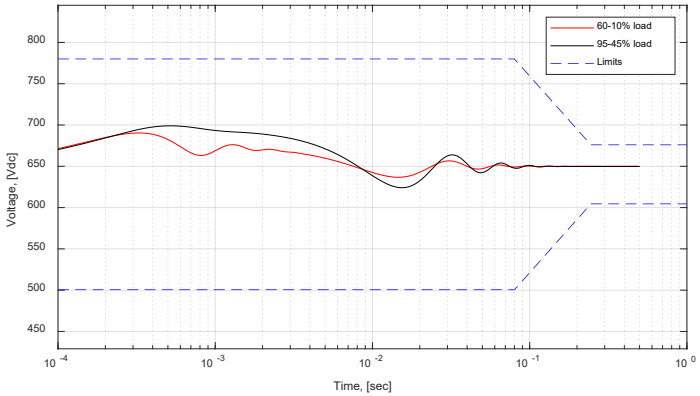
- **Requirement: Steady-State Voltage must remain between 0.93-1.04 p.u. at UE Terminals**
  - Covers No-Load to Full-Load
  - 604.5 to 676 Vdc at UE Terminals
- **No Load Voltage of 650Vdc**
- **Full Load Voltage 649.1Vdc**



Load Step Transient Voltage

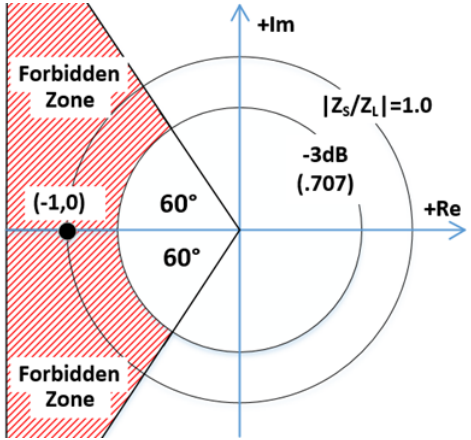
- **Requirement: EPS Transient Voltage must remain within the defined window limits under 50% load steps**
  - Resistive Loads stepped 10 to 60%, 60 to 10%, 45 to 95%, and 95 to 45% at UE Terminal Locations
  - Worst-case voltage response was at Cruise Motor Terminals
  - Spikes <10usec ignored

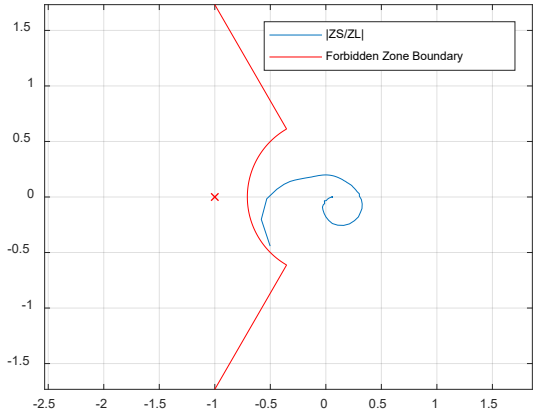




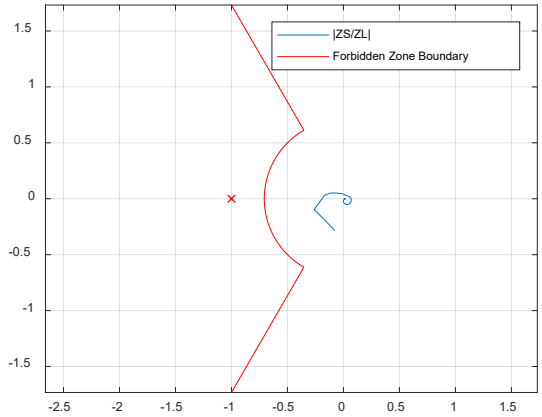
Small Signal Stability

- **Requirement: Ratio of Source to Load Impedance from 30Hz to 100kHz shall remain within the 60 degree, 3dB bounds shown**
  - Required modifying controller gains & input/output filters
  - Stayed within the required bounds for all loads & at main bus





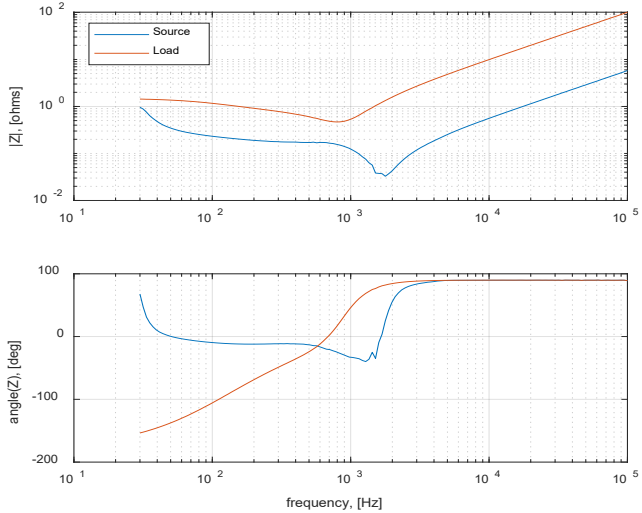
|Zs/Zl| at Cruise Motor Terminals



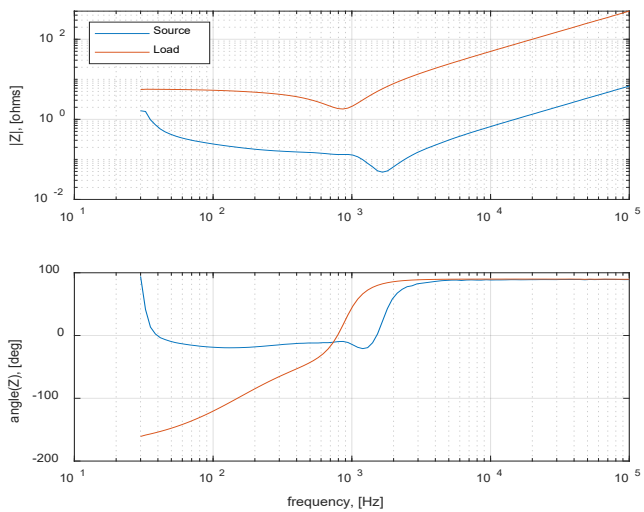
|Zs/Zl| at Lift Motor 8 Terminals

Small Signal Stability (cont.)

Source and Load Complex Impedance Plots



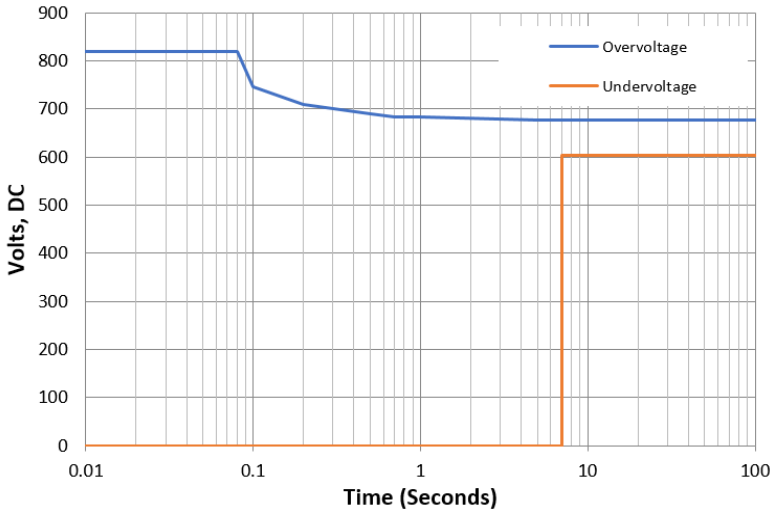
Cruise Motor



Lift Motor 8

Abnormal Voltage Response

- **Requirement: EPS Transient Voltage must stay within the over- and under-voltage limits shown in event of a fault**
  - Introduced short circuit faults onto Lift Motor branch circuits
  - Observed lift motor terminal voltages on unfaulted branch circuits
  - Spikes <10usec ignored



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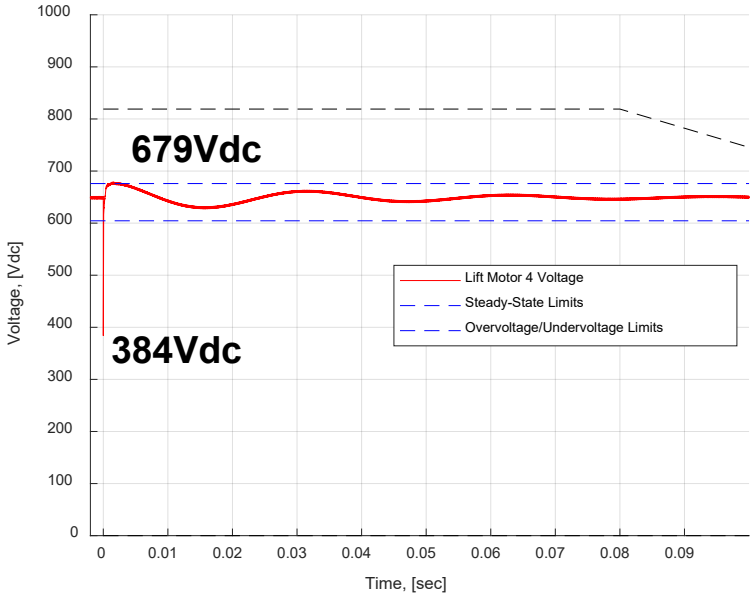
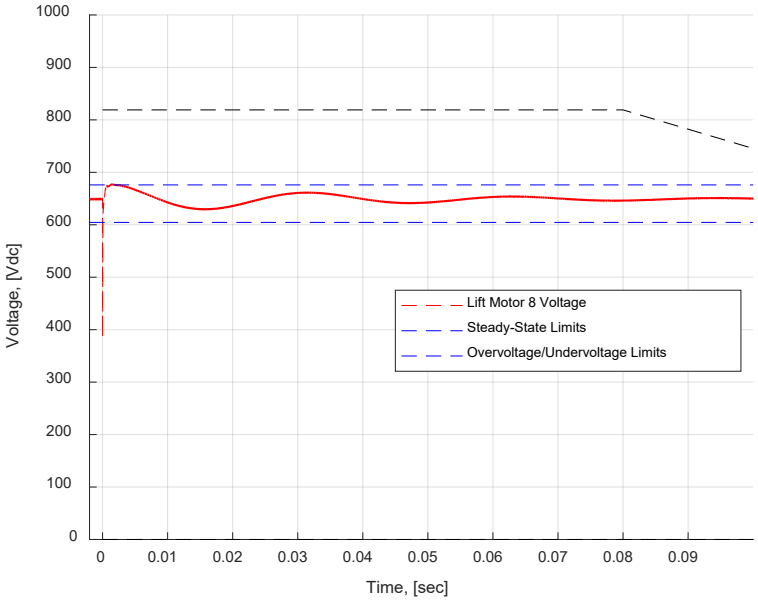
Abnormal Voltage Response (cont.)



Lift Motor 4 UE Terminal Voltage
Fault Initiated/Cleared on Branch Circuit 8



Lift Motor 8 UE Terminal Voltage
Fault Initiated/Cleared on Branch Circuit 4

Conclusion and Future Work

- **Designed and Tuned 650Vdc, <1MW UAM Power System**
- **Met Internal PQS Requirements**
- **Normal and Abnormal Response Data to provide point design for standards development**
- **Future Work**
  - Currently analyzing soft faults (may require updates and re-evaluation)
  - De-tuning filters to analyze marginal stability
  - Analyze different fault strategies / responses
  - Introduce cross-tie and analyze bus recovery & other PQ metrics

Questions

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