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Validation of the NASA Electrical Power System – Sizing and Analysis Tool (EPS-SAT)

**Patrick A. Hanlon, Brian P. Malone, David J. Sadey, Keith R. Hunker,
Casey J. Theman, Xavier Collazo-Fernandez, Trey D. Rupp, and Paul M. Nowak
NASA Glenn Research Center, Cleveland, OH**

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Contents

Introduction

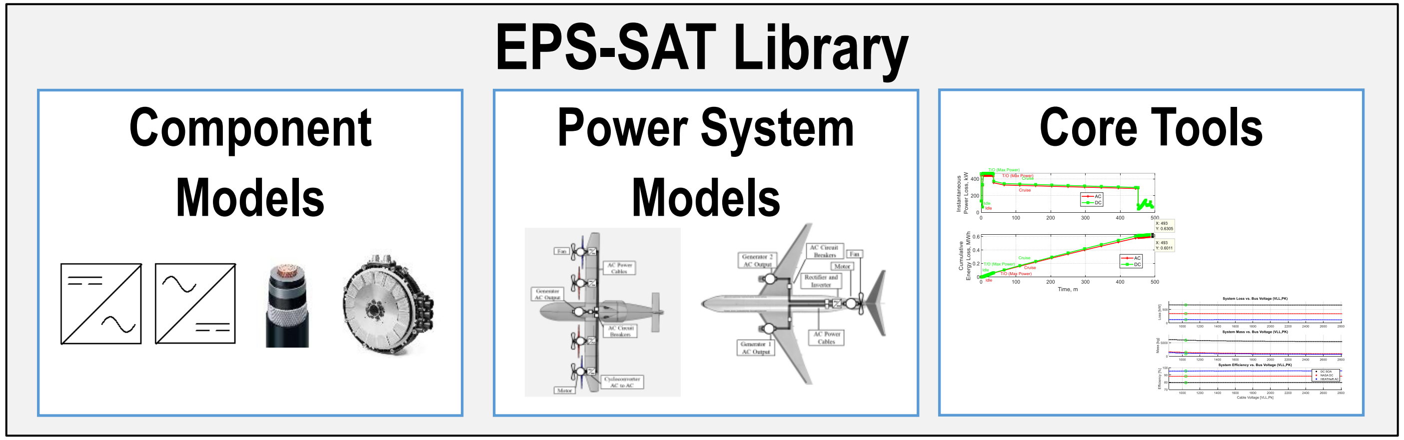
- Revolutionary Vertical Lift Technology (RVLT) Project
  - The RVLT project invests in cutting-edge technology and tools development
    - Ensure electric vertical takeoff and landing (eVTOL) vehicle reliability and safety
    - Reduce environmental impacts and noise
    - Create sustainable transportation system with broad economic benefit (advanced air mobility (AAM))
  - RVLT Power Management and Distribution (PMAD) group at Glenn Research Center (GRC) has built testbeds and modeling tools to investigate eVTOL power systems
    - Power quality, including off-nominal (faulted) operation
    - Modeling, simulation, analysis, and tool development for trade studies
      - There exist few sizing and analysis tools for electric aircraft propulsion (electrical power system specifically)

Introduction

- Electric Power System – Sizing and Analysis Tool (EPS-SAT)
  - Introduced to satisfy need for tool specifically intended for sizing and analysis of electrical power systems
    - System and component sizing
    - Power system architecture studies
    - System-level and component-level trades
  - Exposes design strengths and weaknesses
  - Can be used to direct investment dollars

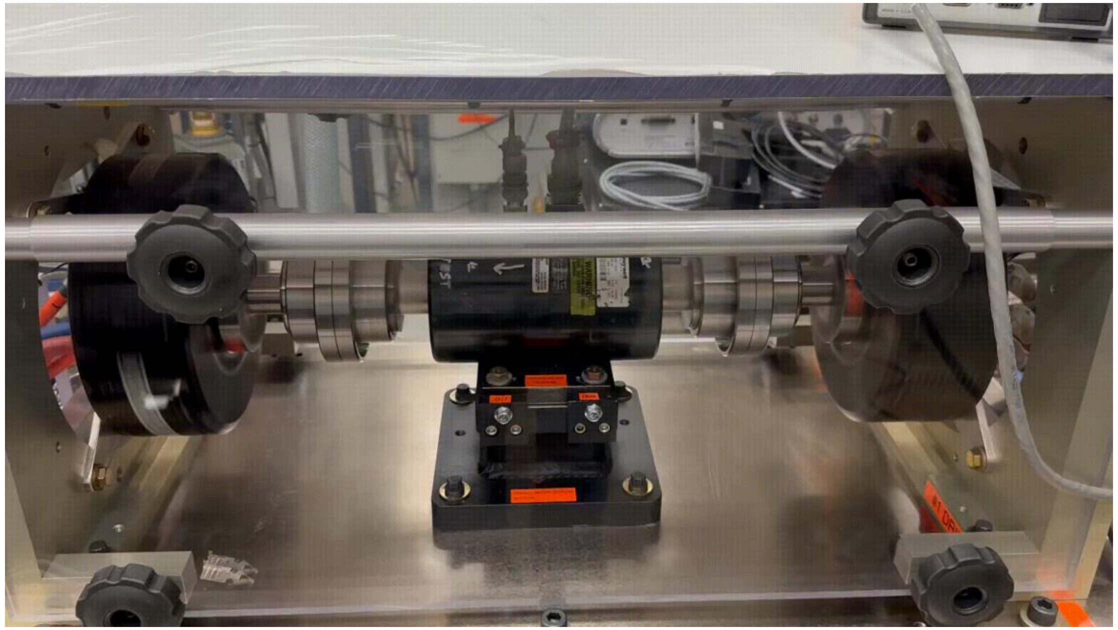
EPS-SAT

- Object-oriented MATLAB-based coding framework
  - Supports DC and single-phase or polyphase AC
  - Newton-Raphson solver for solving power flow equations
- Components and systems are sized in on-design mode
- Mission profiles and energy storage are specified in off-design mode
- Evaluate whether design closes given constraints (mass, range, system failure rate, etc.)



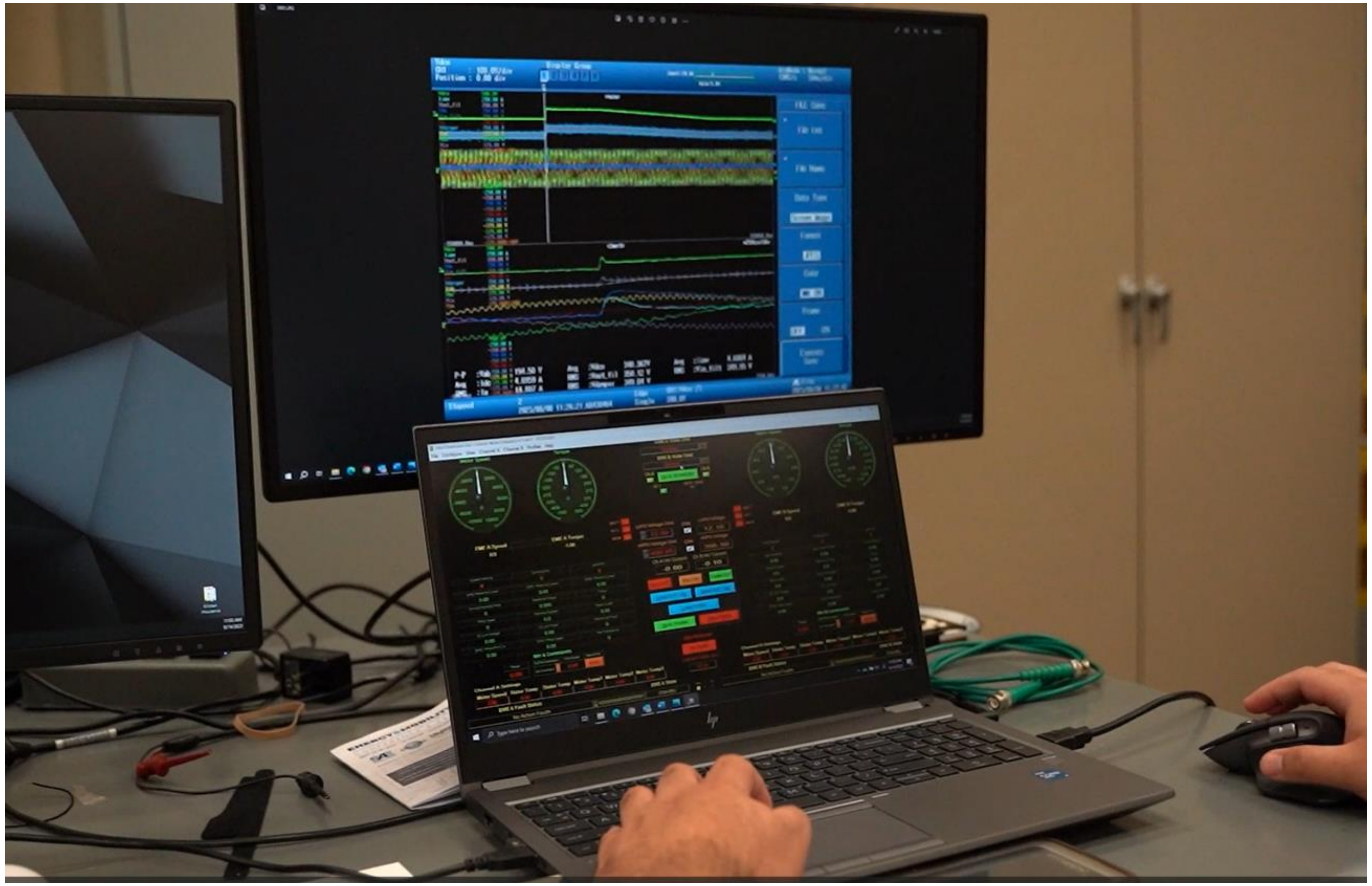
AREAL Testbed

- This was the hardware used for extracting mechanical and electrical validation data
- 200 kW, HVDC (max 1 kVDC)
- Reconfigurable and capable of both normal and faulted operation
- Physical PMSMs as well as motor emulator
- Bi-directional DC sources able to be programmed as dynamic sources and loads



Testing and Data Processing

- Single-string configuration (single source and load)
- Steady-state values (718 VDC, 250:250:5500 rpm, 20:20:100 Nm) - 110 total
- Made mechanical (torque and speed) and electrical (voltage and current) measurements



Performance Map Extraction

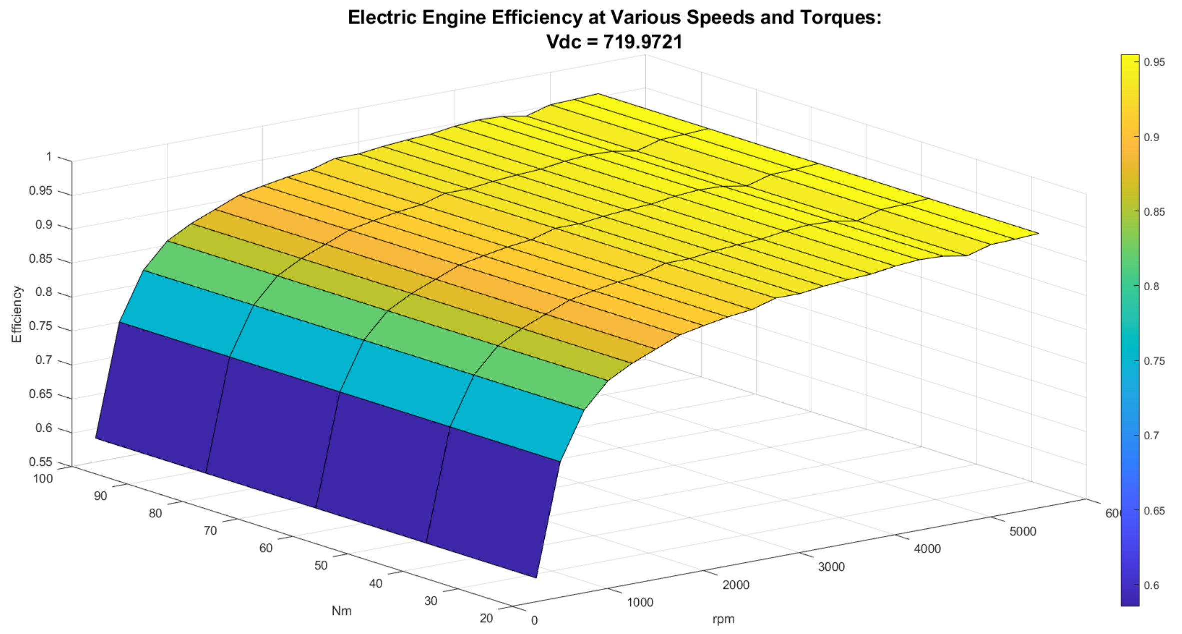
- Motor, inverter, and electric engine efficiency plots generated from motor and inverter power calculations
- Two wattmeter method incorporating FFT

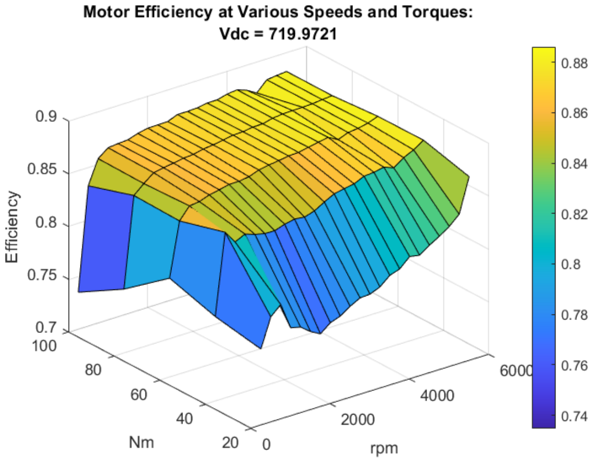
$$P_{AC,1} = \Sigma(real(fft(V_{AC}).fft(I_A^*)))$$

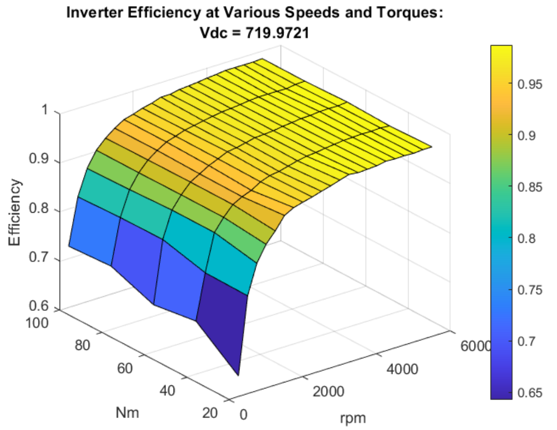
$$P_{AC,2} = \Sigma(real(fft(V_{BC}).fft(I_B^*)))$$

$$P_{AC,TOT} = P_{AC,1} + P_{AC,2}$$

- Sanity check on EPS-SAT electric engine efficiencies

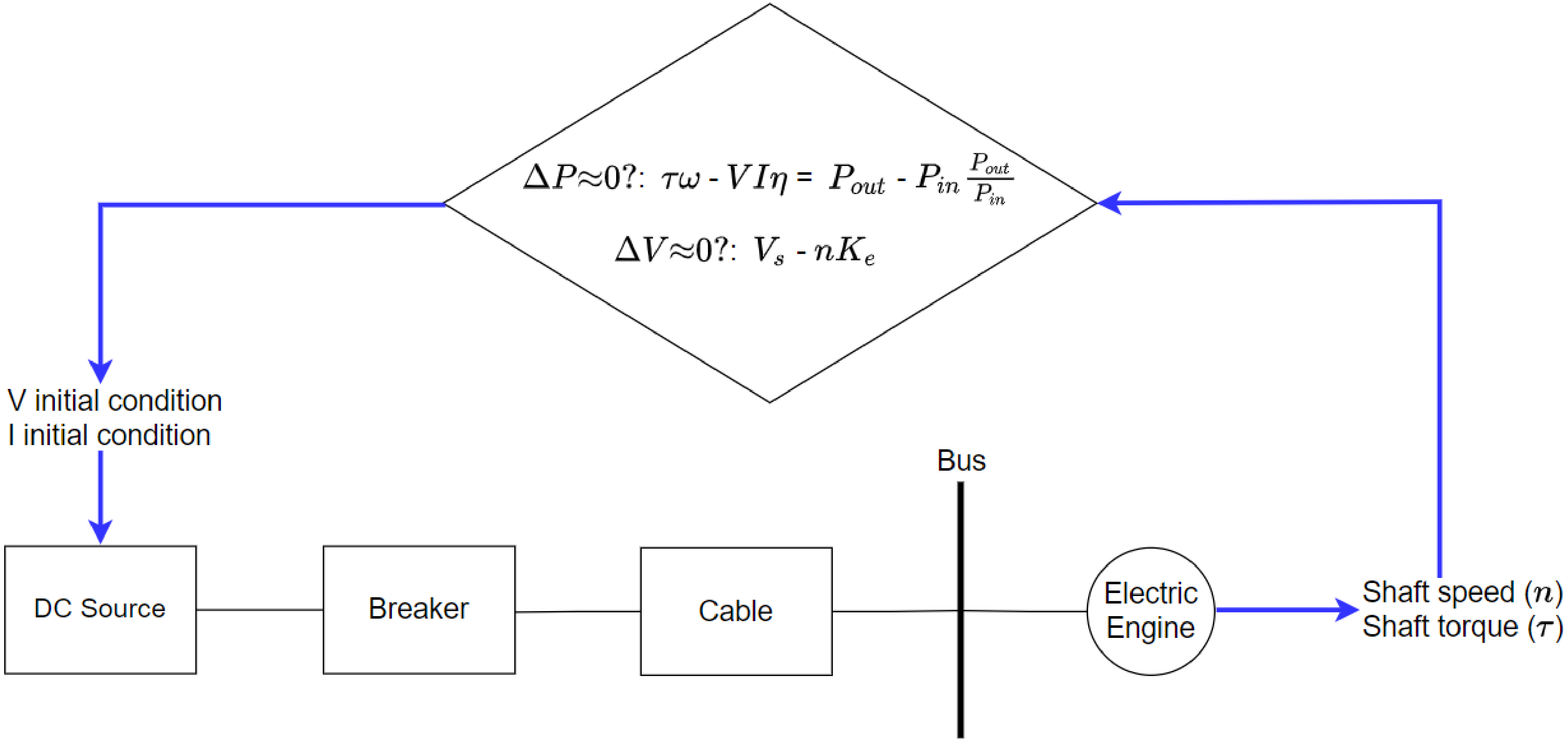






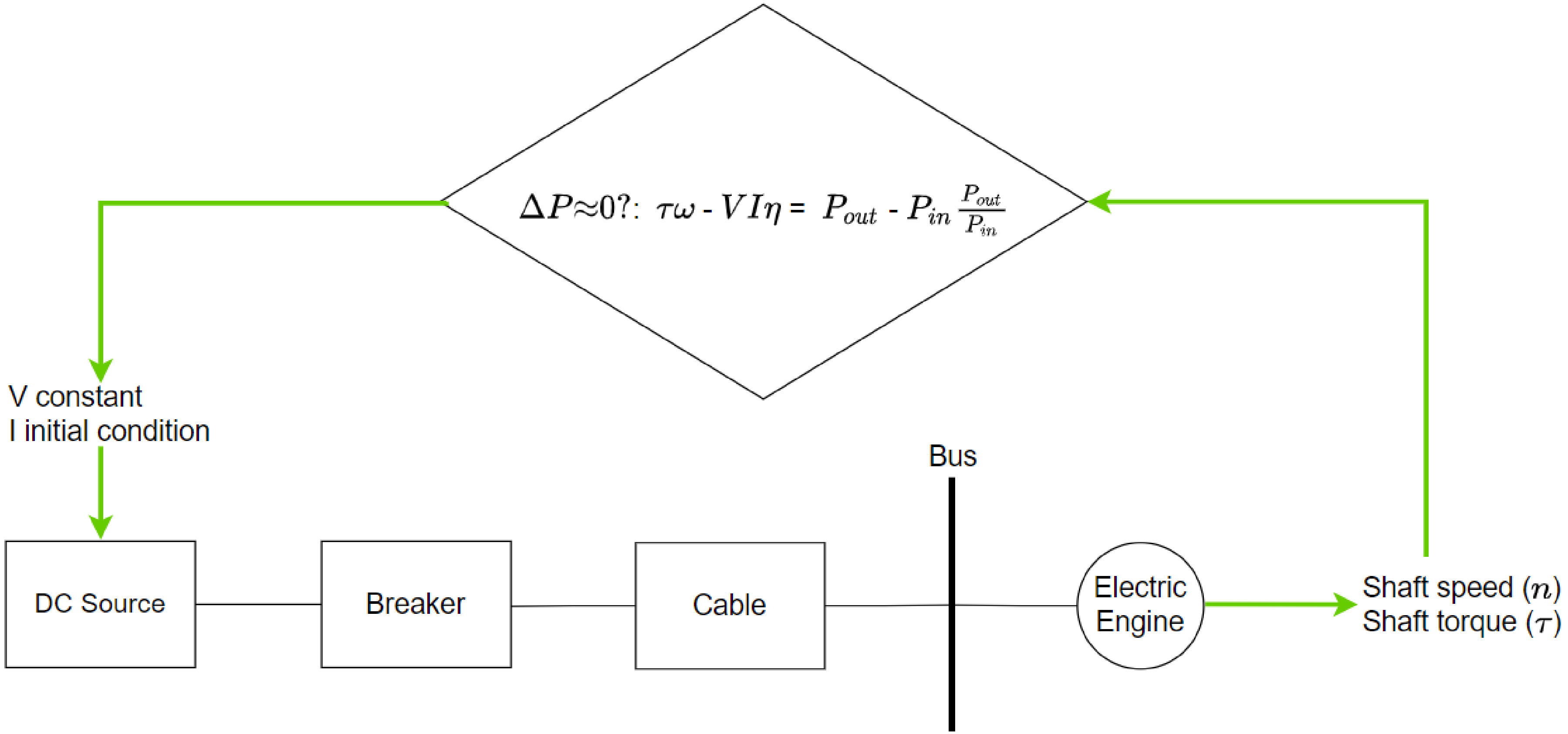
EPS-SAT Electric Engine Model Calculations

- On-design: given speed and torque setpoints, vary input voltage and current
  - Calculated electric engine input power varied until it equals DC input power (efficiency LUT)
  - Calculated electric engine input voltage (bus voltage) varied until it equals rated voltage (back EMF constant)



EPS-SAT Electric Engine Model Calculations

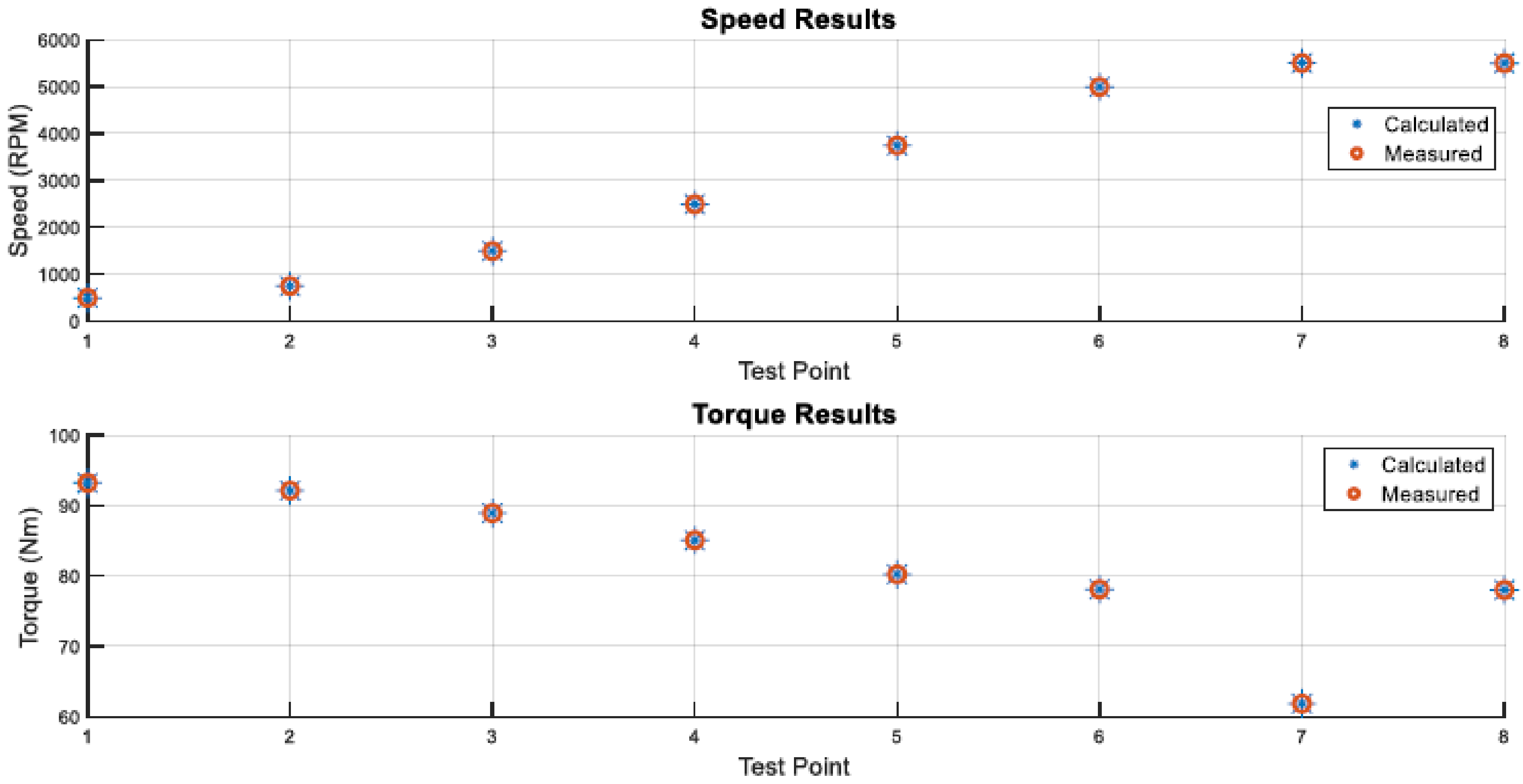
- Off-design: given speed, torque, and bus voltage, vary input current
  - Calculated electric engine input power varied until it equals DC input power (efficiency LUT)



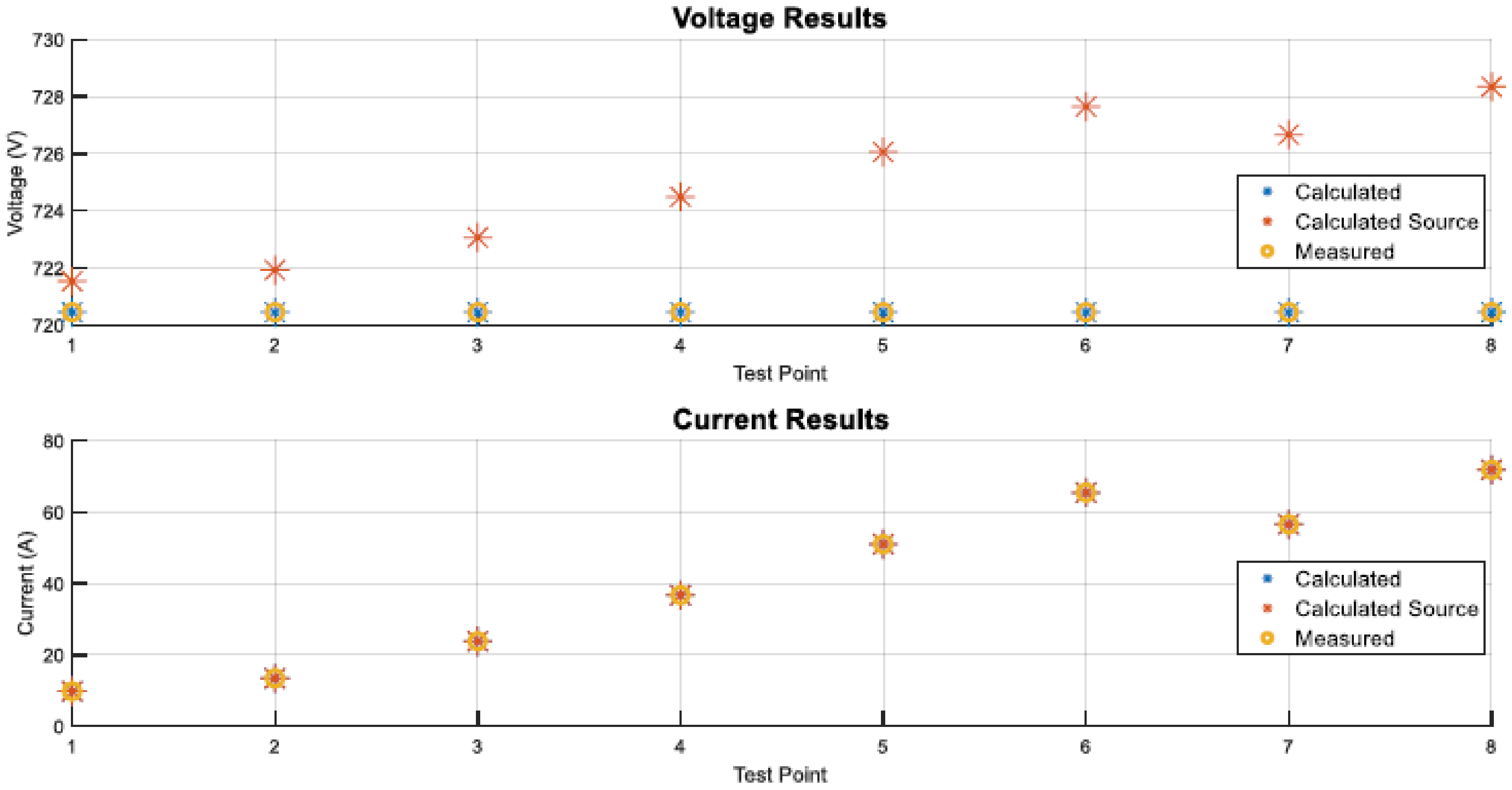
Validation Strategy

- AREAL hardware data points were the baseline
- Ran AREAL data points in EPS-SAT
- Evaluated results
    - Input the speed and torque at max continuous speed and torque
    - Expected:
        - EPS-SAT to produce matching voltage and current at the source terminals of the electric engine
        - Speed and torque at the load to match
        - Electric engine efficiency to match

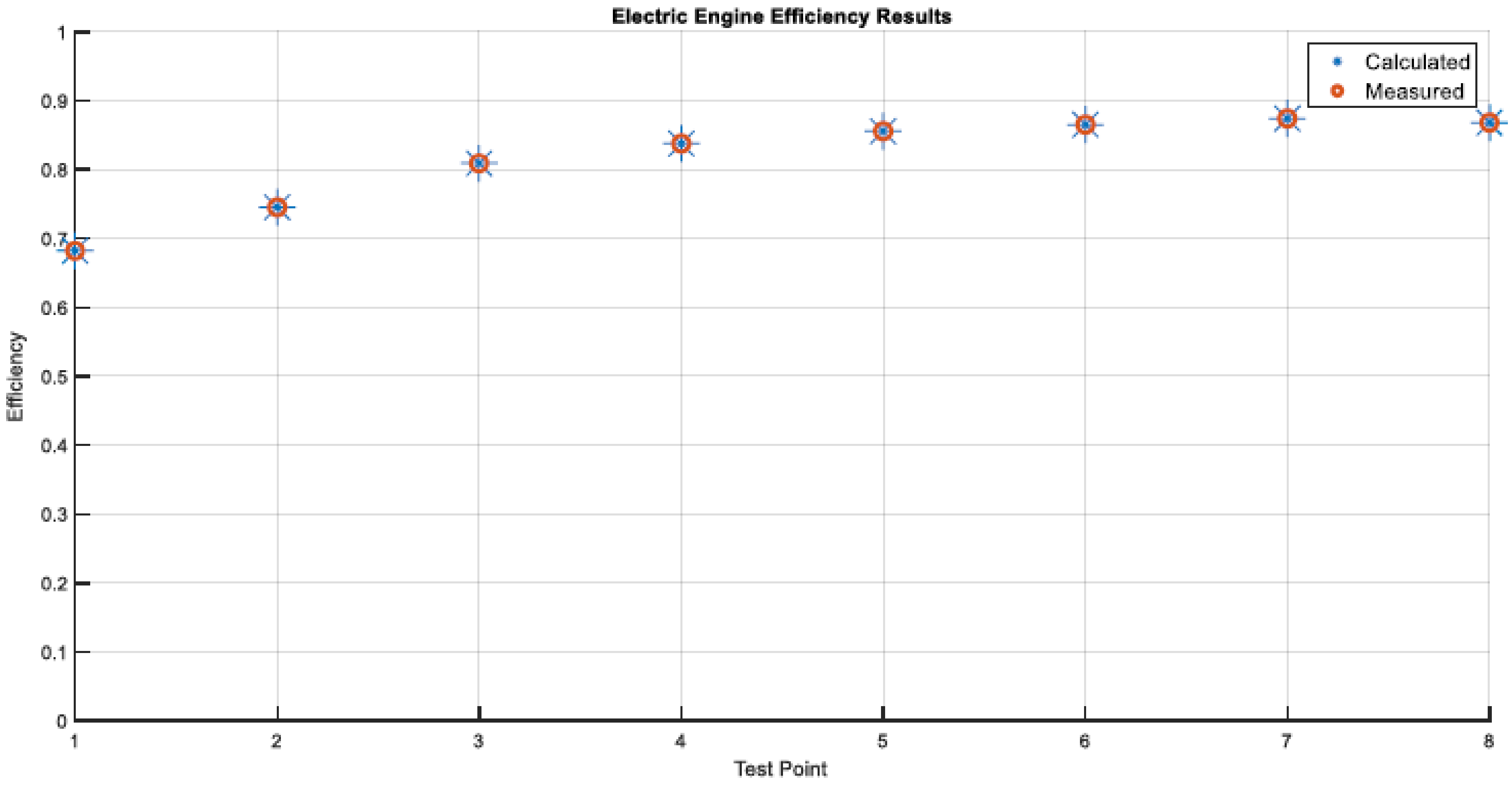
EPS-SAT and AREAL Validation



EPS-SAT and AREAL Validation



EPS-SAT and AREAL Validation



Future Work

- Add capability to model inverter and motor AC powers (and efficiencies)
- Compare realistic flight profile data measured in AREAL to flight profile data modeled in EPS-SAT
- Improve model for mass calculation

Conclusion

- AREAL single-string hardware configuration was modeled in EPS-SAT
- Single-string AREAL testbed steady state testing results at 718 VDC validate EPS-SAT software calculations
  - Almost no difference between electric engine efficiencies, speeds, torques, DC voltages, and DC currents
- EPS-SAT is a useful tool for high-level, rapid design and evaluation of EAP systems

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