National Aeronautics and Space Administration

NASA Glenn Power Division Power Management and Distribution Branch (PMAD)

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GRC Power Division - Power Management and Distribution Branch

- John Glenn Research Center Power Division
- Division Composition – 92 Civil Servants
  - Power Management and Distribution Branch
    - Current Staff
      - 24 Civil Servants
      - 5 Full Time In House Support Service Contractors
      - Facilities -
        - Square foot - 27,178
        - 60 ft high bay test area (9000 sq ft) Class III Clean Rm
        - Vacuum Facilities - 2
        - Assembly Areas - 4

FLIGHT PROJECTS

Gateway level 2 power development and integration co-leads

Gateway Power Prop Element power development lead

Gateway PPE Hall Effect Thruster Power Processing Unit development lead

Orion European Service Module power system technical lead

Planetary surface power development

AGENCY FUNCTIONS –
MARS CAMPAIGN OFFICE – PMAD PORTFOLIO

- Advanced Modular Power Systems - Developing Modular Electronic Standard for Space Power Systems (MESSPS)
- Advanced Energy Management Systems - Developing power controller to manage power distribution and transmission on the lunar surface including vehicle to vehicle and over a power grid
- Power Exchange Interface - Developing standard interface connector for all elements to send/receive power
- Dust Tolerant Connectors - Delivering dust-tolerant technology to meet high cycle needs
- Long-Distance Power Transmission
  - Developing standard interface for long-distance power transmission
  - One side of the converter meets current 120 VDC power requirements, the other side deals with transmission
- AC Cables - Developing light weight AC cables for lunar and Martian surfaces
- Grounding - Developing guidelines for grounding elements and interacting with long-distance transmission

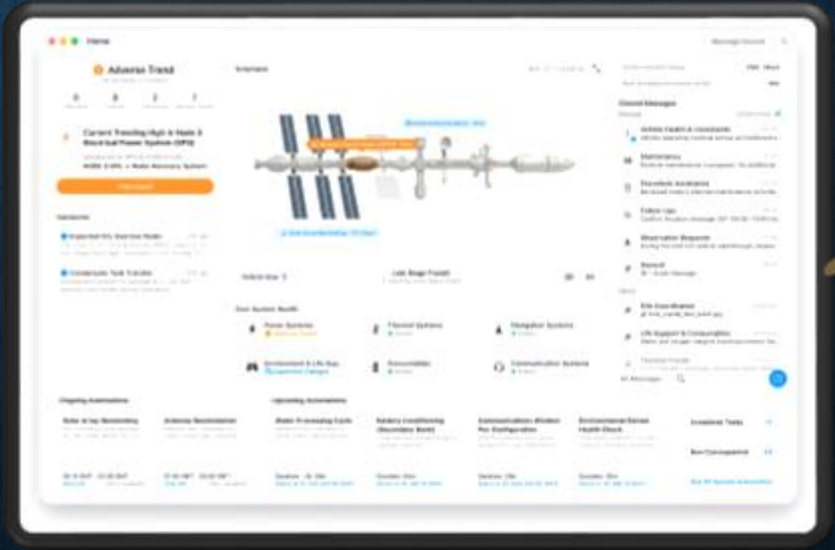
AGENCY FUNCTIONS –
MOON TO MARS – SYSTEMS ENGINEERING & INTEGRATION

- Power Subject Matter Expert - M2M SE&I on Systems Integration and Test (SIT) Team
    - Standards & Interoperability
        - Support standards development/updates to meet M2M needs
    - Technology Development
        - Identify power related technology gaps in M2M program and advocate for funding / technology development from MCO and STMD
            - Future systems integration
        - Support M2M Future Systems lead in identifying appropriate power requirements for new elements and support emplacement studies/analysis.
            - Support MPH Energy Storage needs during Transition into M2M
            - Support Integrated Power Project (Integration Lead role)

Agency Functions –
Earth Independent Operations (EIO)

Tasks
- Develop improvements to power system diagnostic algorithms using simulation, AMPS, and ISS ops data
- Develop conventional fault management system for AMPS hardware (caution and warning / QSI TEAMS)
- Support integration of AMPS with ECLSS at MSFC
- Develop crew interfaces for AMPS hardware
- Develop autonomous and crew procedures for AMPS hardware
- Support EIO27 integrated software release

Current GRC Project Support:
- AR-1 & AR-2: Fault Diagnostics
- IST-2: AMPS Testbed
- CI-5: Crew Interface Development (power)
- Vehicle Management Portfolio

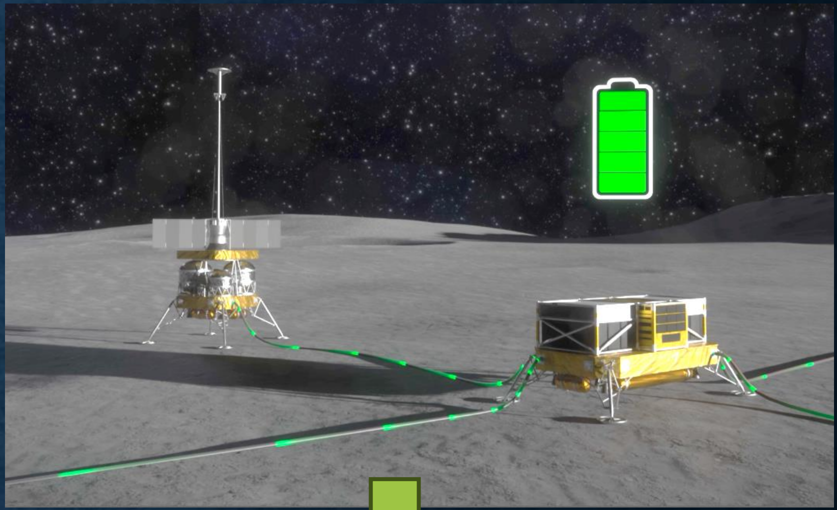


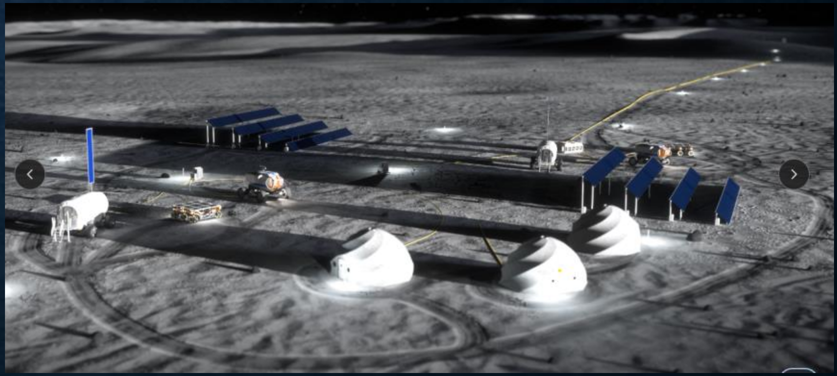
Agency Functions –
Independent Power Pre Planning (IPP)

<u>Lunar Grid Planning</u>

- Define Trades
  - Draft trade list to include power generation, energy storage, distribution/transmission, mobility/logistics
- Develop Architectures
  - Determine/define extensibility

2030 Representative System





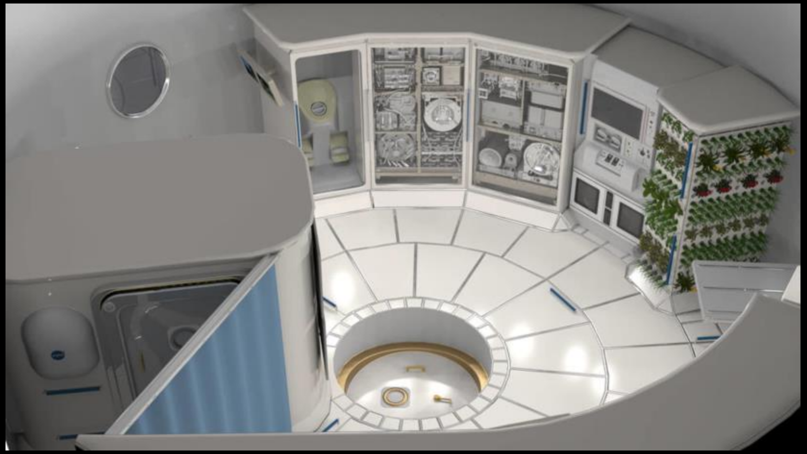
Extensibility

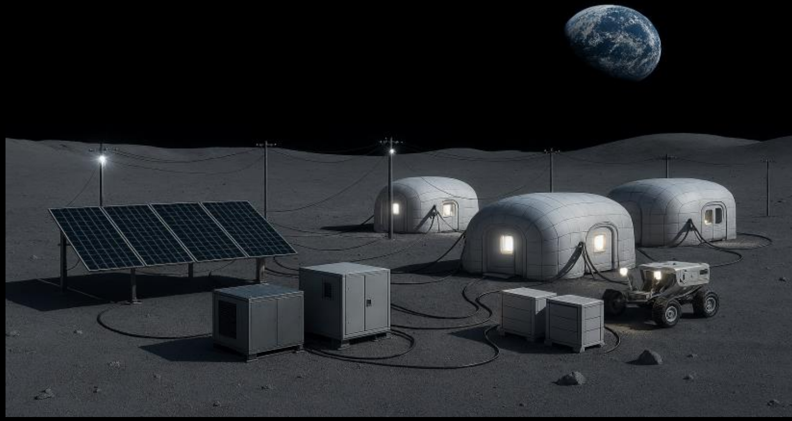
Planetary Power Management & Distribution (PMAD)

Power Management and Distribution Branch (LEM)

Planetary (Moon and Mars) PMAD

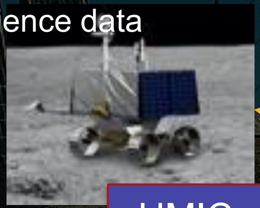
- **Element PMAD**
  - Standardized modular and common power system designs for all elements
    - Standard PMAD design allows for swapping of components between elements
    - Vendor independence, increased redundancy, and lower sparing mass/costs
  - Standard power interface
    - Common standard power interface for power connections between elements
- **Power Transmission**
  - Long-distance power transmission (1 km - 10 km)
    - Power availability into PSRs and other locations that power generation is not possible
  - Ultra long-distance power transmission (10 km – 20 km)
    - Ability to connect Artemis locations
- **Global Power Management**
  - Highly automated PMAD system that minimizes human interaction
    - Ensure power delivery to most critical elements





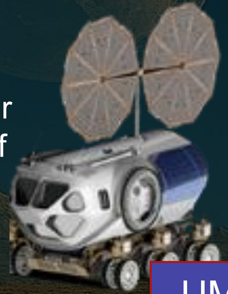
Planetary PMAD

Exploration Rovers
Smaller mobile platforms to explore the lunar surface, conduct surface operations, and collect science data



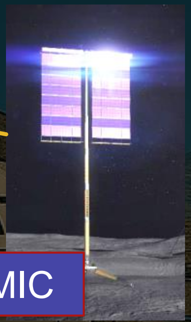
UMIC

Pressurized Rover
Mobile habitat to enable wider ranging human exploration of the lunar surface



UMIC

Vertical Solar Array Technology (VSAT)
Large vertical solar arrays that will operate at 10 meters above the surface at the lunar south pole.



UMIC

Lunar Surface Habitat
Stationary habitats to enable local exploration of the lunar surface

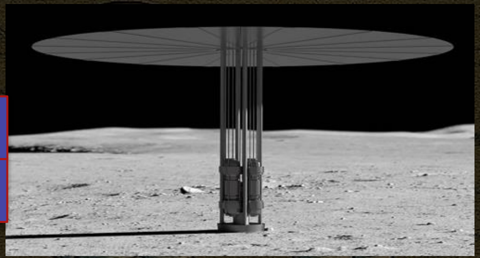
UMIC

UMIC

Planetary Power Grid

UMIC

UMIC

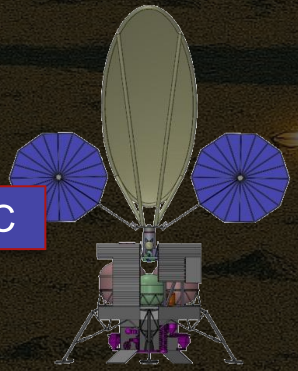


FSP (Fission Surface Power)
kW-class nuclear power source for Mars or lunar surfaces during daylight or night

Regenerative Fuel Cell (RFC)
Energy storage technology using water electrolysis to store energy in hydrogen for later conversion into electrical power by a fuel cell.

UMIC

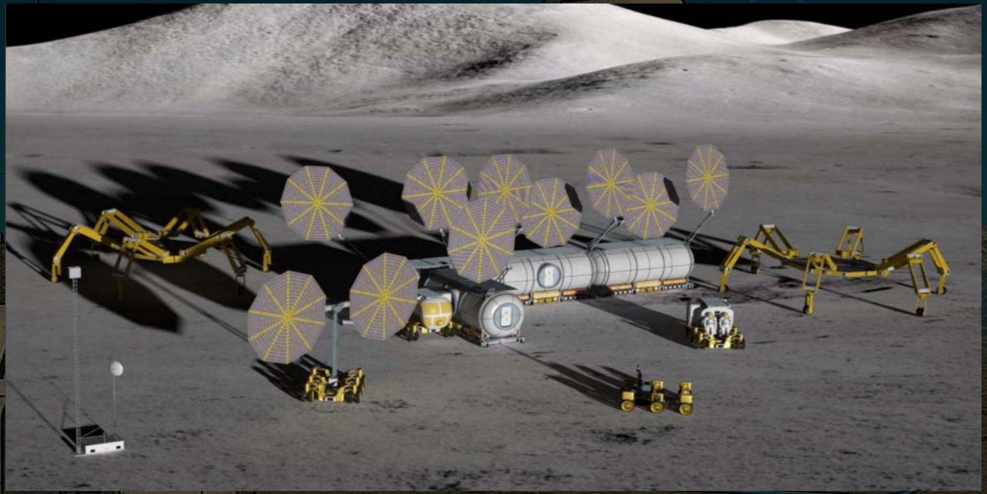
UMIC

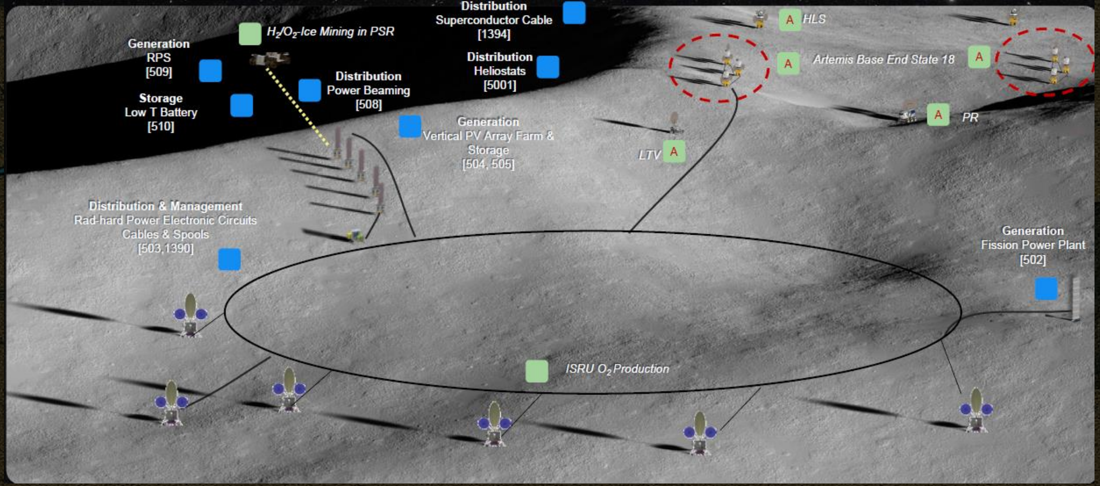


In Situ Resource Utilization (ISRU)
Surface systems to recover and process materials from and within the lunar regolith to support lunar surface operations

Planetary Power PMAD –
Short Range/ Long Range Transmission PMAD

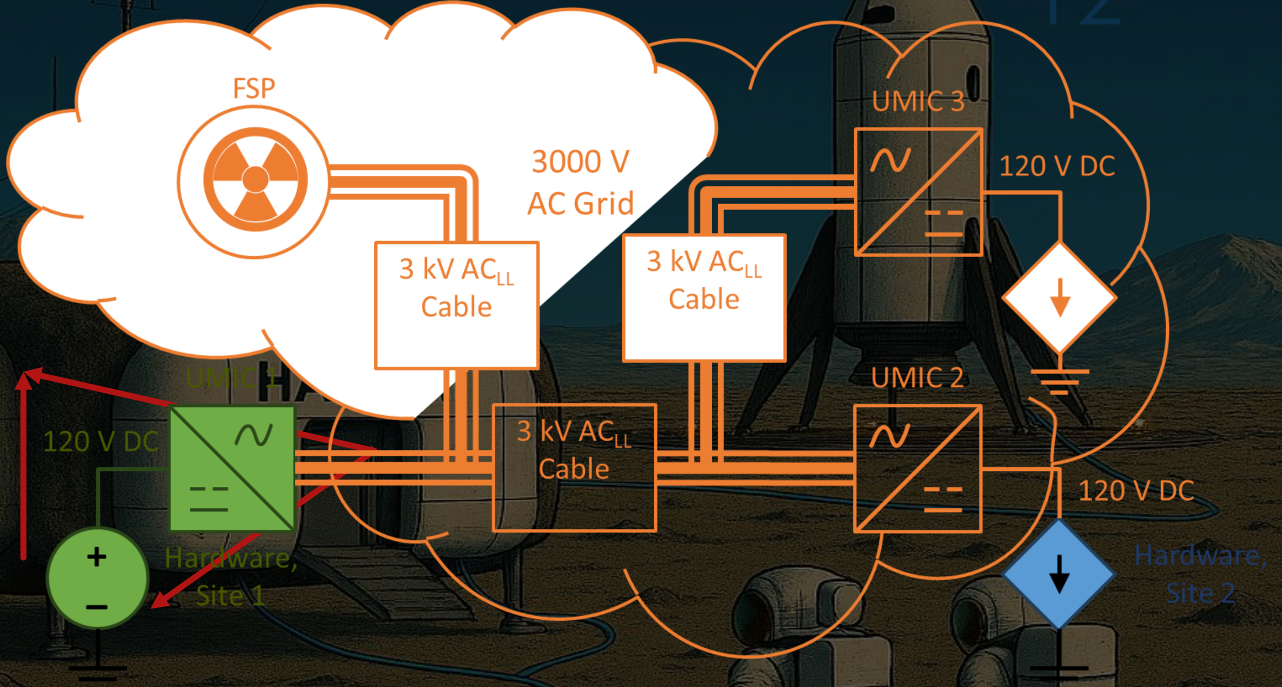
- AC vs DC Local Distribution
  - Assumptions
    - Local Distribution 120VDC
- AC vs DC Long Distance Transmission
  - GRC MIPS Study
    - Concluded that Long Distance Transmission 3kV 1000kHz AC





Lunar Power Grid Hardware-in-the-Loop Development - ExCELS

- NASA developing Hardware-In-The-Loop (HIL) capability called Experimental Communications and Electric Power for Lunar Surface (ExCELS)
  - Developing tools for distributed power HIL simulation
  - Connect 120 VDC and 3 kVAC hardware located at separate sites to a single, simulated grid
  - Ulitize a deviice call the Universal Modular Interface Converter (UMIC)



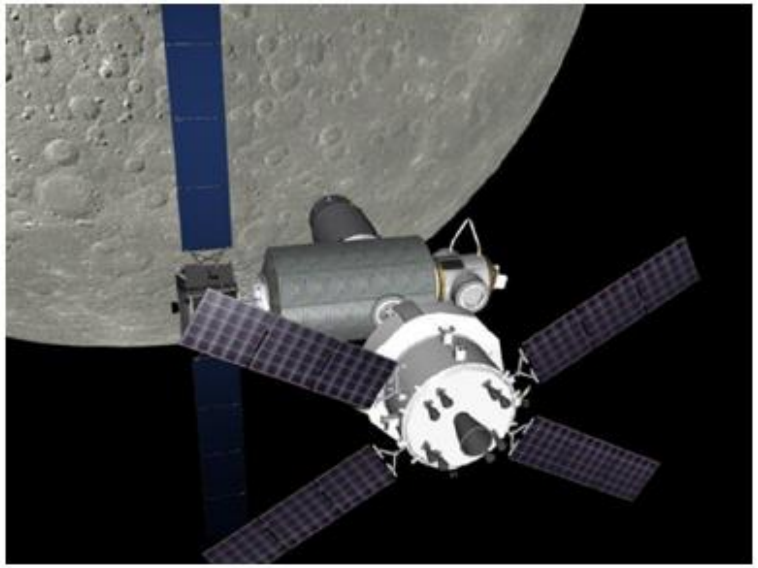
- **Next steps through 2030**
  - Further develop ExCELS capability through integration with separately developed autonomous power control (APC) software infrastructure
  - Develop controls past reactive layer and into grid control layer
  - Develop endpoint node hardware to integrate research hardware assets into the APC control network

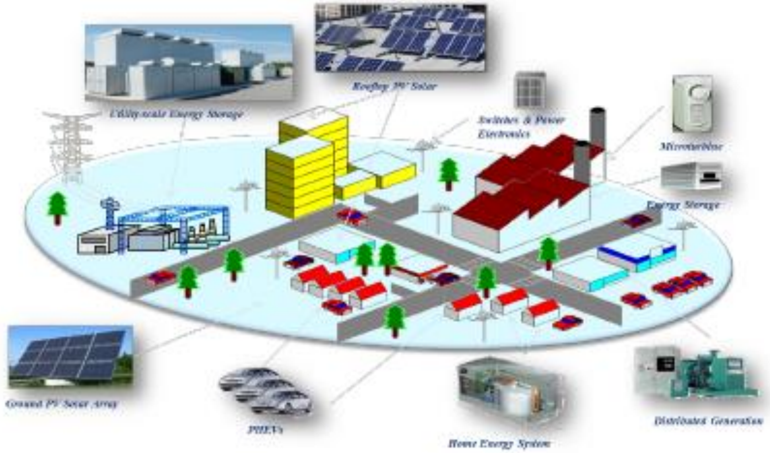
AUTONOMY –
AUTONOMOUS POWER SYSTEM CONTROL - APC

- Power System Functions
  - Operate safely at all times
    - Power generation / energy storage devices
    - Power distribution system
  - Provide power to as many high priority loads as possible

- Power System Control Functions
  - Manage the power system
    - Fault management
    - Energy management
    - Contingency management (recovery)

- Autonomous Power System Control Functions
  - Manage the power system <u>*without human intervention*</u>
  - Permit humans to consent to any operations / actions during habitation





Autonomy - Advanced Power Control Laboratory

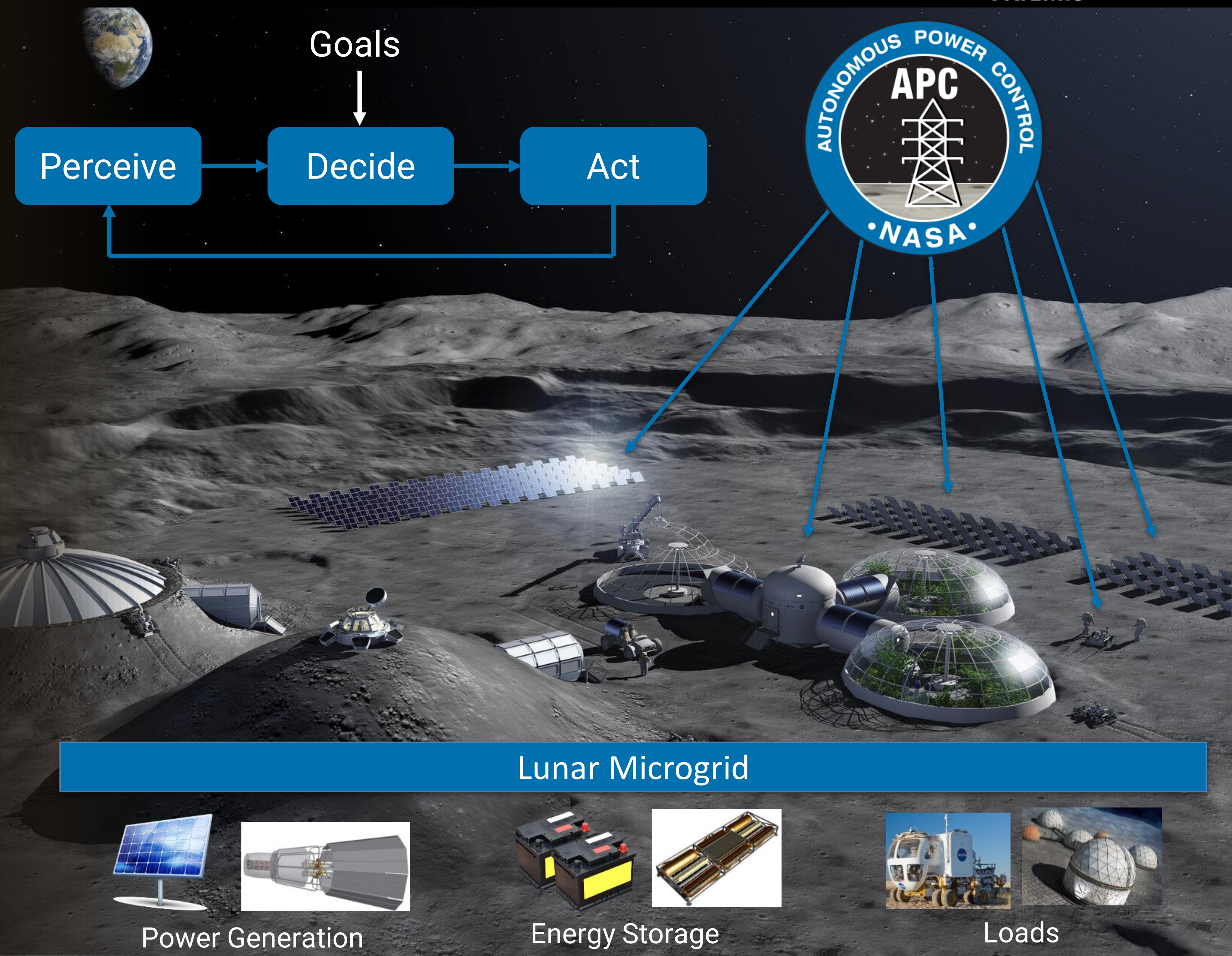
The APC laboratory provides *intelligent* and *robust* management of NASA's electric power systems

Future missions to the Lunar and Martian surfaces will demand highly reliable, distributed power systems akin to terrestrial microgrids.

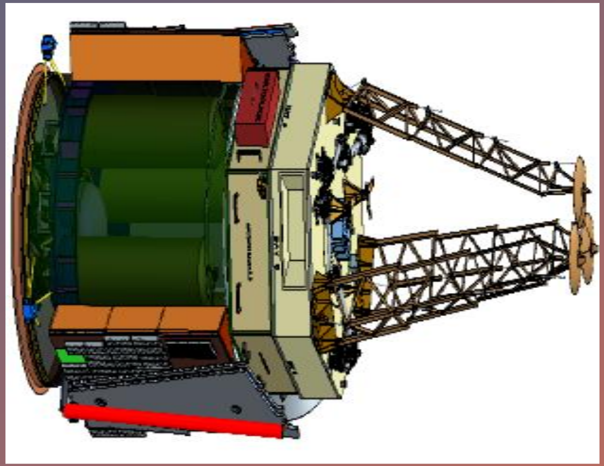
APC provides methods to:

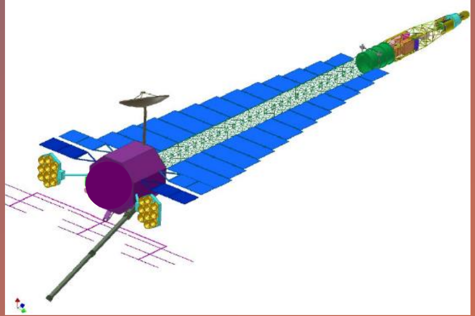
- Optimize usage of distributed energy resources to manage loads
- Detect and diagnose faults using AI/ML
- Intelligent reconfiguration to minimize outages
- Enable interoperability of new devices through "plug-n-play"

Fuel Cell

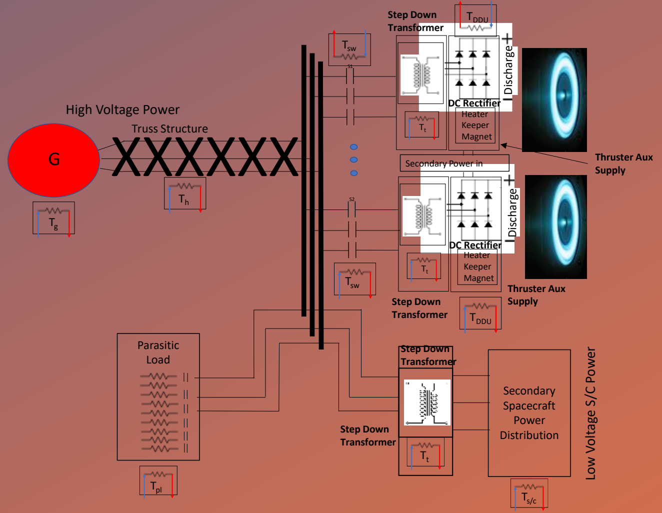


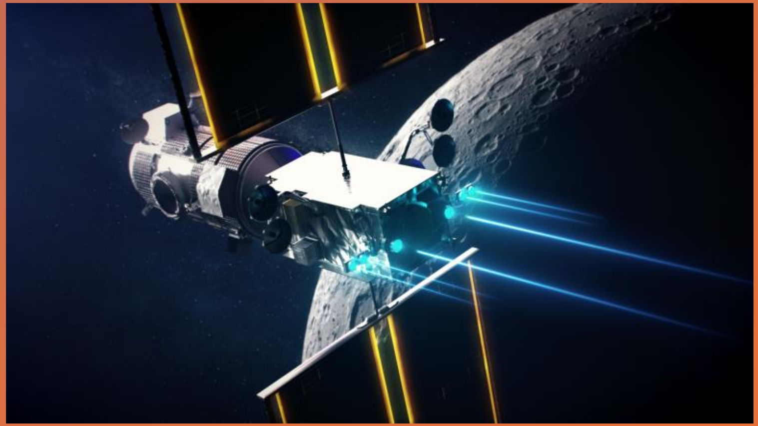
Space Power Architectures





- ARRM EPS
- PPE EPS
- Nuclear Electric Propulsion Vehicle Power EPS
- Mars Transport EPS





PMAD Technologies –
AES Modular Power Systems (AMPS) – Project

- **Why is this project important?**
  - Modular power systems provide opportunities to minimize maintenance operations, improve power system availability, and reduce the number of unique spare parts, thus enabling **sustainable** future exploration missions and systems
  - This project develops modular power system technologies, inclusive of modular power standards, modular power electronics, and autonomous power controls, in support of NASA's future exploration missions, including the cis-lunar Gateway
- **Objectives:**
  - The AMPS project seeks to ***transform future space power systems*** by applying a modular approach, standardizing the power system at the electronics module level, and proving the technology through ground-based demonstrations

Autonomous Power Controller

provides vehicle-level interface for:

Modular Electronic Standard for Space Power ns S)

defines interfaces, form, fit, and functions of:

Electronics Modules

- Intelligent Controller
- Housekeeping
- High Current Switchgear
- Bus Switchgear
- Load Switchgear
- Bi-Directional Converter
- Portable Equipment Panel (PEP) Module

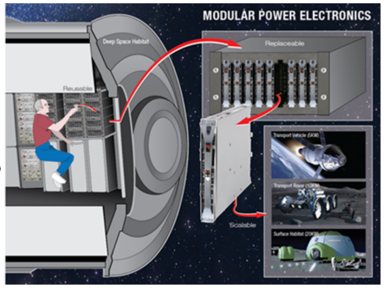
can be arranged to build:

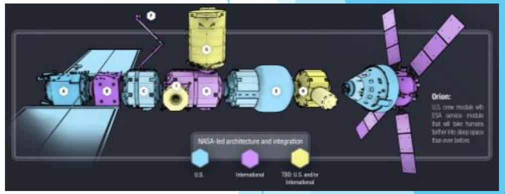
Modular Electronic Units

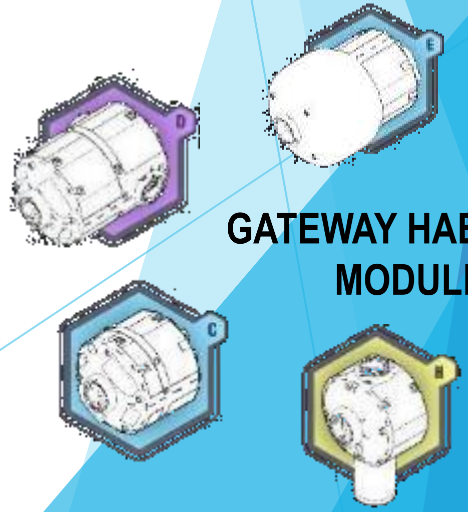
- *Main Bus Switching Unit (MBSU)*
- *Secondary Bus Switching Unit (SBSU)*
- *DC-DC Converter Unit (DDCU)*
- *Power Distribution Unit (PDU)*
- *Battery Charge Discharge Unit (BCDU)*

can be arranged to build:

Modular Architectures

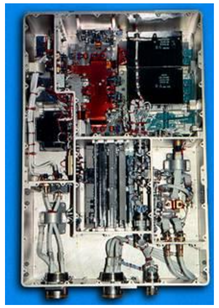






GATEWAY HABITATION MODULES

PMAD Technologies –
Traditional versus Modular Power Architectures



DC to DC Converter Unit

Main Bus Switching Unit

Remote Power Controller

Traditional ISS-Like Power Architecture

Modular Electronic Standard for Space Power Systems (MESSPS)

define interfaces, form, fit, and functions of:

Electronics Modules

- Intelligent Controller
- Housekeeping
- High Current Switchgear
- Bus Switchgear
- Load Switchgear
- Bi-Directional Converter
- Portable Equipment Panel (PEP) Module

can be arranged to build:

Modular Electronic Units

Main Bus Switching Unit (MBSU)

Secondary Bus Switching Unit (SBSU)

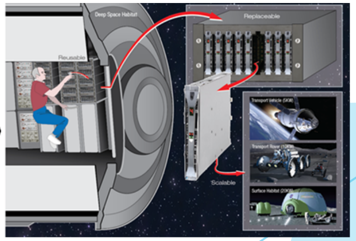
DC-DC Converter Unit (DDCU)

Power Distribution Unit (PDU)

Battery Charge Discharge Unit (BCDU)

can be arranged to build:

Modular Power Architecture

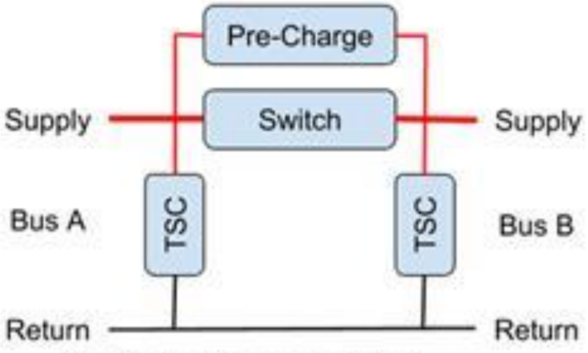


High Power PMAD –
High Power Switchgear

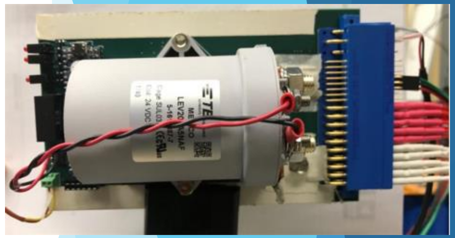
High Current Switchgear Module (HCSM)

Functions:

- Bidirectional supply-side switch
- Bidirectional pre-charge circuit*
- Configurable, resettable trip
- Transient suppression*



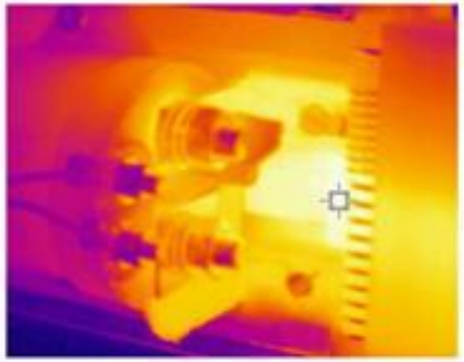
TSC: Transient Suppression Circuit



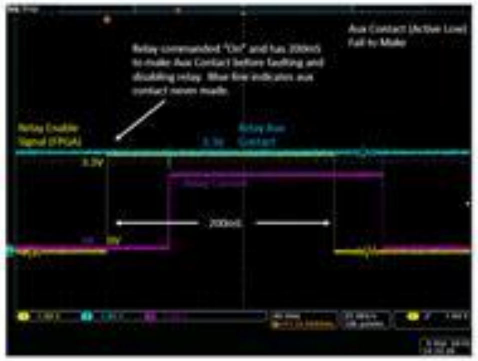
Input/Outputs: 2 ports @ 120VDC, 200A

Size: 3U x 3 Slots
TRL: 4
Status:

- 2nd gen. prototype demonstrated



Thermal Test @ 200A



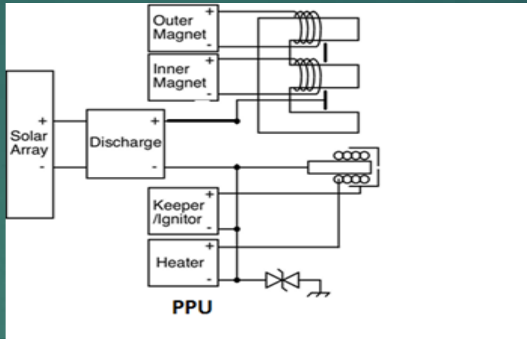
Electrical Test

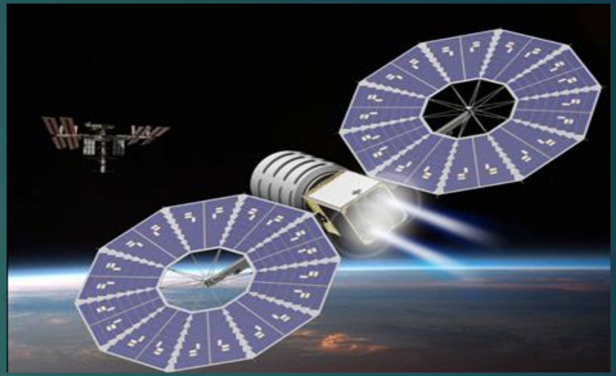
Rapid Prototyping – PPE HET Thruster Igniter

- The ignitor/keeper supply is one of the supplies in the Power and Propulsion Element (PPE) power processing unit (PPU), used to ignite the cathode of the Hall Effect Thruster (HET)
  - Outputs a periodic high voltage pulse when impedance is high (before cathode ignition)
  - Once plasma is initiated between keeper and cathode during cathode ignition, sustains constant keeper current at specified value
- Power Management and Distribution Branch engineers developed an ignitor circuit that emulates the behavior of the PPE ignitor, for use in ground testing for the Advanced Electric Propulsion System (AEPS) 12 kW thruster
  - Certified to NASA-STD-5005D ground support equipment standard to interface with flight hardware
- Used during flight thruster test campaigns at GRC, qualification thruster and cathode testing at JPL, and other various engineering thruster and cathode tests

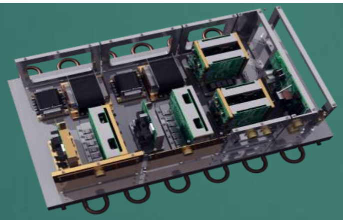
Rapid Prototyping – HV SiC Power Converter

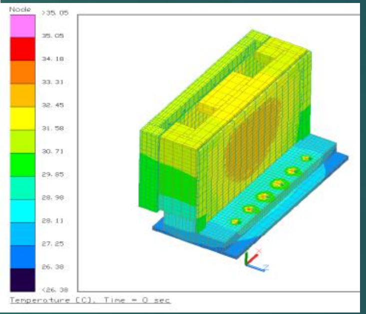
STMD HP-300V HALL EFFECT POWER PROCESSING



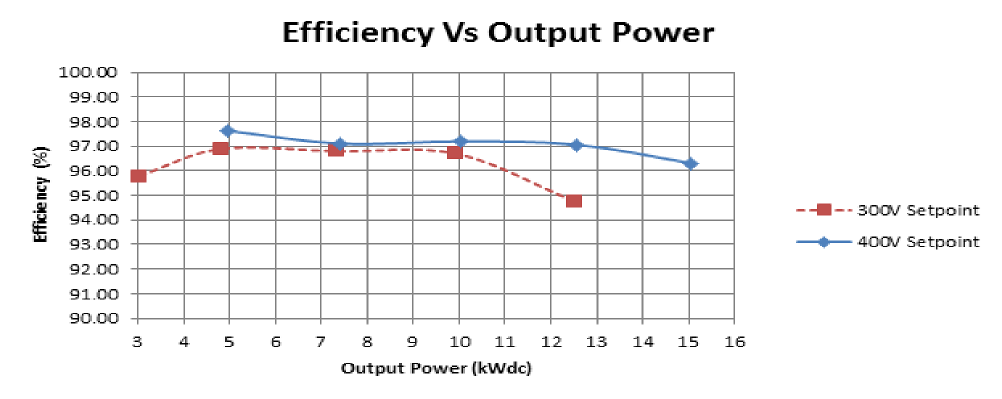


Hall Effect Thruster with Modular
Power Processing Unit and Direct Drive Unit





High Performance



POWER PROCESSOR CHARACTERISTICS

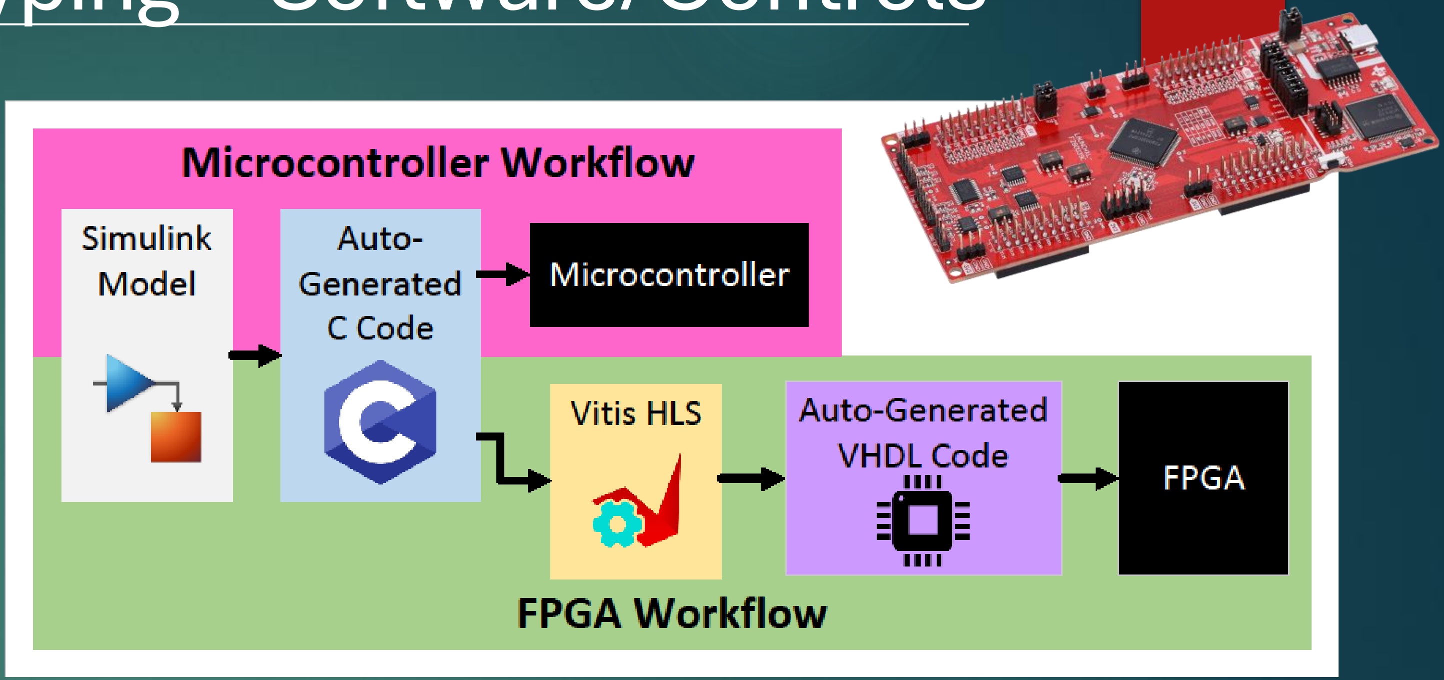
- 15kW Modular Design
- Output 200 to 500V_{DC}
- Input Voltage 250 to 330 V_{DC}
- Peak efficiency ≥ 96%
- Mass ~ 3kg/kW
- Silicon Carbide Full Bridge Design
- Each Discharge Module is rated for 7.5kW

Rapid Prototyping - Software/Controls

Capabilities

Code generation from Simulink models

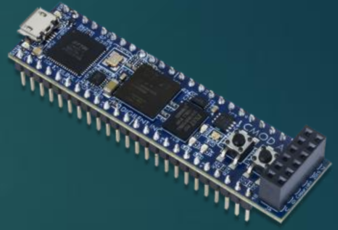
- Targeting microcontrollers (C code)
- Targeting FPGAs (VHDL code)
- Simulation and controller implementation tested together



Accomplishments

Acceleration of many LEM efforts

- X-57 HLMC
    - Cleared through 7150.2 software assurance process
- AATT and SVTT motor controllers
- CIF Matrix Converter



Used for Speedgoat programming

Rapid Prototyping - Electrical Hardware

Capabilities

B333 2nd floor electronics prototyping lab

- LPKF PCB milling machine
    - Two-sided PCBs
    - Fine pitch ICs

B333 3rd floor 3D printing lab

- Several PLA printers

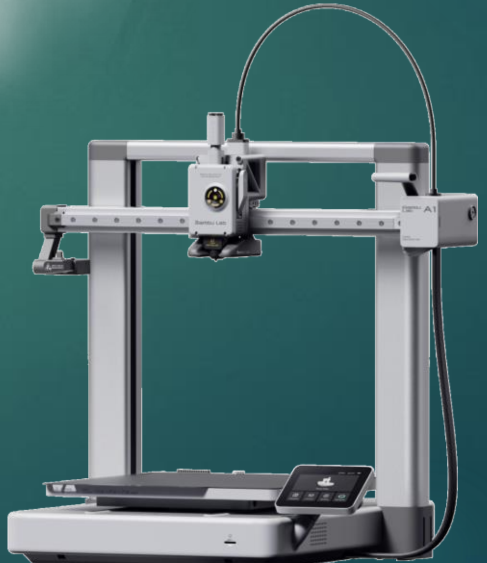
Accomplishments

Provided same-day PCB prototypes for many LEM efforts

- AATT, X-57, LGL UMIC

3D printing offers quick tooling and packaging prototypes in-house

- AMPS module ejector levers



Technology Development –
MW Scale Cryogenic Motor Drive

Project: SVTT (Subsonic Vehicle Technologies and Tools)

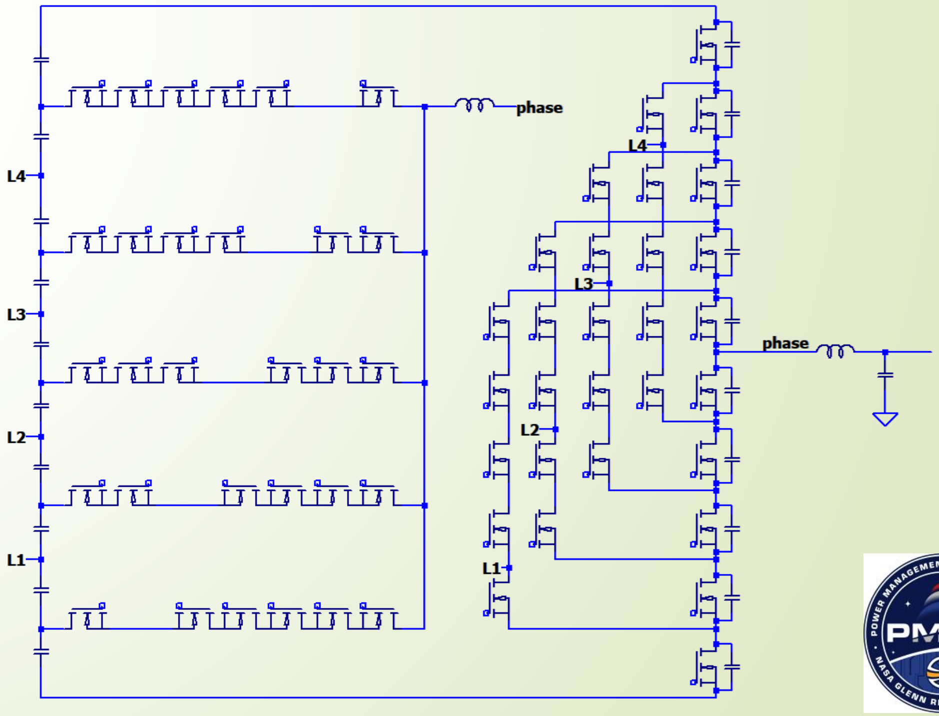
- MW scale motor drive
  - Operational in cryogenic environment
  - Ultra clean AC output to minimize motor loss
  - 2kV operation with series stacked GaN
  - Resonant inverter topology for low loss and filter mass minimization

Goal

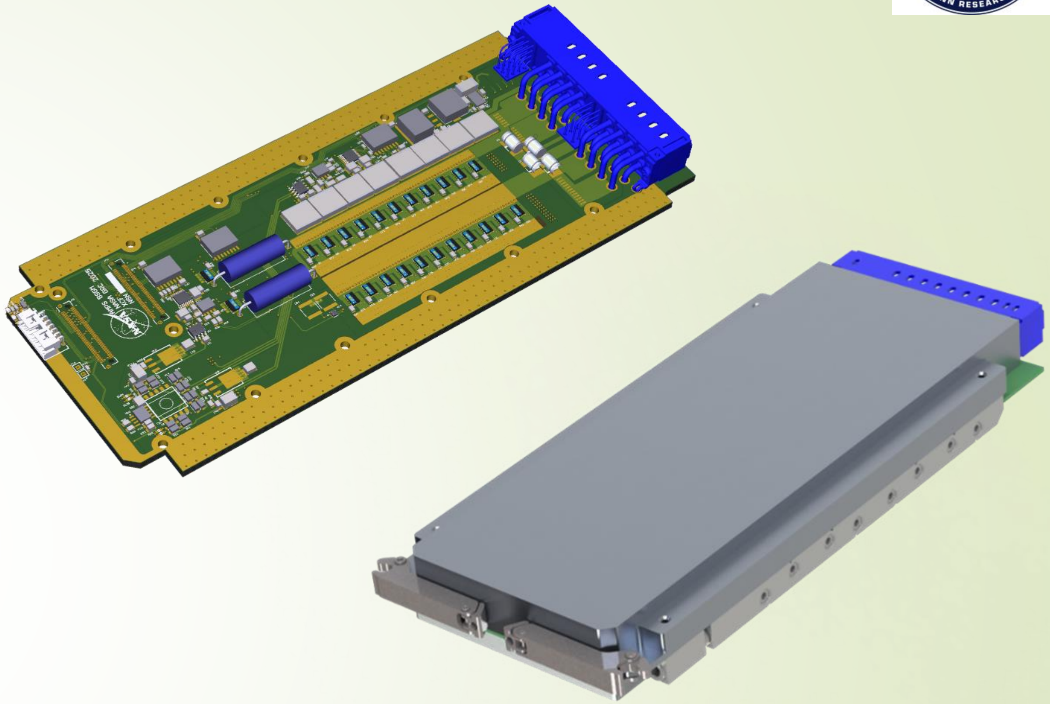
- Combined testing with motor in 2030
  - Up to 2 MW

Impact

- Necessary technology for cryogenic motors
- Cryogenic powertrains
  - Ultralight
    - Superconducting
    - Fuel doubles as cooling source
  - Projected 99.5% efficiency



Technology Development –
Advanced Modular Power Systems



<u>Project</u>: AMPS

- Raise TRL of prototype hardware from 4 to 6
  - Inform standards development
  - Discover and overcome challenges in TRL 6 module design
- Update modular power standard
- Infuse AMPS into industry

<u>Goal</u>

By 2028

- MEU and module reference designs released
- AMPS standard released

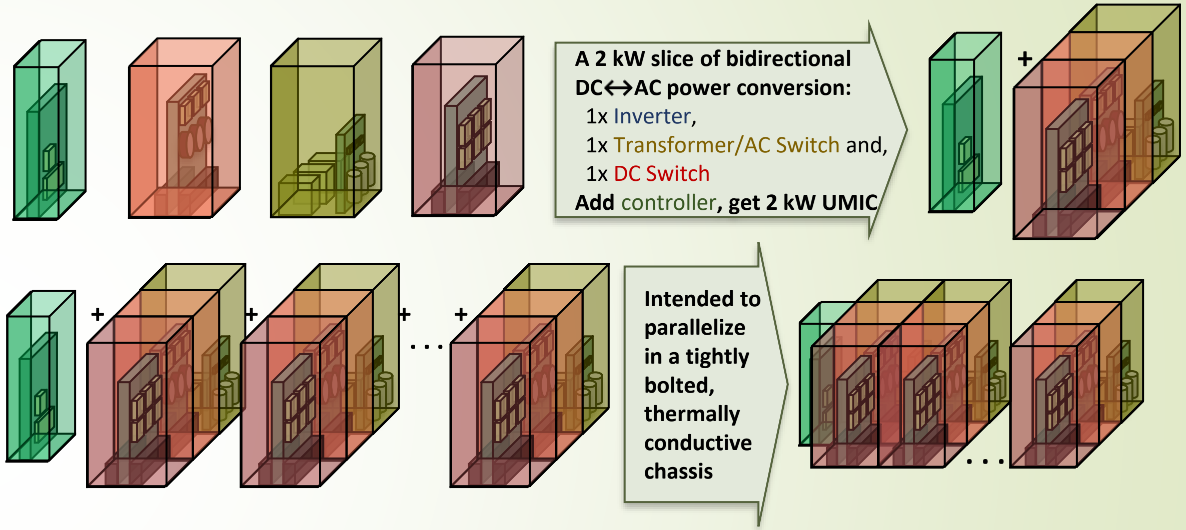
<u>Impact</u>

- Mission risk reduction through power system standardization
- Significant weight savings through sparing mass reduction

Technology Development –
Universal Modular Interface Converter (UMIC)

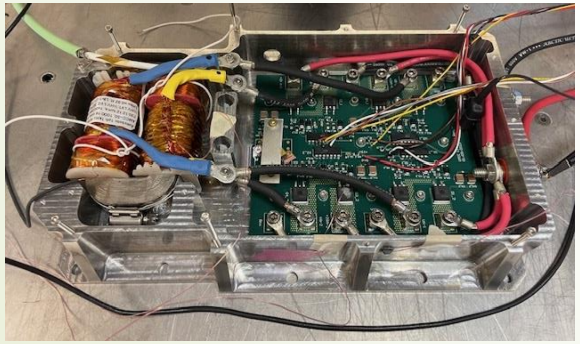
- A Lunar/Planetary Surface Grid Forming Inverter
  - Connects 120 VDC ISPSIS compliant loads/sources to a 3000 VAC, 3ph, 1 kHz grid spanning 1 to 10 km
    - International Space Power System Interoperability Std.
  - Demonstrated to 10 kW (0.9 pf), bidirectional
  - Multiple follow-ons including smaller 1 kW scale, single-phase Astrobotic LunaGrid Lite Project
    - Tested to TRL 6 (Vibe, EMI/EMC, Thermal Vacuum)

- **Next step to develop flightlike packaging, test to TRL 6**
  - Controller, Inverter, Transformer / AC Switch, and DC Switch

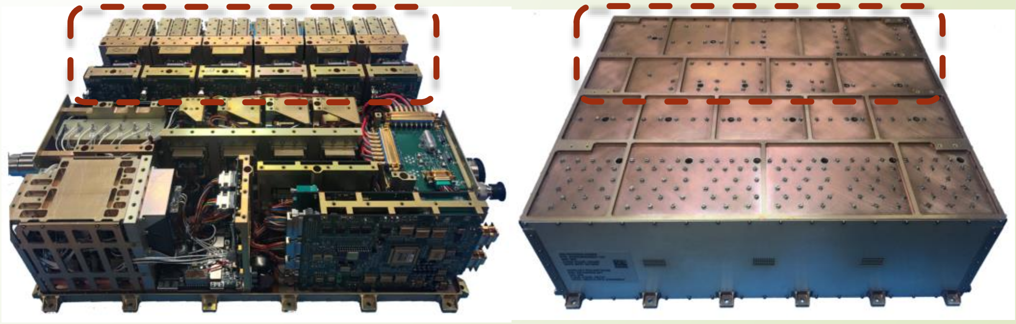


Next-Gen Concept Inspired by Successful Parallelized Power Electronics Designs (i.e. NEXT-C Beam Supply)

10 kW Breadboard UMIC



Early Conceptual LunaGrid Lite UMIC

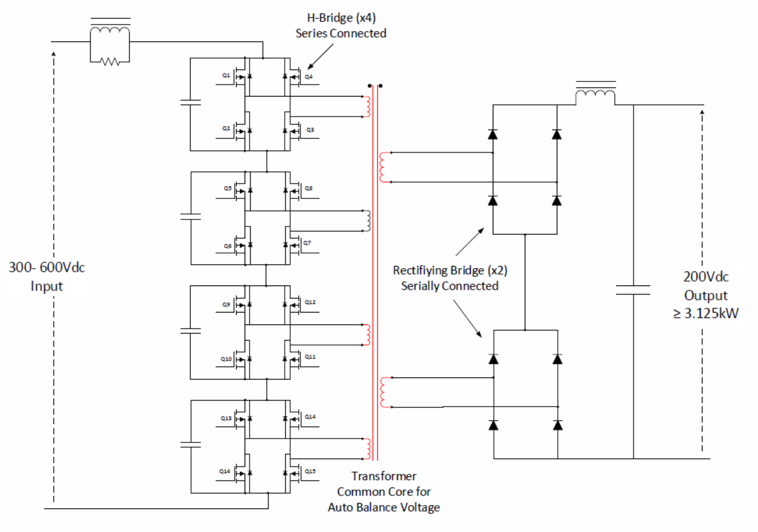


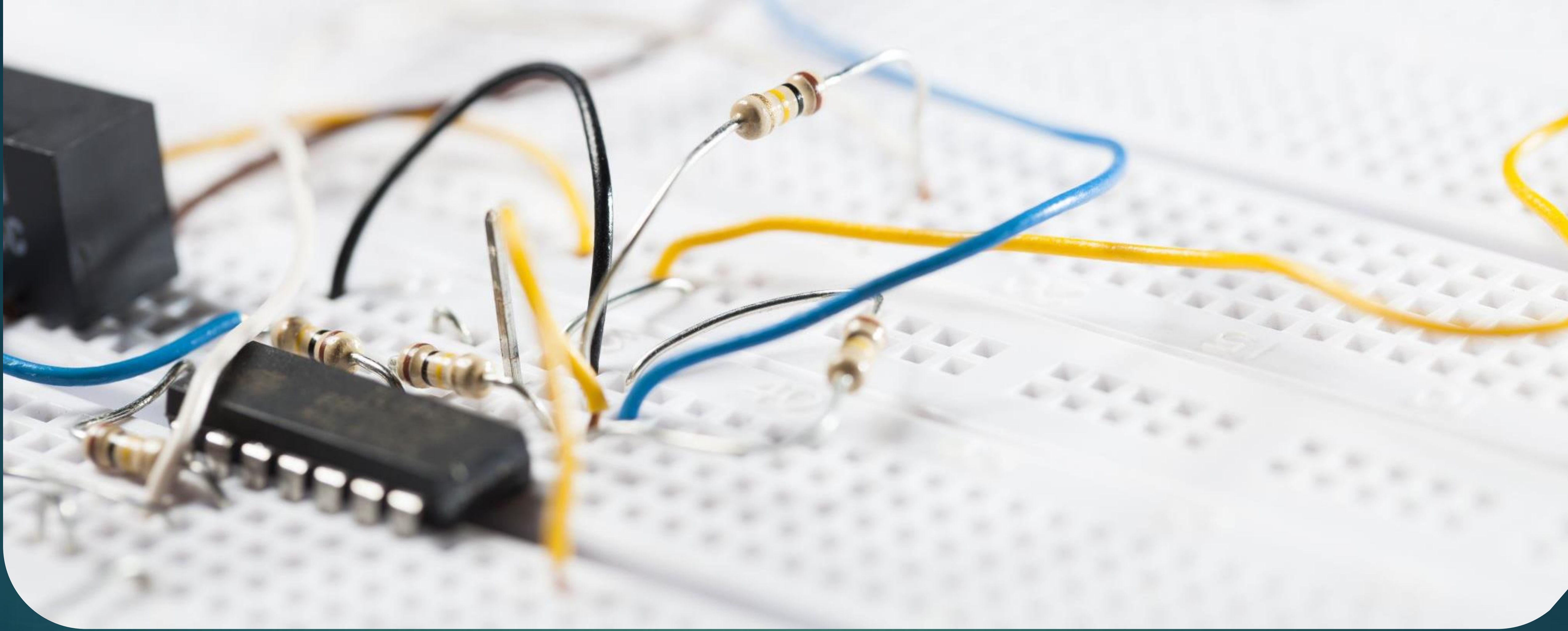
NASA Evolutionary Xenon Thruster – Commercial (NEXT-C) Power Processing Unit (PPU)

Technology Development –

Auto-Balancing Series Stack (ABSS) converter

- **The converter uses identical full bridge converter stages, with common gate commands signals and separate primary transformer windings on a common core.**
- **The theory is that the input voltage will be equally divided between the 4 converter stages.**
- **A module was designed using 4 series converter stages, producing the same 200 volt 4 kW output as the 120 V PPU modules.**
- **This equivalent operating range is 5.33 kW, over an input voltage range of 400 to 600 volts. The output voltage was also increased proportionally to 266 volts.**
- **This is a engineering solution to a parts problem**





High Power Electronics

High Power Electronics –
High Power Converter MW Scale Cryogenic Motor Drive

Project: SVTT (Subsonic Vehicle Technologies and Tools)

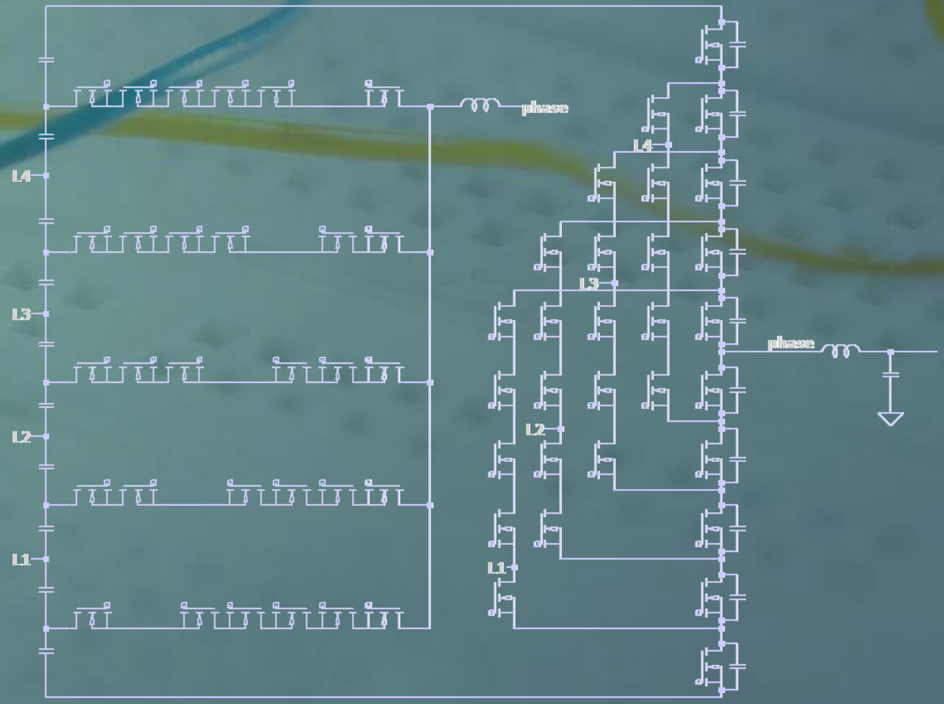
- MW scale motor drive
    - Operational in cryogenic environment
    - Ultra clean AC output to minimize motor loss
    - 2 kV operation with series stacked GaN
    - Resonant inverter topology for low loss and filter mass minimization

Goal

- Combined testing with motor in 2030
    - Up to 2 MW

Impact

- Necessary technology for cryogenic motors
- Cryogenic powertrains
    - Ultralight
        - Superconducting
        - Fuel doubles as cooling source
    - Projected 99.5% efficiency



High Power Electronics –
Matrix Converter for Direct AC-to-AC Power

OBJECTIVES

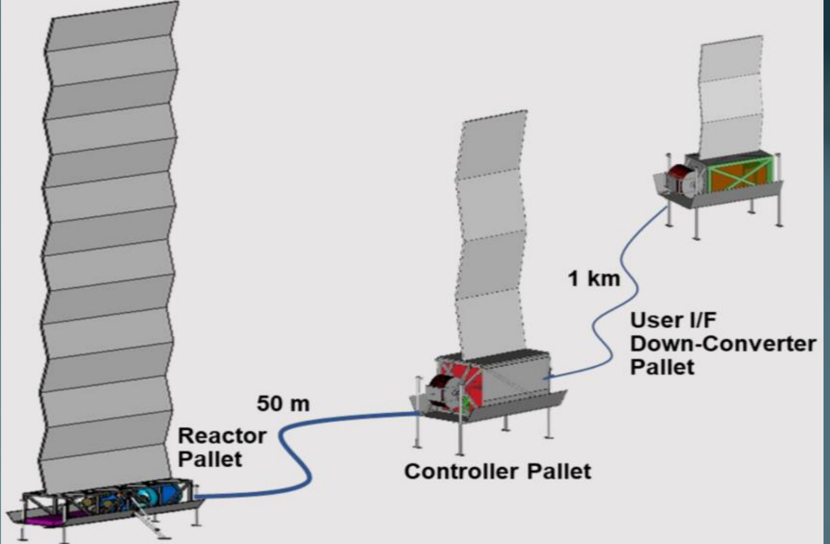
- Develop, demonstrate, and evaluate a direct ac-to-ac matrix converter.

BACKGROUND

- Matrix converters eliminate the dc link and enable direct ac-to-ac conversion w/ bidirectional power.

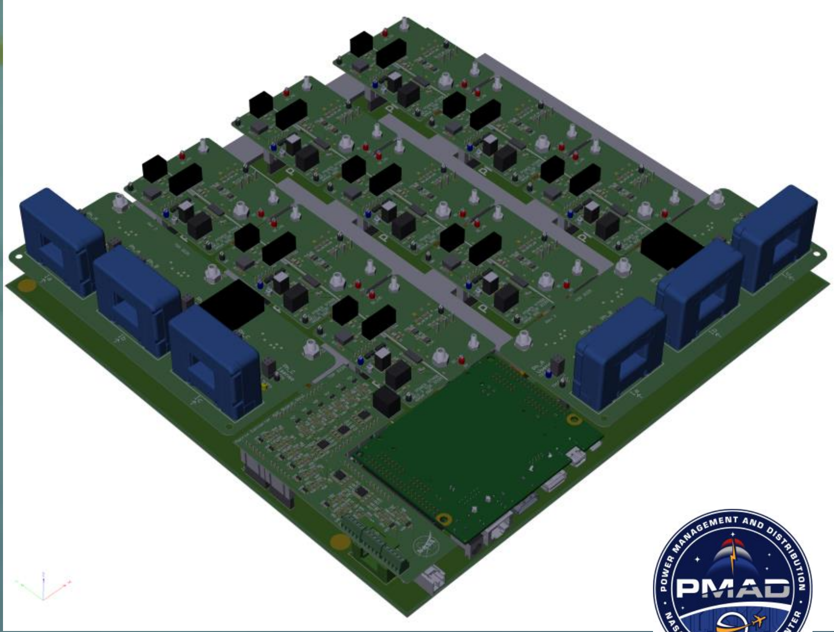
ACCOMPLISHMENTS

- Developed full custom power converter design
- Full simulink model including pll, modulation, safe commutation, and closed-loop current control.



- Lunar deployment. User I/F 1km from the reactor

Deployed configuration



High Power Electronics –
Universal Modular Interface Converter (UMIC)

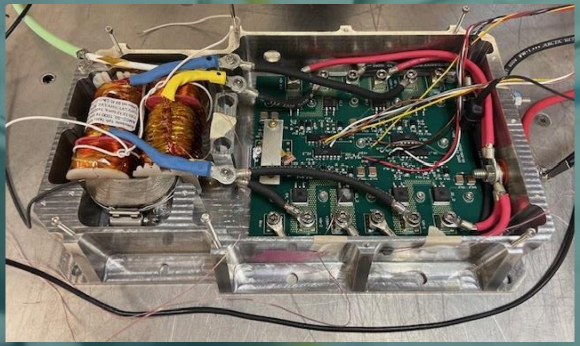
A LUNAR/PLANETARY SURFACE GRID FORMING INVERTER

Connects 120 VDC ISPSIS compliant loads/sources to a 3000 VAC, 3ph, 1 kHz grid spanning 1 to 10 km

Demonstrated to 10 kW (0.9 pf), bidirectional

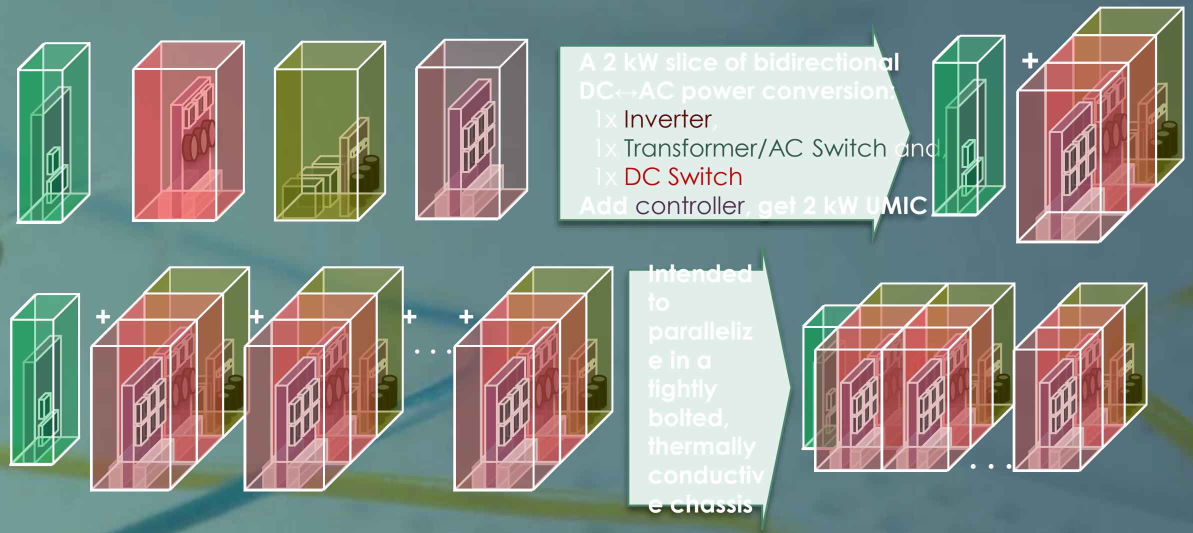
Multiple follow-ons including smaller 1 kW scale, single-phase Astrobotic LunaGrid Lite Project

Tested to TRL 6 (Vibe, EMI/EMC, Thermal Vacuum)

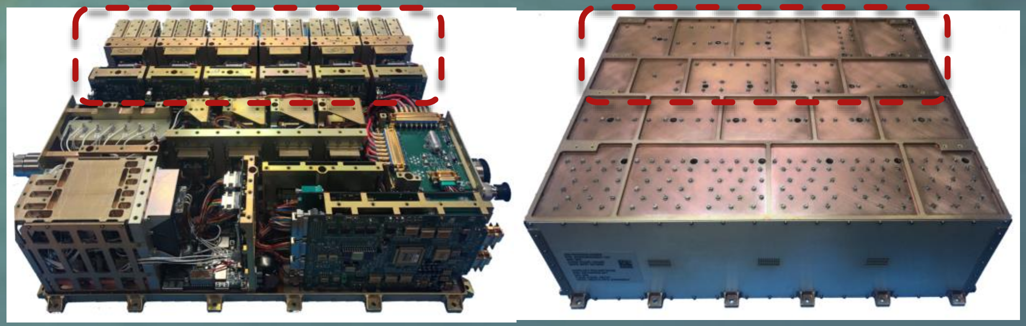


Early Conceptual LunaGrid Lite UMIC

- **Next step to develop flightlike packaging, test to TRL 6**

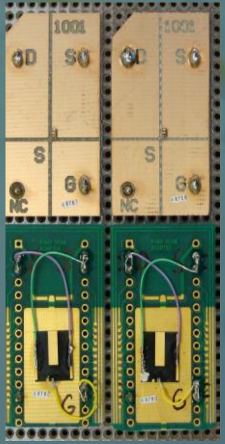


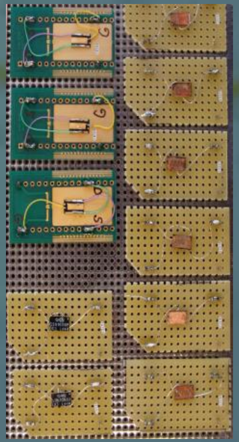
Next-Gen Concept Inspired by Successful Parallelized Power Electronics Designs (i.e. NEXT-C Beam Supply)



High Power Electronics –
EEE Parts and NEPP

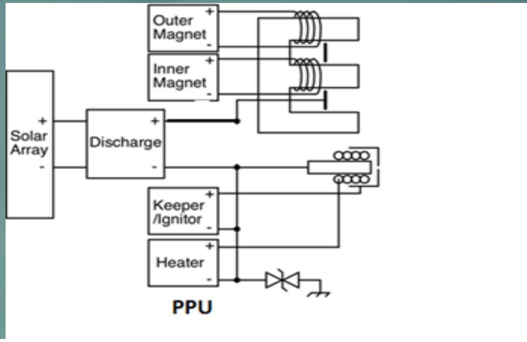
- NASA ELECTRONIC PARTS AND PACKAGING (NEPP) PROGRAM
  - GRC NEPP tasks:
    - Collaborate with GSFC and JPL to evaluate reliability of irradiated and control SiC and GaN power devices under multi-stress (electrical/thermal) conditions in GRC Extreme Temperature Environments Lab
    - Test a variety of COTS parts to evaluate their performance at extreme temperatures
  - Publish test results and body of knowledge documents and present findings at annual NEPP Electronics Technology Workshop
  - Represent GRC in NEPP and EEE Parts agency-wide face-to-face meetings
- GRC REPRESENTATIVE FOR ELECTRICAL, ELECTRONIC, AND ELECTROMECHANICAL (EEE) PARTS STANDARDS DEVELOPMENT AND EEE PARTS ASSESSMENTS:
  - NASA-STD-8739.10: EEE Parts Assurance Standard
  - NASA-STD-8739.11 (draft): EEE Parts Selection, Testing, and Derating Standard
  - NESC Recommendations on Use of COTS Parts Phase I and II Assessments
  - NESC Cold Electronics Assessment
- ADVISE GRC PROGRAMS AND PROJECTS ABOUT EEE PARTS

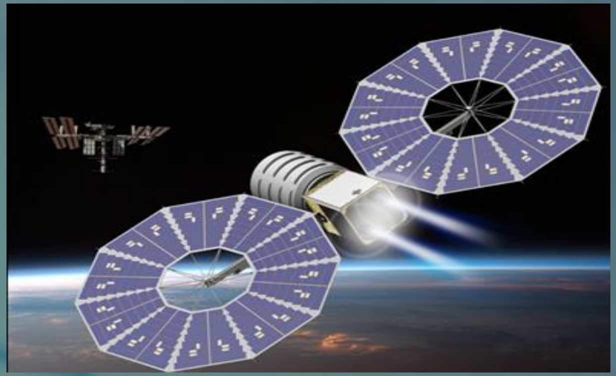




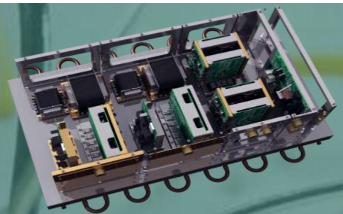
High Power Electronics

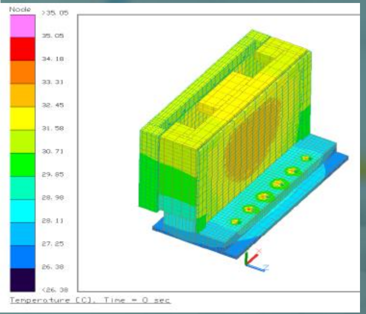
STMD HP-300V HALL EFFECT POWER PROCESSING



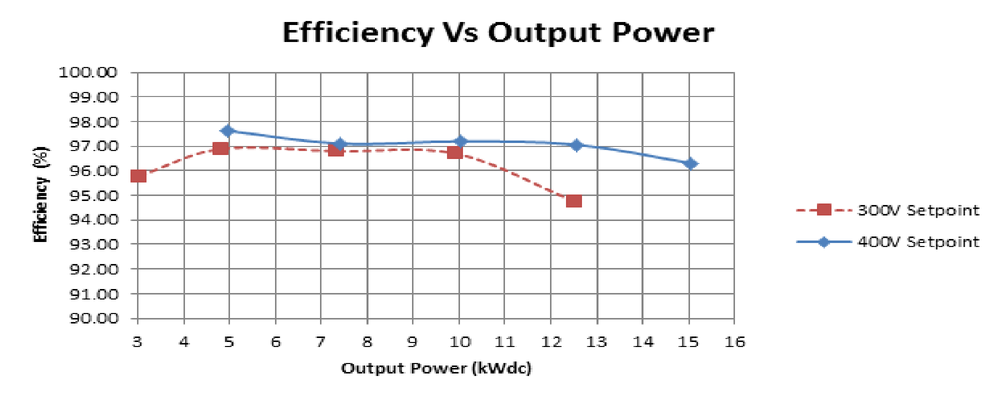


Hall Effect Thruster with Modular
Power Processing Unit and Direct Drive Unit





High Performance



POWER PROCESSOR CHARACTERISTICS

- 15kW Modular Design
- Output 200 to 500V_{DC}
- Input Voltage 250 to 330 V_{DC}
- Peak efficiency ≥ 96%
- Mass ~ 3kg/kW
- Silicon Carbide Full Bridge Design
- Each Discharge Module is rated for 7.5kW

High Power Electronics –
Auto-Balancing Series Stack (ABSS) converter

- **The converter uses identical full bridge converter stages, with common gate commands signals and separate primary transformer windings on a common core.**
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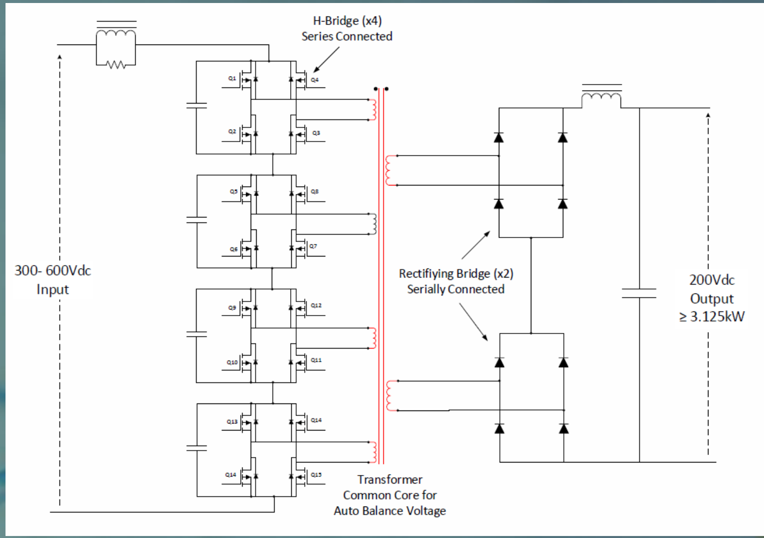
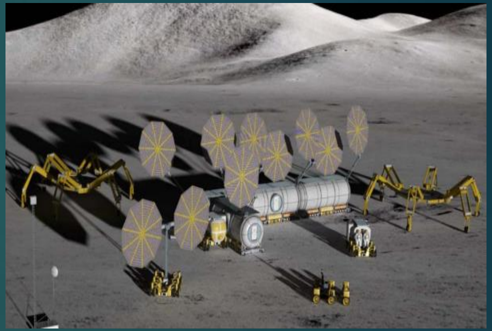


Power System Safety

System-agnostic Arc Fault Detector Implementation

External Partners

- Deploy hybrid DC arc fault detector on FPGA-based aerospace switchgear

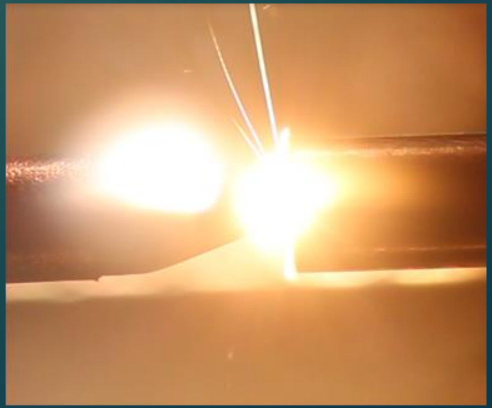


Facilities

- Integrate equipment to test at high power (≤25kW), high voltage (≤270VDC), at simulated altitudes (≤30,000ft), and under different load impedance conditions

Modeling and Software

- Automate detector designs using interpretable ML models trained on arc fault data



Mature human-interpretable DC series arc fault detection for adoption by the aerospace industry

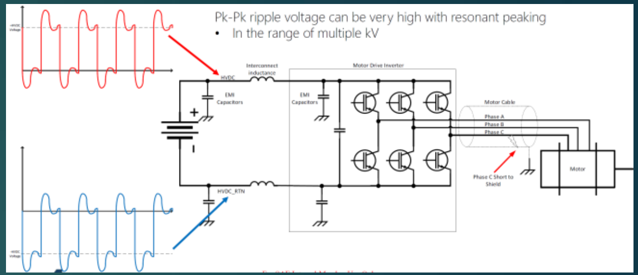
Power System Safety –
Common-Mode (CM) Ground Fault Evaluation for Power Systems

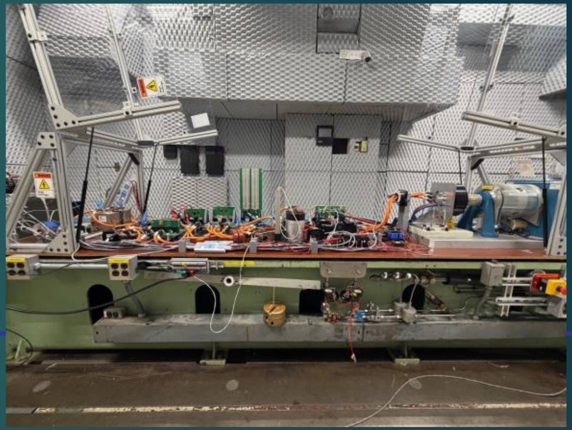
Overview:

- A ground fault at the output of inverters operating off systems with high-impedance ground networks has been identified as a potentially catastrophic failure-mode
  - The failure-mode and corresponding common-mode system response are unique and were not well understood
  - Can apply to electrified aircraft and developing space power systems
- The NASA Revolutionary Vertical Lift Technology (RVLT) Project worked with SAE to analyze the fault and corresponding abnormal response, including development of an in-house test to demonstrate a fault-clearing solution

Major Accomplishments:

- Worked with Crane Aerospace to complete and deliver a dynamic simulation model to SAE assessing the failure-mode and possible solutions.
- Designed and built a test bed/representative system within the Scaled Power ElEctrified Drivetrain Facility to conduct testing.
- Completed testing and demonstrated a working solution to quickly detect and clear the fault, along with documentation of lessons learned for component sizing/de-rating, sensor placement, and protective relaying.





Impacts:

- Results informed/will inform developing standards and industry designs
- Brings clarity and knowledge to a previously unknown and misunderstood failure-mode, its corresponding effects, and solutions to detection and clearing
  - Certification of upcoming high voltage aircraft

Next Steps:

- Present findings to SAE, NASA stakeholders (NESC, M2M, Aeronautics Projects)

POWER SYSTEM ANALYSIS TOOLS – EPS-SAT

Objectives

Calculate the size and performance of electrical power systems

Help guide investment dollars

Perform sensitivity studies (ie. voltage, current, power)

Perform trade studies (ie. AC vs DC)

Space and aeronautics applications

MATLAB based tool that anyone with a license can use

SMEs can develop individual components or systems

Accomplishments

Blue Origin Reimbursable SAA for lunar surface power distribution analysis

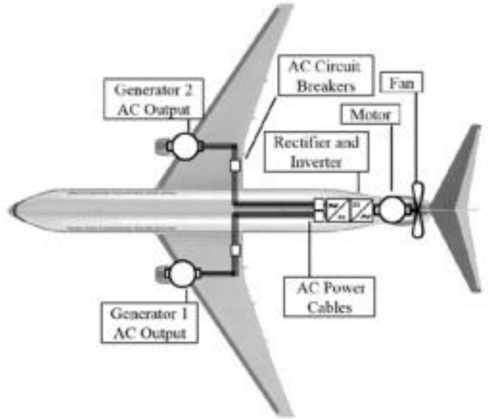
Validation of models with hardware data

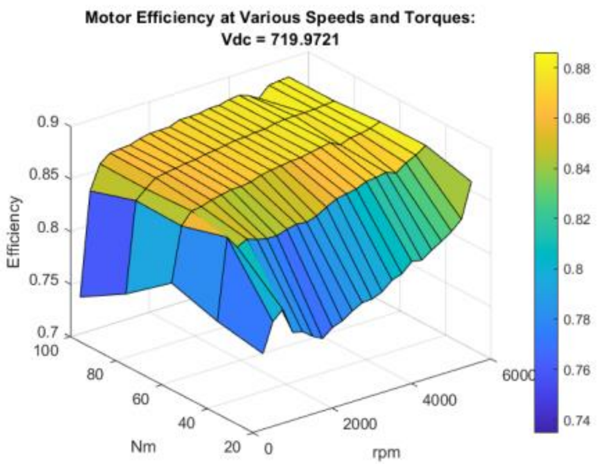
Publicly available software available on software.nasa.gov

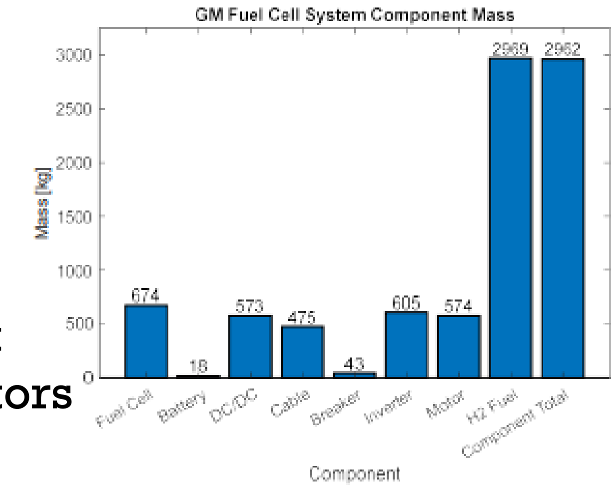
Power system redundancy study on eVTOL Quadrotors

Hydrogen Fuel Cell powered aircraft trade space development

1. A Generalized Power System Architecture Sizing and Analysis Framework
2. Power System Redundancy Design Trends for All-Electric eVTOL Quadrotors





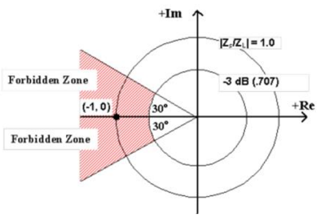


POWER SYSTEM ANALYSIS TOOLS

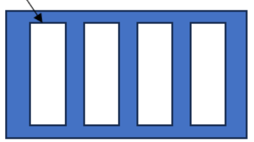
GRC POWER BRANCH IMPEDANCE BOUNDING ANALYSIS TECHNIQUES

Analysis Techniques and Capabilities:

- **MATLAB and SPICE tools have been developed by NASA to design requirements and/or predict power quality impedance and transient performance for any DC-DC converter system given minimal initial bounding conditions**
- **Bounding Design Criteria**
  - A card based scalable converter design approach works best but is not necessary
    - Example: four 1.5kW per cards totaling 6kW max converter capability
  - Standard PID controller and converter filter structure
  - PI gains constrained by load design criteria (source impedance correlated to gain values)
  - Min and max expected cable lengths assumed in model
  - Maximum expected load steps
- **Card scaling approach**
  - The source controller is modeled in such a way that makes it possible to scale the number of converter cards that are on/active and/or failed. This modeling approach allows to run non-normal scenarios such as converter card failures or removals and ensure Power Quality compliance



1.5kW Slice example



1.5 → 6kW Modular Converter

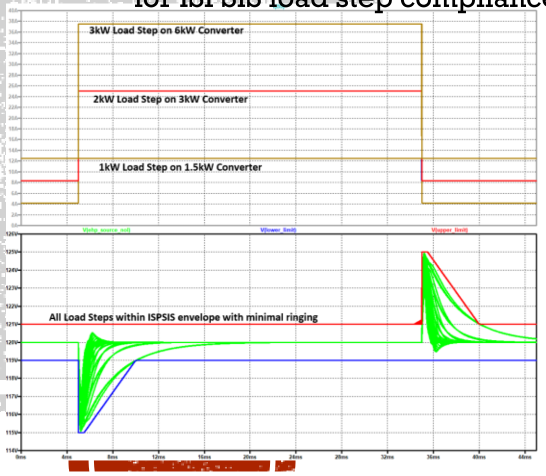
Impedance and Transient Derivation Example:

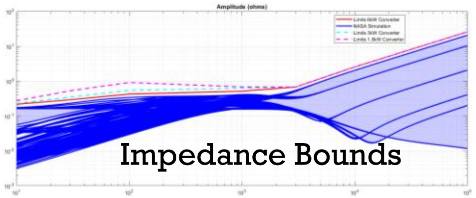
- Varying each of the bounding design criteria parametrically to meet desired load step performance Impedance bounding curves can be derived.
  - 50% load step with ISPSIS transient in this example

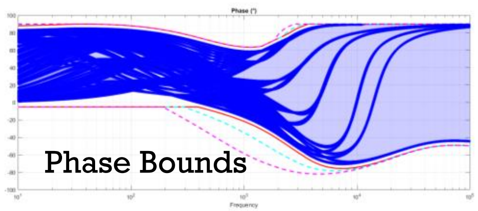
Parameters Varied:

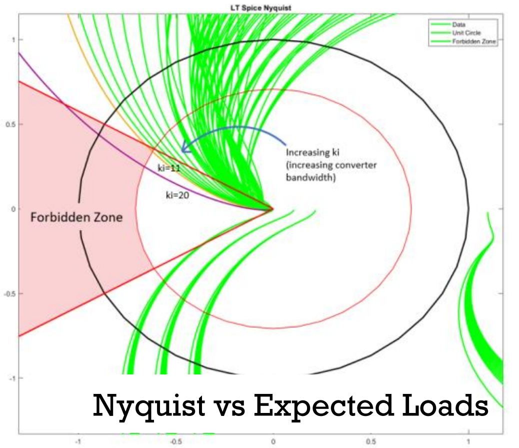
- Number of converter cards
- PID Parameters
- Converter Output filter
- Min and Max cable lengths
- Load steps
- Load filtering

Bounding Parameters Chosen for ISPSIS load step compliance









STANDARDS

STANDARDS

NASA INTERNATIONAL SPACE POWER SYSTEM INTERFACE STD (ISPSIS)

- Collaborations within the International Space Station (ISS) and Gateway memberships to establish:
  - interoperable interfaces,
  - terminology,
  - techniques

These standards are for international and commercial partnerships.

Standards are established and internationally recognized to increase commonality, decrease unique configurations.

- Standardizing interfaces reduces the scope of the development effort.

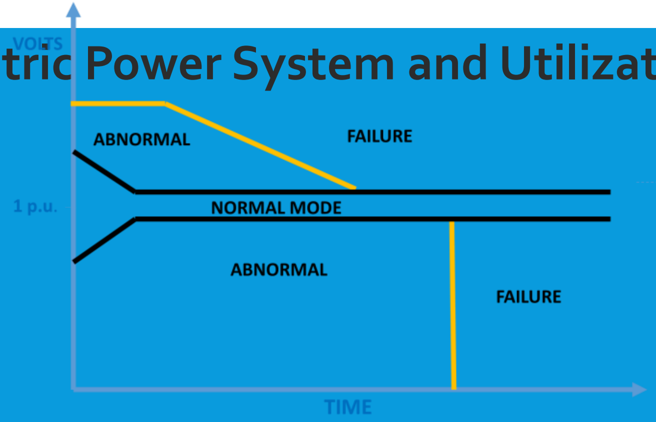
- The information within this document represents a set of parameters, which if accommodated in the system architecture support greater efficiencies, promote cost savings, and increase the probability of mission success.

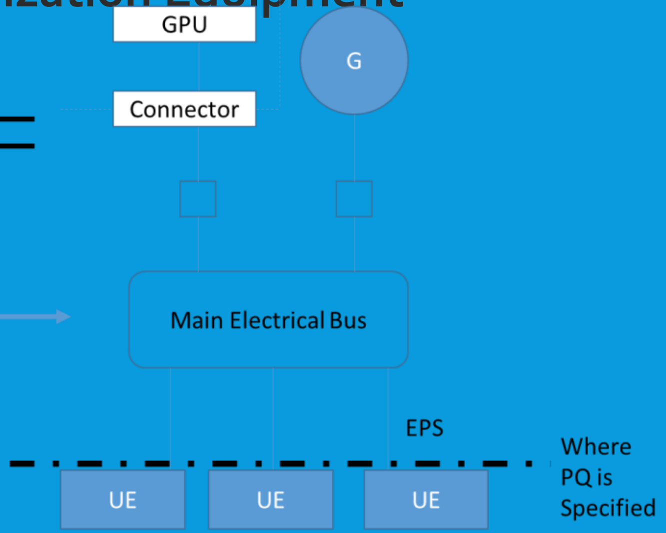
These standards are not intended to specify system details needed for implementation nor do they dic design features behind the interface; specific requirements will be defined in unique documents.

STANDARDS
SAE AS7499 HIGH VOLTAGE DC POWER QUALITY FOR AIRCRAFT

- **Power quality standard for HVDC Aircraft**
  - Per-unit standard applicable for primary propulsion busses up to 1kVdc
  - Covers various source- and grounding architectures
    - Battery/fuel-cell/generator-rectifier/converter fed, solidly- vs. high-impedance ground networks
  - Differential-mode and common-mode requirements

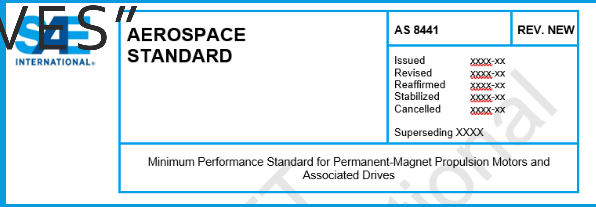
- **Defines the interface requirements between the Electric Power System and Utilization Equipment**
  - Normal, abnormal, & emergency performance
  - Contains Verification
  - Recommended testing methods
- **Status March 2026**
  - Affirmed within the engineering committees
  - Ready for final vote with SAE Council





STANDARDS

SAE AS-8441 “MINIMUM PERFORMANCE STANDARD FOR PERMANENT MAGNET PROPULSION MACHINES AND ASSOCIATED DRIVES”


SAE INTERNATIONAL

AEROSPACE STANDARD

AS 8441	REV. NEW
Issued XXXX-XX Revised XXXX-XX Reaffirmed XXXX-XX Stabilized XXXX-XX Cancelled XXXX-XX Superseding XXXX	

Minimum Performance Standard for Permanent-Magnet Propulsion Motors and Associated Drives

Scope

Applicable to hybrid and all-electric electric engines

Applies to a minimum set of components: permanent-magnet (PM) motor, electronic motor drive, EWIS, and sensors that provide propulsion to an aircraft

Includes manufacturer declarations, technical requirements, acceptance testing, environmental testing, durability requirements

Background

Currently a draft standard

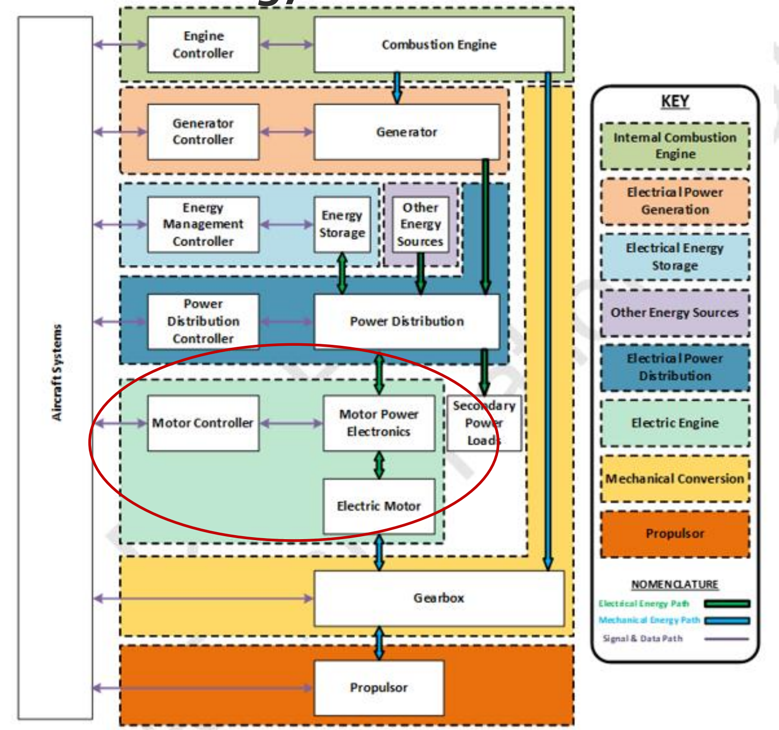
Began development in 2017

Part of the AE-10 High Voltage Committee

International team consisting of governments, academia, and industry

Status

Reviewing comments



STANDARDS

SAE AS 5698 SPACE POWER STANDARD

- ***Develop a space power standard equivalent to the aerospace standards such as 704.***

  Closed loop system standard

  A high impedance *source standard*

  Provide a common set requirements for space electrical systems and loads of that will ensure proper operation

- ***Allows for commonality, interchangeability, and interoperability***

Special Thanks to Contributors

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Marc Carbone - NASA