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A Modular AC to DC Interface Converter to Enable Lunar Surface Power Transmission

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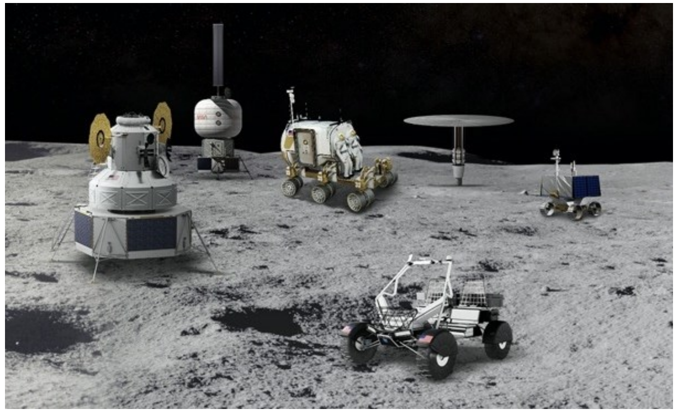
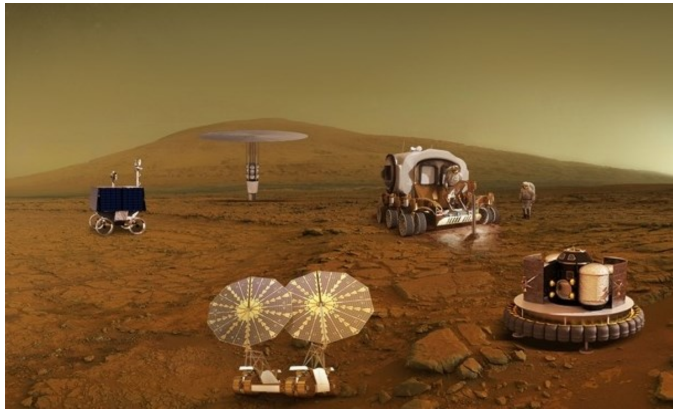
Background

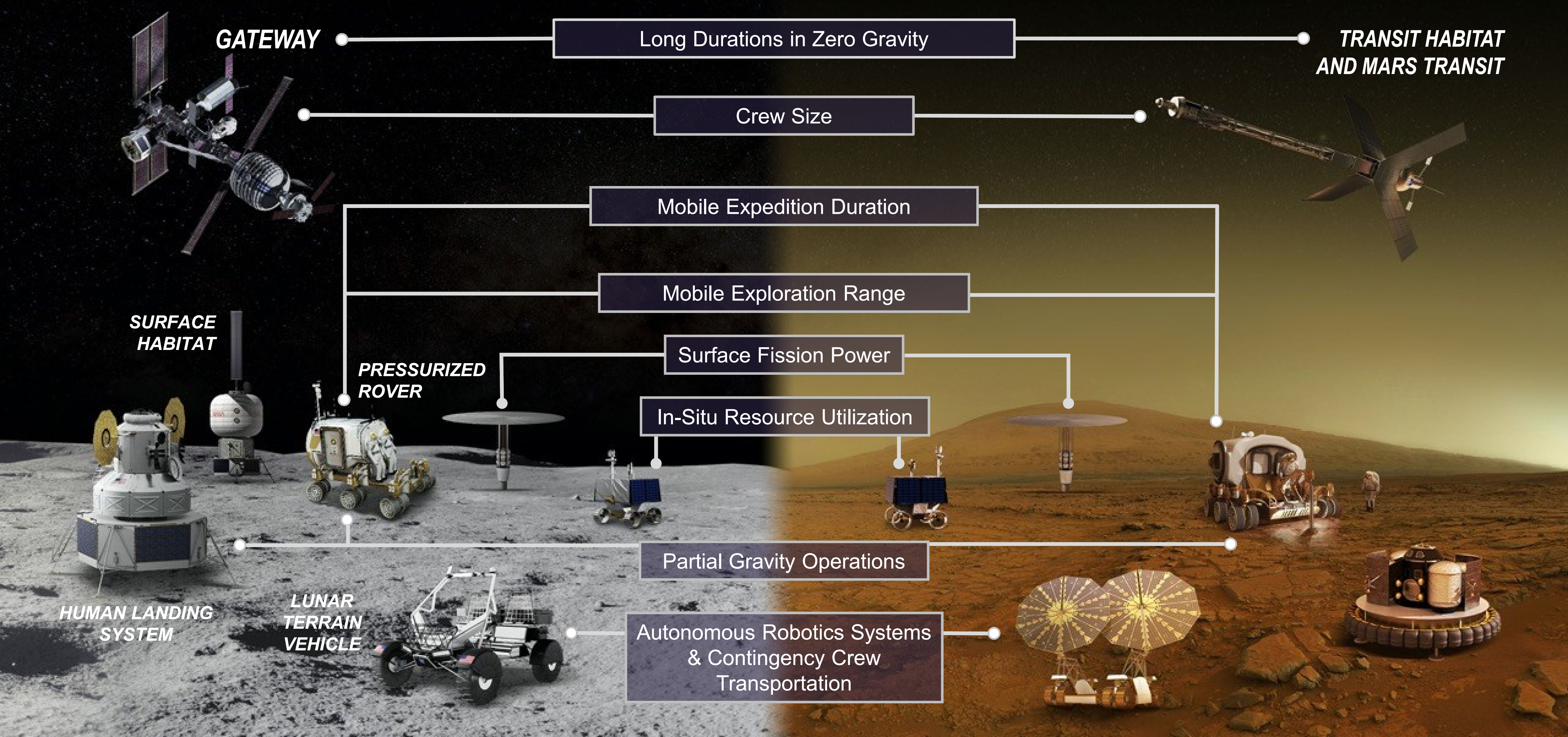
- NASA's long term vision includes crewed Mars missions
- Current focus is on Artemis program
  - Demonstrate key Mars enabling technologies
  - Anticipating expansion to commercial lunar economy
- Artemis and future planetary surface missions require highly available and reliable power
  - Power needs to be as reliable/universal as terrestrial utility
  - Expansion necessitates planetary surface power grids
- NASA's STMD investing in R&D work for an Artemis grid
  - Microgrid Definition and Interface Converter for Planetary Surface (MIPS)





Moon to Mars Exploration

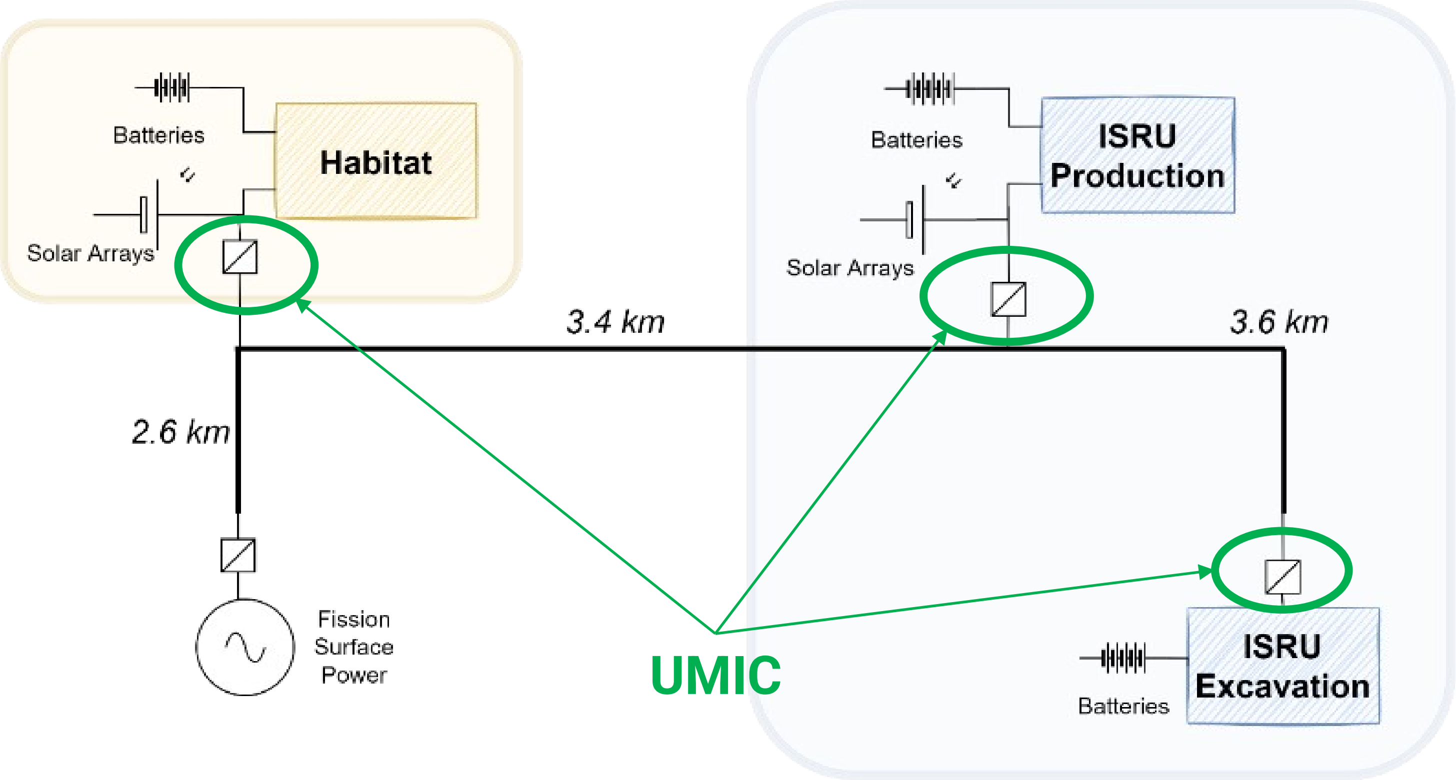
Operations on and around the Moon will help prepare for the first human mission to Mars



Universal Modular Interface Converter

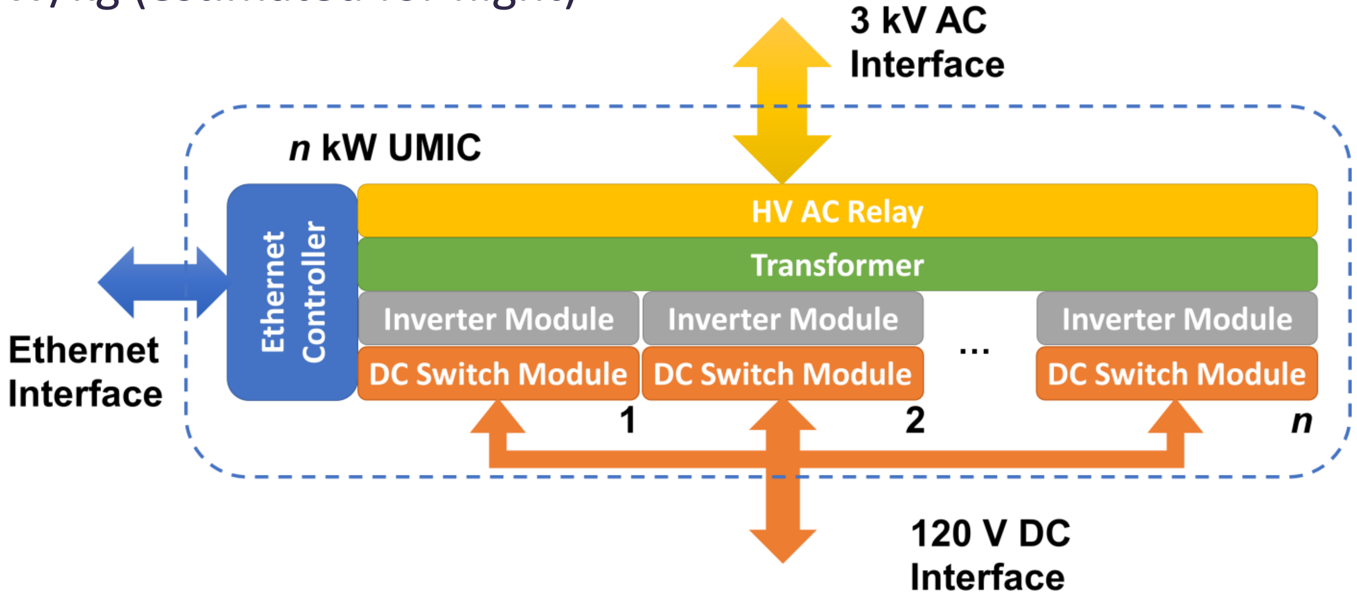
UNIVERSAL MODULAR INTERFACE CONVERTER
UMIC

- Anticipate 120 VDC local lunar power systems
  - Converter is necessary to interface these to grid
- MIPS set out to develop Universal Modular Interface Converter (UMIC)
  - Conducted trade studies to identify grid design parameters



UMIC Concept Design

- Goals
  - Standardized interface converter between 120 VDC users and 3 kV 3-phase AC 1 kHz grid
  - Consisting of field-replaceable, bidirectional, modular grid forming inverters
  - 1 kW per module, 10 kW total power or greater
- Objectives
  - Efficiency >95%, specific power >350 W/kg (estimated for flight)
- Conceptual Implementation
  - HV AC relay for isolation
  - Line frequency transformer(s)
  - Parallelable inverter modules
  - Current limiting solid-state DC Switch Module (DC switchgear)
  - Ethernet Controller for external comms interface



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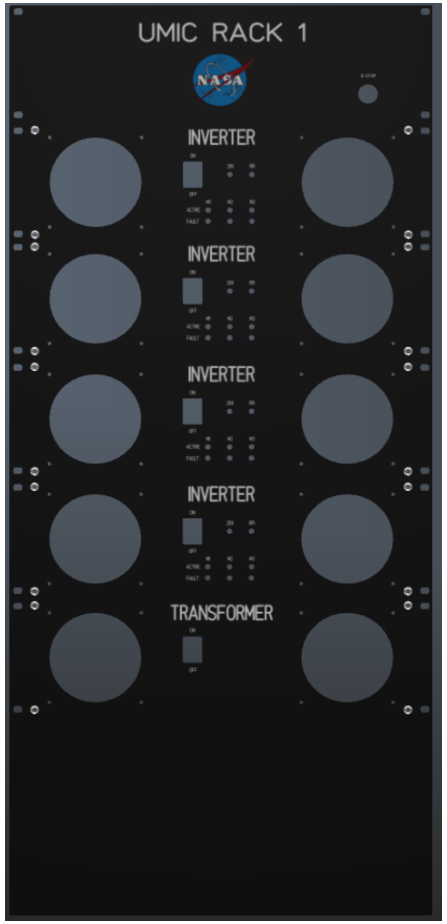
UMIC 10 kW Breadboard Rack

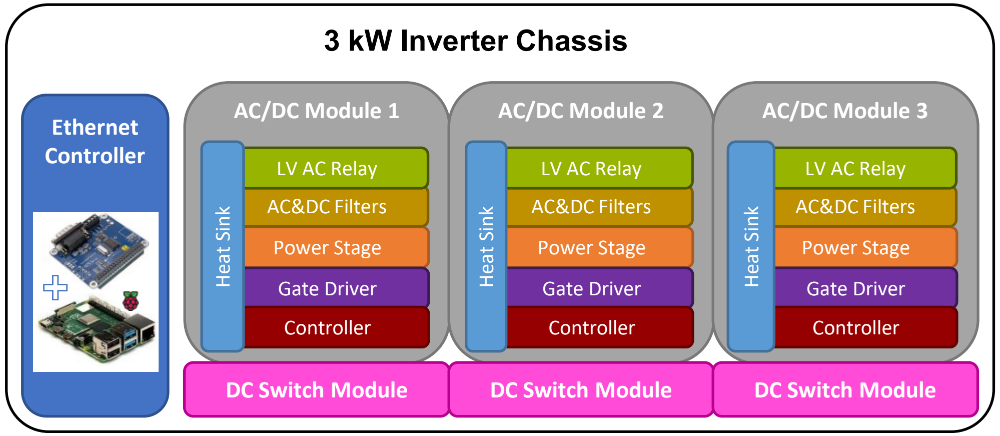


- Breadboard Implementation
  - 10 kW nominal power capability (12 kW peak)
  - 19” rack based breadboard form factor
  - Composed of one transformer chassis and multiple parallel inverter chassis
  - Parallelable - can provide more than 10 kW at single location
  - Design goals:
    - >95% efficiency
    - 350 W/kg power density (est. for flight)
  - Capability:
    - Grid forming
    - Synchronization with existing grid power

UMIC 3 kW Inverter Chassis

- 3 kW inverter chassis (3U 19” rack mount form factor)
  - Each contains 3x 1 kW inverter modules

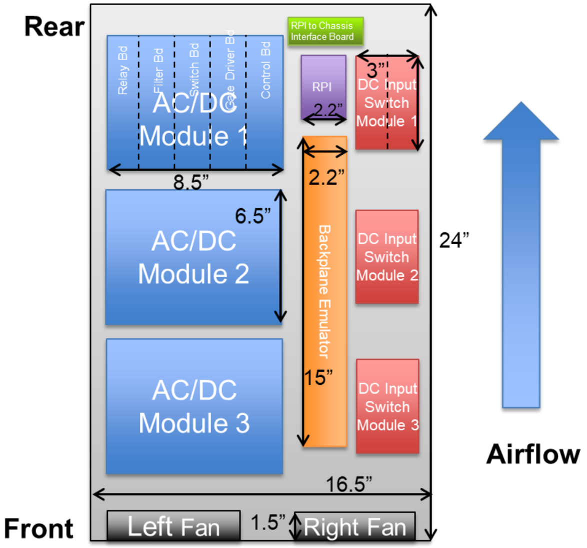
Conceptual Breadboard Inverter Chassis Design



120 VDC

Front and Rear Panels

Chassis Top View



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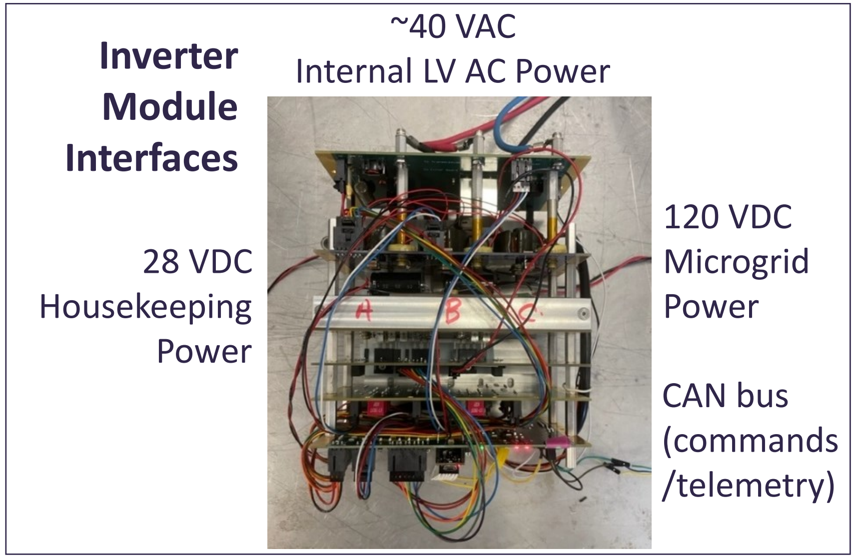
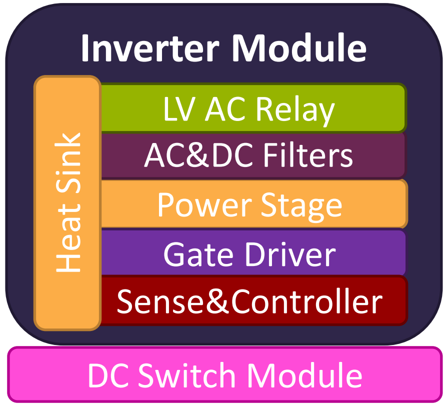
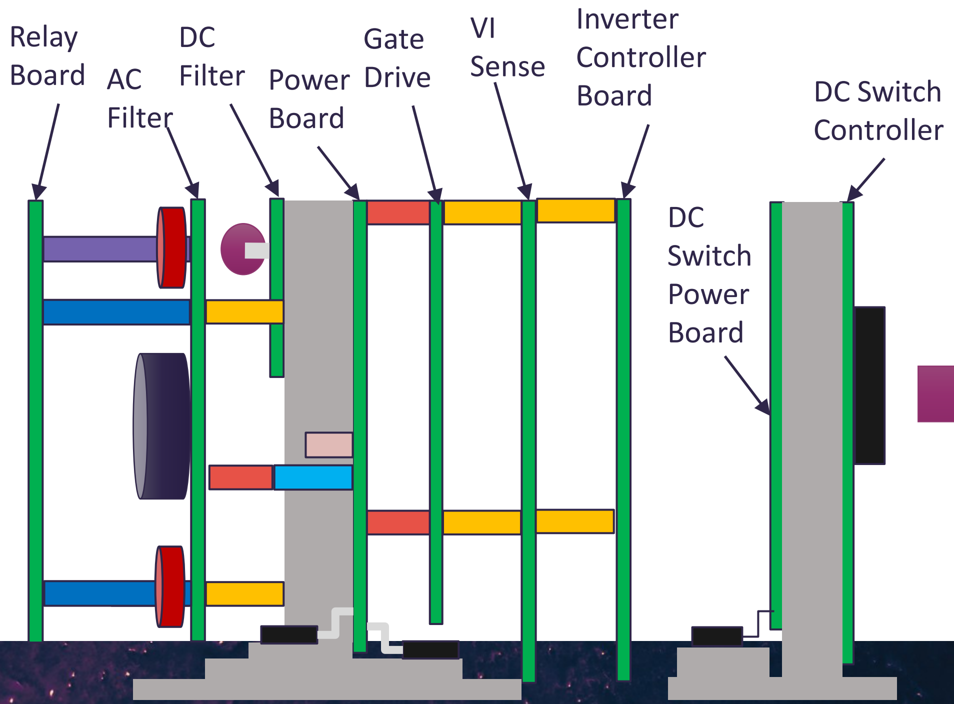
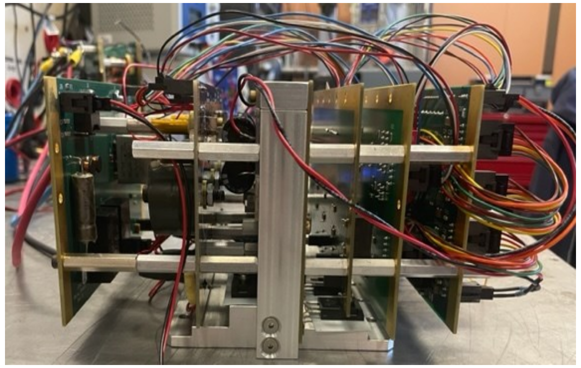
UMIC 1 kW Modular Electronics

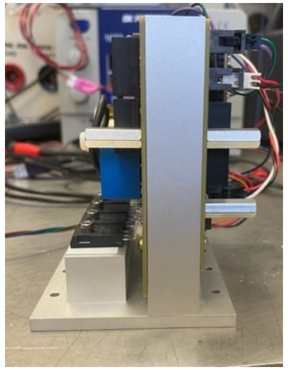
- 1 kW Inverter Module plus 1 kW DC Switch Module
  - Inverter: Converts 120 VDC to/from UMIC internal LVAC bus
    - Includes filters, power control logic, AC isolation
    - Consists of 5 main subsystems in a stacked card form factor
  - DC Switch: Provides DC-side current limiting & isolation





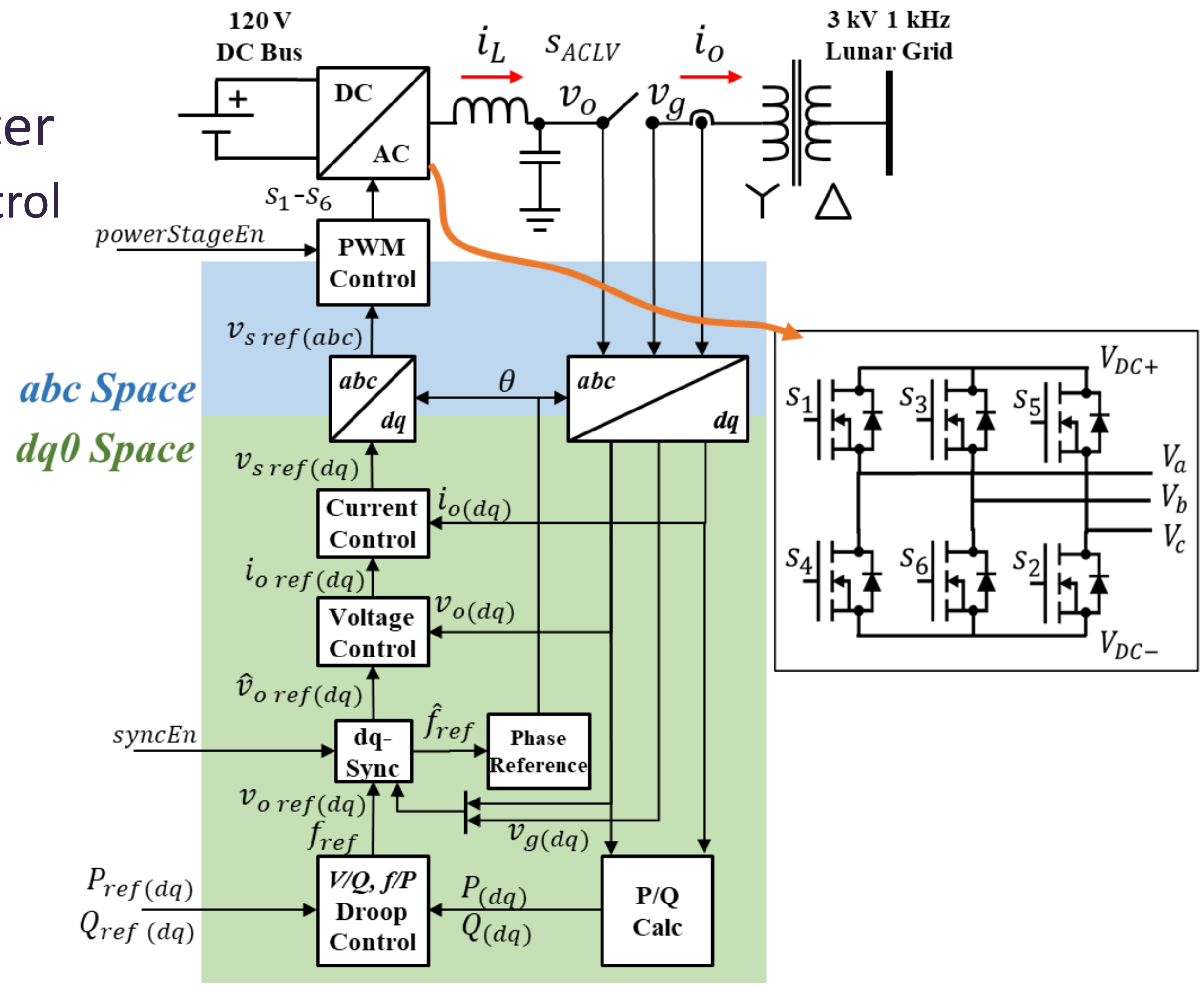






UMIC Control Algorithm

- Independent FPGA control in each inverter
  - Cascaded, closed-loop, dq-based droop control
    - 50 kHz PWM
    - 50 kHz Current loop
    - 10 kHz Voltage loop
    - 5 kHz Droop loop
  - Approach based on terrestrial grid forming inverter literature



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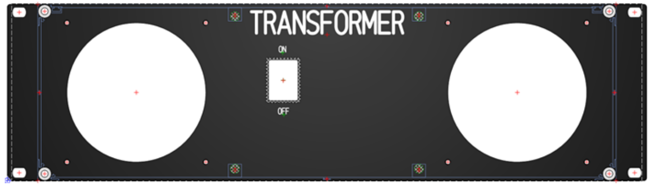
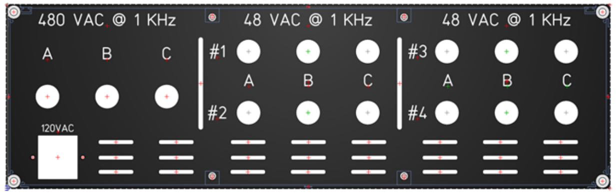
UMIC Transformer Designs

- Transformer chassis to include all transformers needed at a given site (scales with power)
  - Modular (1 kVA) transformer designs (both single and 3-phase types)
    - 10x 1 kVA three phase transformers (10 kVA total)
  - Centralized transformer design (single-phase type only)
    - 3x 3.3 kVA single phase transformers (10 kVA total)

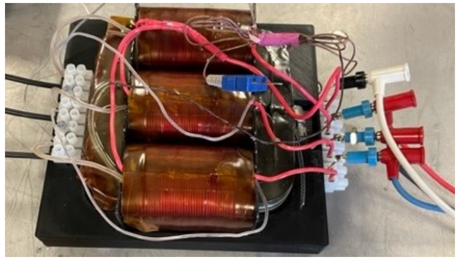
TRANSFORMER FRONT



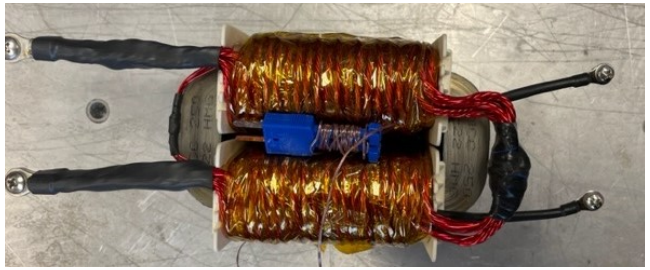
TRANSFORMER REAR



NASA 1 kVA 3-phase design

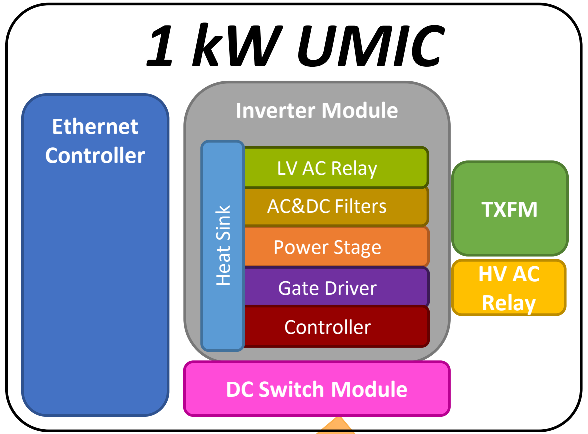


3.3 kVA single-phase design
(3x for 10 kW)

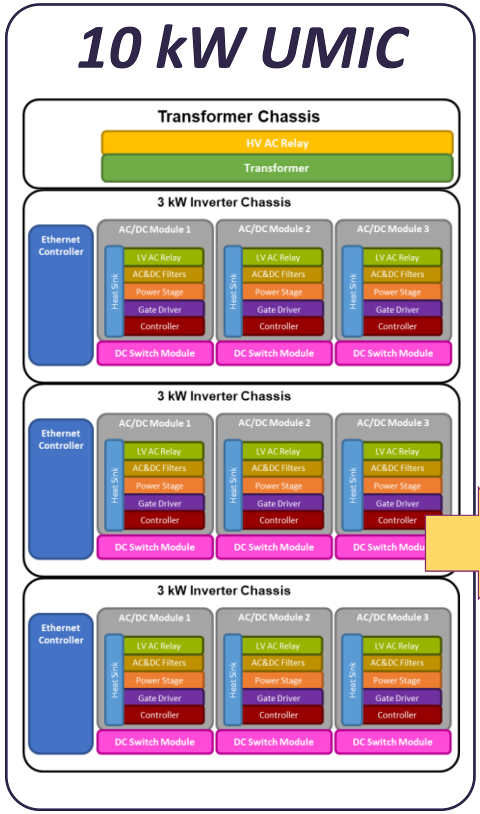


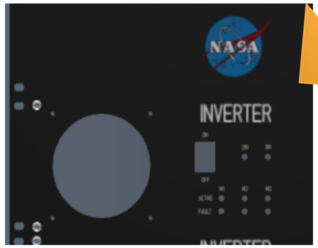
Scalability and Applicability

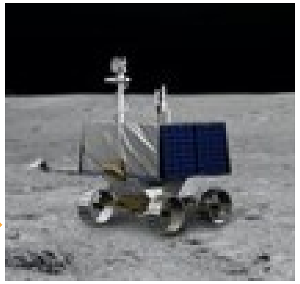
1. Modularity allows UMIC to scale based on site needs
2. UMIC designed for compatibility with different DC loads/sources
   - e.g., 1 kW rover vs 10 kW VSAT

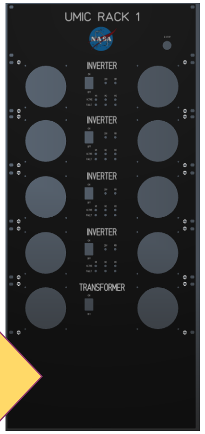


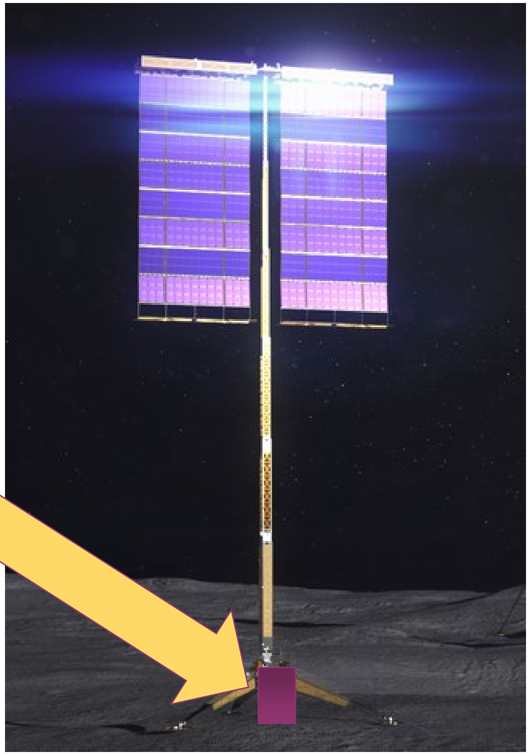
Add modules to go from
Low Power to High Power











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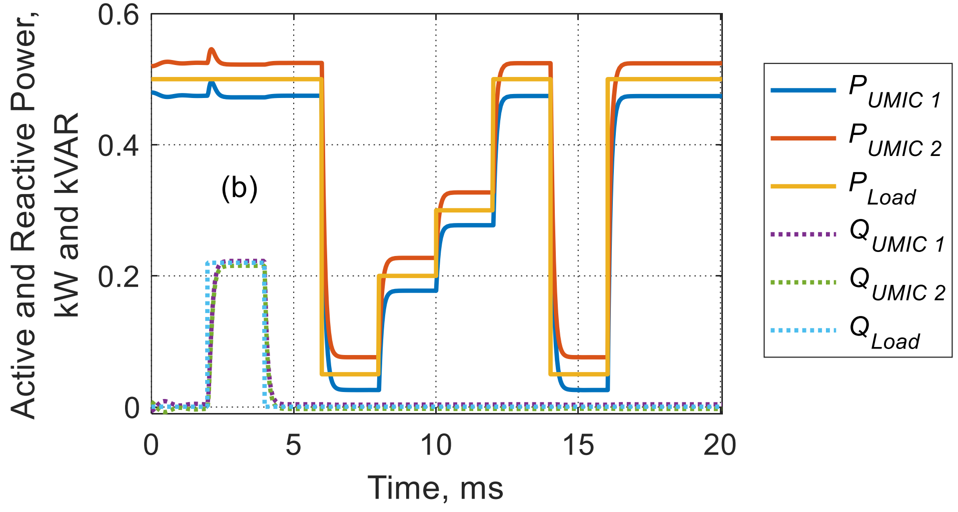
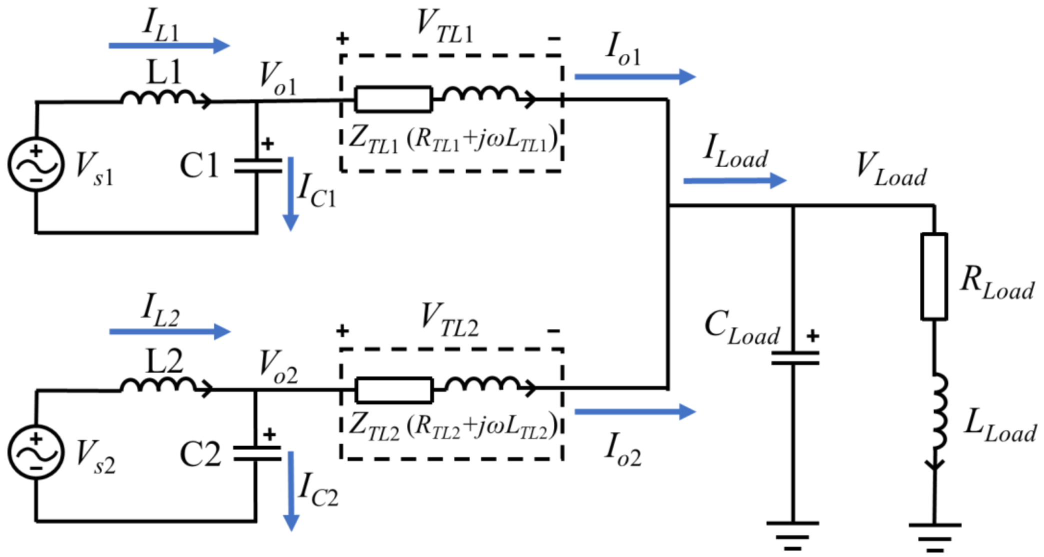
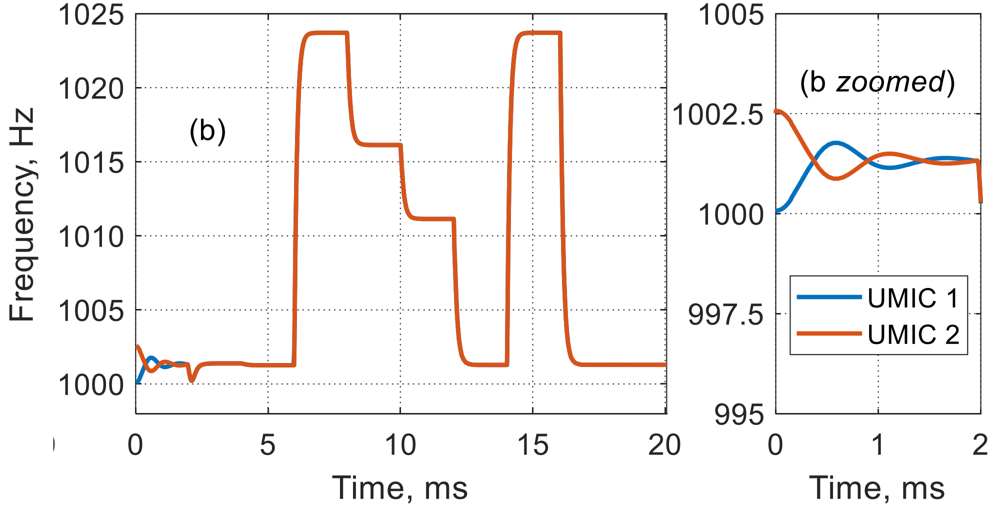
UMIC Modeling and Simulation

- Modeled two UIMCs w controllers
  - Used to help prove concept, inform control tuning in hardware
  - Successful synchronization and power sharing even when the UMICs have differing circuit or sensor bias parameters







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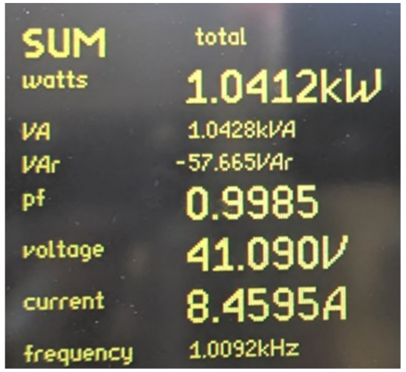
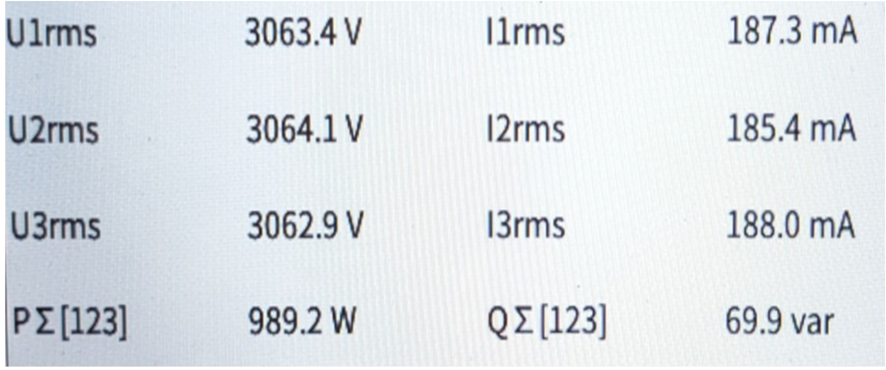
UMIC Module Test Progress

- Closed loop controllers validated in informal hardware bench testing
- Instrument photos shown from initial test at rated load
  - Shows ability of circuit to handle rated power and interface rated 3 kVAC to 120 VDC voltages
  - Efficiencies shown lower than expected: 94% for inverter, 95% for transformer
    - Significant room to optimize both subsystems

(a) DC Power



(b) Internal LVAC Power



(c) Grid AC Power

Breadboard Expected Outcomes

- Validate concept with the following demo
  - Bidirectional AC power transfer between two 10 kW UMICs via 1 km cable

- Characterize UMIC to inform future development
  - Identify challenges, find areas for improvement in HW design
  - Determine suitability of UMIC interface definition

Conclusions

- Future planetary surface missions will need universal access to reliable power
  - Artemis
  - Commercial Lunar Development
  - Mars
- The UMIC enables high voltage, bidirectional power transmission
  - Necessary for universal, reliable planetary surface power over km distance
- NASA is making investments to advance the UMIC technology and make it available for future government and industrial use

Future Work

- Seek opportunities to advance UMIC technology
  - Increase TRL
    - Build for and demonstrate in environments beyond lab
    - Provide a solution for tech demos requiring power transmission
  - Push beyond breadboard
    - Design for form and fit in addition to function
  - Demonstrate wide applicability, a truly universal solution
    - Grid-to-120 VDC load or grid-to-120 VDC source interface converter
    - Solar and/or energy storage interface converter
    - Capable of different AC grid voltages or frequencies with different transformer

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