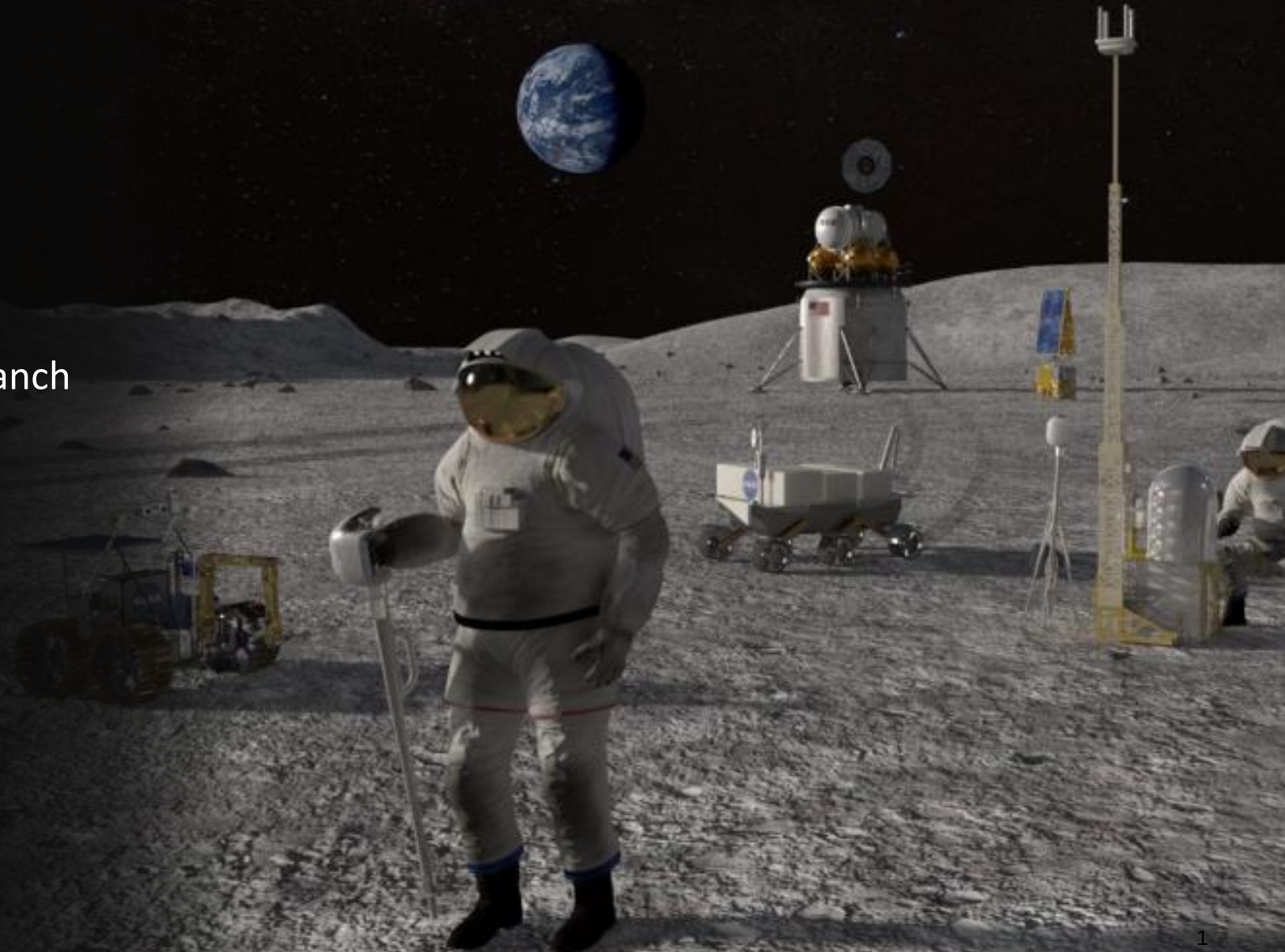


Microgrids for Space and Aeronautics

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Energy Tech 2021
VIRTUAL
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Overview



- **Space and the Lunar Surface**
 - Artemis Mission
- **Aeronautics**
- **Glenn Research Center Microgrid Study**





NASA Artemis Plans

Artemis I: First human spacecraft to the Moon in the 21st century

Artemis II: First humans to orbit the Moon in the 21st century

Artemis Support Mission: First high-power Solar Electric Propulsion (SEP) system

Artemis Support Mission: First pressurized module delivered to Gateway

Artemis Support Mission: Human Landing System delivered to Gateway

Artemis III: Crewed mission to Gateway and lunar surface

Commercial Lunar Payload Services

- CLPS-delivered science and technology payloads

Early South Pole Mission(s)

- First robotic landing on eventual human lunar return and In-Situ Resource Utilization (ISRU) site
- First ground truth of polar crater volatiles

Large-Scale Cargo Lander

- Increased capabilities for science and technology payloads

Humans on the Moon - 21st Century

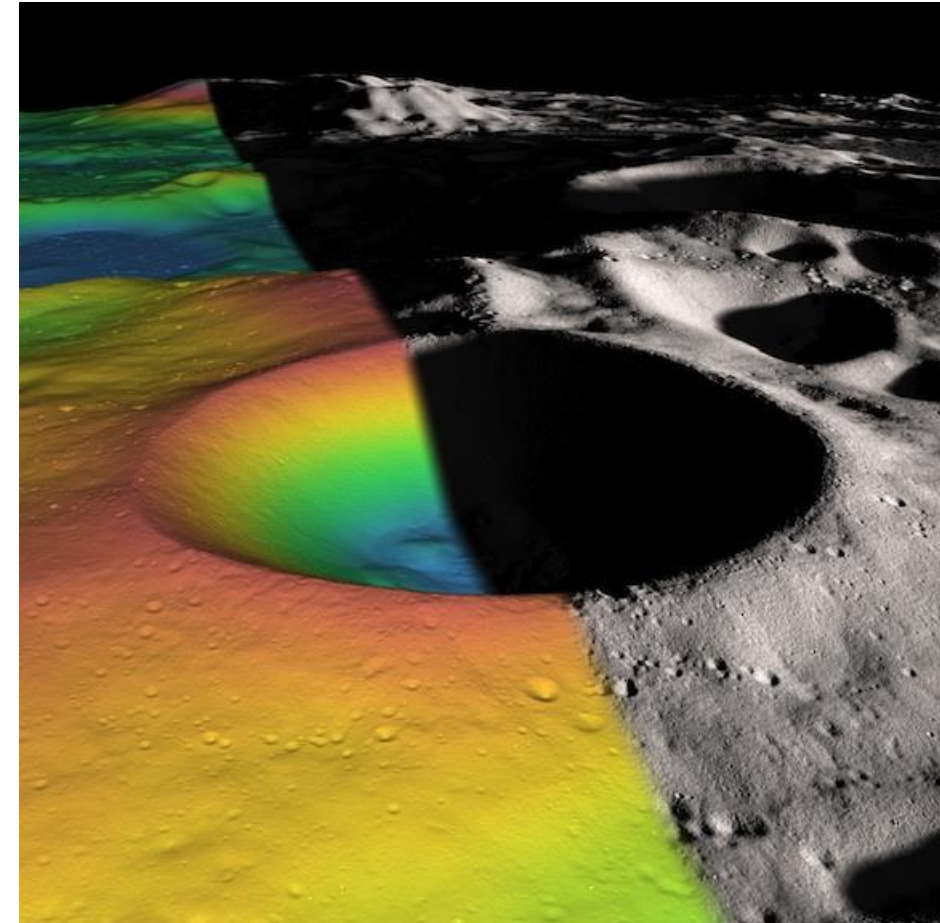
First crew leverages infrastructure left behind by previous missions

LUNAR SOUTH POLE TARGET SITE

Lunar Exploration - Shackleton Crater



- **Impact crater at the South Pole**
- **Named after Antarctic Explorer Ernest Shackleton**
- **Size:**
 - 21 km (13 mi) in diameter and 4.2 km (2.6 mi) deep
- **Rims are in almost continuous sunlight**
 - More than 80% yearly illumination
 - Sun is always low on the horizon
- **Interior is perpetually in shadow (eternal darkness)**
 - Average temperature -183 C (90 K)
 - Temperature never exceeds -173 °C (100K / -280 °F)
 - Any water vapor that arrived at the lunar surface from comets or meteorites would have been trapped

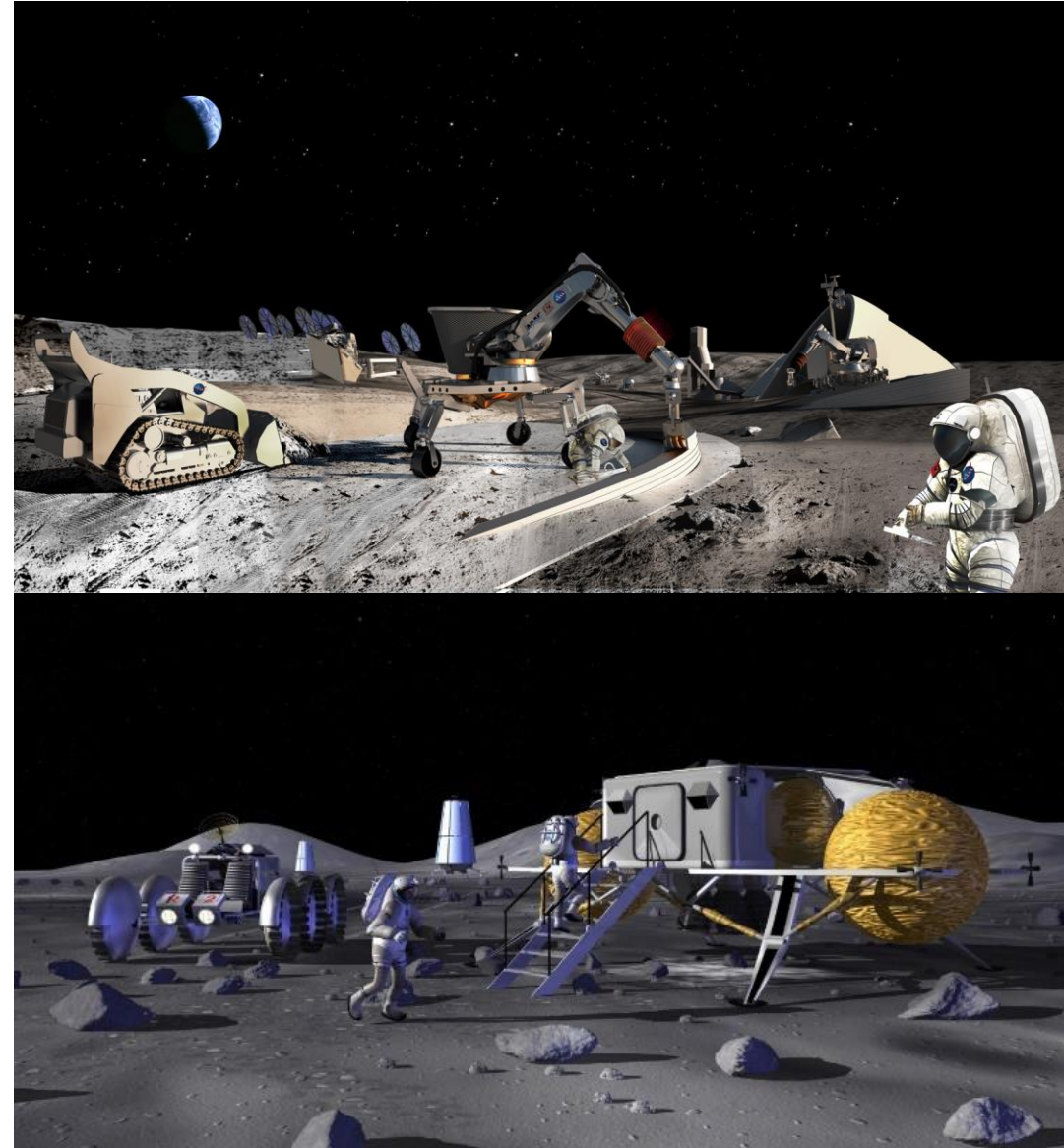


Future Human Lunar Exploration



- **Living beyond Earth**
 - Testing and demonstrating technologies for sustained presence (Lunar and Mars)
- **Manufacture propellant**
 - Fuel landers for round trips between the Lunar surface and Gateway
 - Mining/excavation regolith
 - In-Situ Resource Utilization (ISRU)
- **Support crew operations**
 - Crew of four Astronauts for at least 30 days / four times per year
- **Lunar science and technology demonstrations**

A sustainable Lunar presence requires highly reliable and available electrical power



Lunar Surface Sustainable Power Challenges



- **Architecture Challenges**

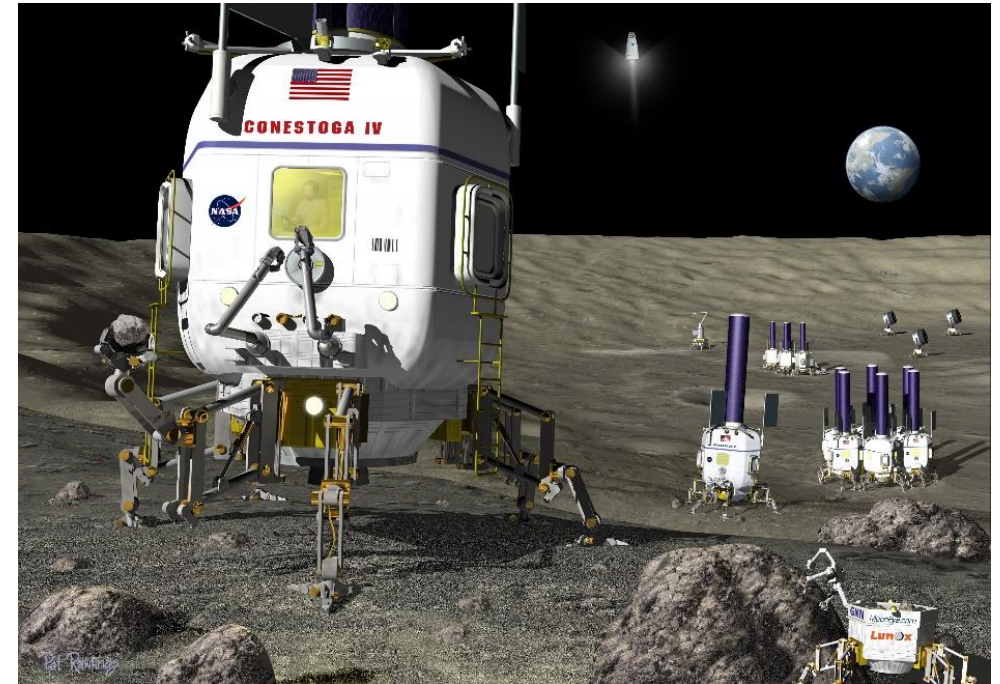
- Complex power strategy (generation / energy storage)
 - Include dissimilar power sources
 - Needs to evolve over time
- Distributed distribution architecture
 - Mix of generation, storage, and loads
 - Systems of systems approach

- **Power Availability Challenges**

- Total power demand will grow over time
- Night-time power demand will grow over time

- **Operational Challenges**

- Robotically deployable PMAD / power systems
- Autonomously operated PMAD systems



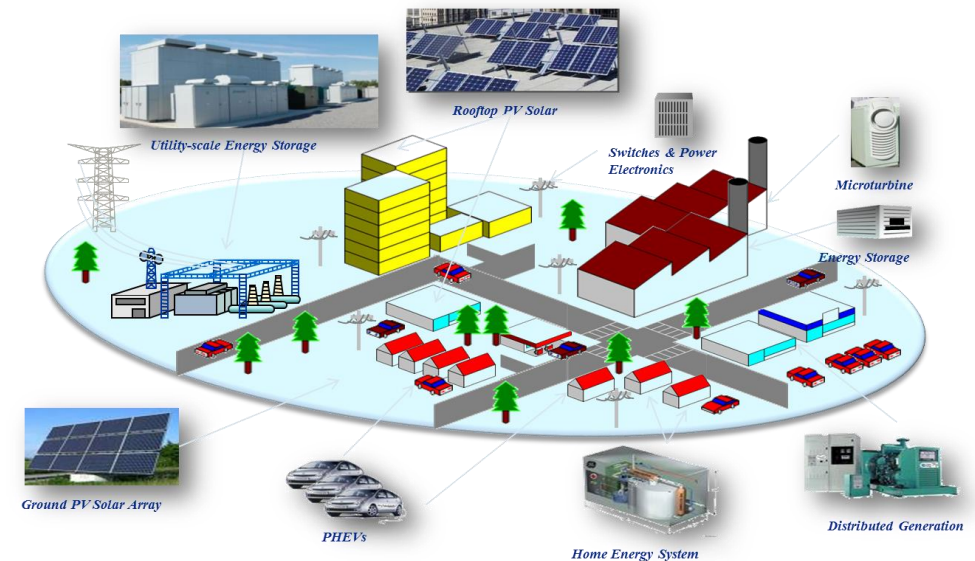
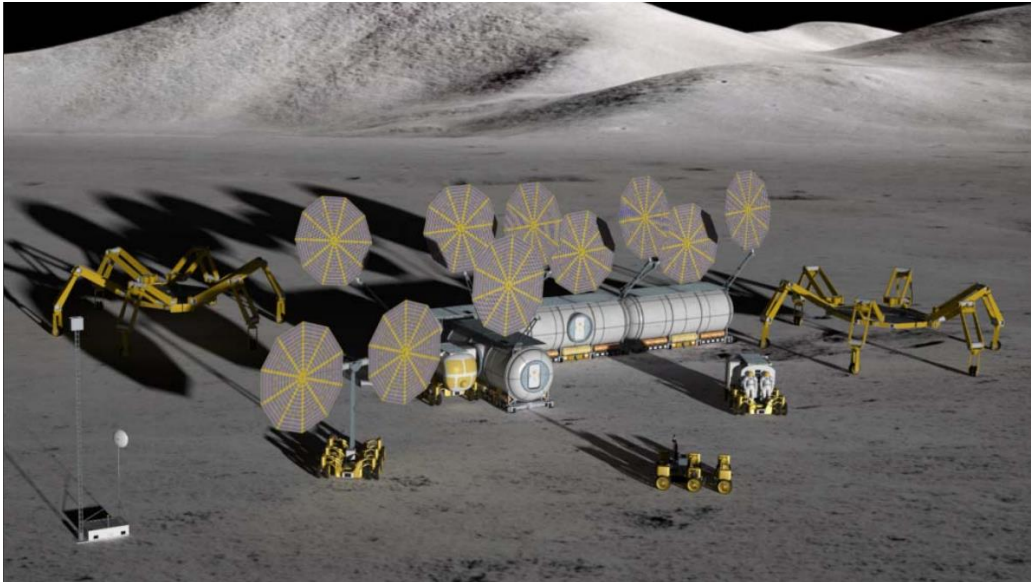
These are the same challenges/barriers for terrestrial based microgrids

Case for a Lunar Microgrid



- **Benefits of a lunar microgrid**

- Optimal dispatch of power sources / energy storage to service loads
- Use of dissimilar source and storage methodologies to enhance reliability and availability
- Systematic integration of new sources and loads as lunar surface activities evolve
- Adoption of a common grid interface for source and loads facilitate growth and interchangeability
- Deployment of future science loads that do not need to carry their own power generation



Microgrid Definition and Interface Converter for Planetary Surface

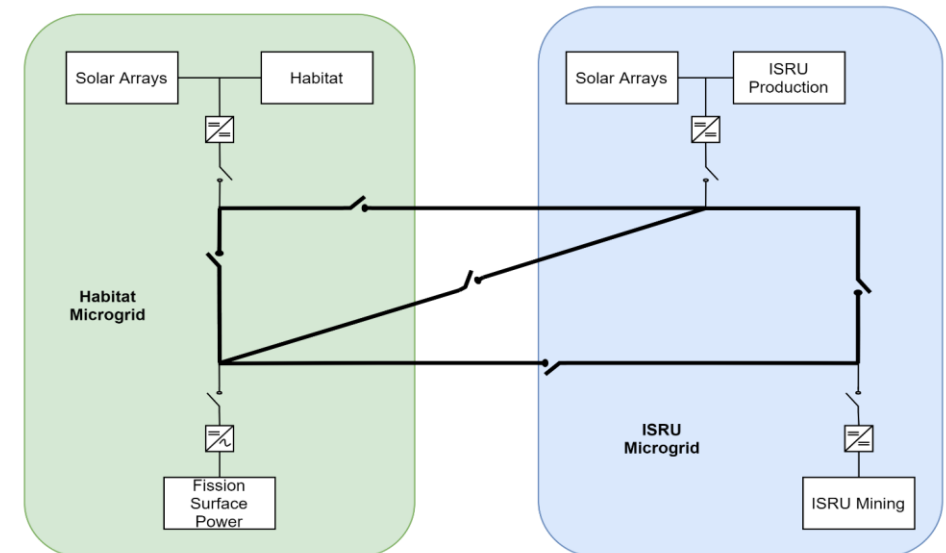
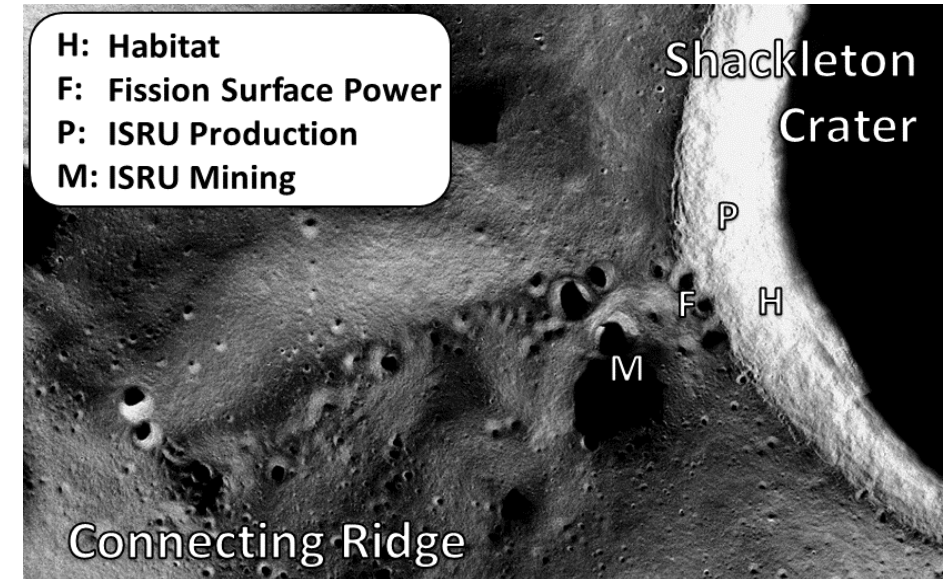


- **Microgrid Definition and Interface Converter for Planetary Surface (MIPS)**
 - FY21 & FY22 Lunar Surface Power Architecture
 - Design of a Lunar Surface power architecture that can integrate dissimilar power sources and is evolvable, reconfigurable, and reliable (Lunar microgrid)
 - Define grid architecture (Radial, Ring, etc)
 - Define grid parameters such as power type (DC/AC) and voltage level
 - FY23 & FY24 Universal Modular Interface Converter (UMIC)
 - Design and demonstration of a Universal Modular Interface Converter
 - Create common interface for connecting loads (at 2 standard space power voltages) to the grid

Microgrid Study



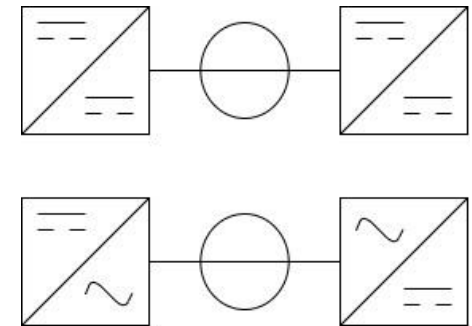
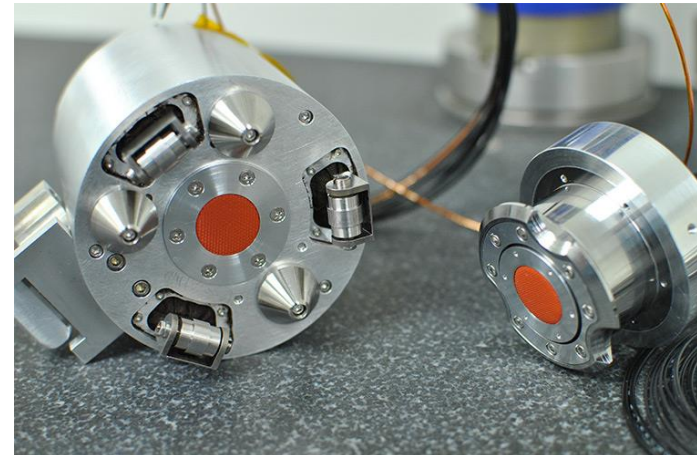
- **Assume lunar surface activities centered around Shackleton Crater**
 - ISRU Mining in cold trap near Shackleton Crater
 - ISRU Production and Lunar Habitat on rim
- **Trade studies used to design microgrid**
 - Architecture
 - Radial vs Ring vs Zonal
 - Fault tolerance, mass, efficiency
 - Operating parameters
 - Define distribution voltages
 - Cable sizes, lengths, etc.
- **Trade studies and power distribution architectures drive requirements for the Universal Modular Interface Converter (UMIC)**



Universal Modular Interface Converter (UMIC)



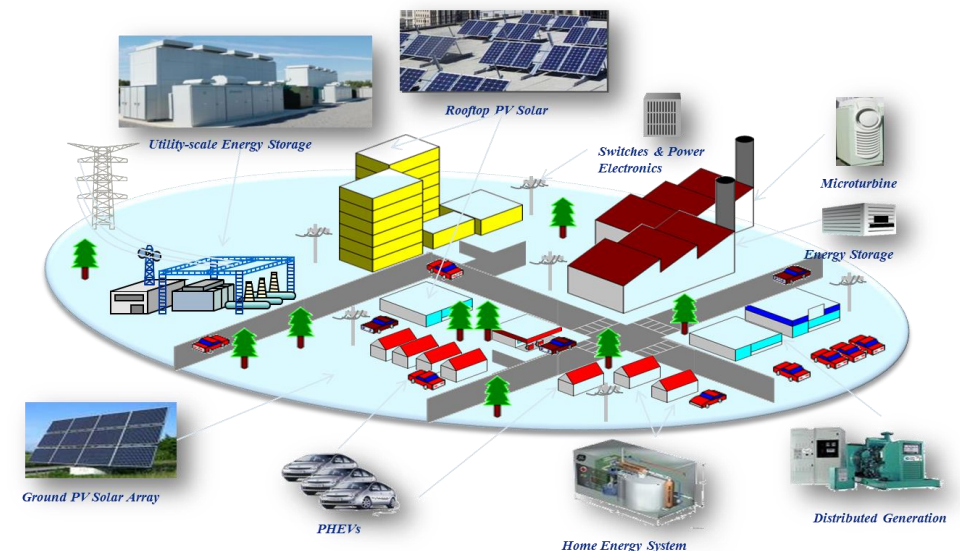
- **Converter between grid power (TBD) and standard space power (120 VDC or 28 VDC)**
 - Allow for standardized connection between sources and loads
- **Technology Development Plan**
 - Draft requirements (3/2022) – Systems Requirement Review (SRR)
 - Physical requirements
 - Connector requirements, etc.
 - Functional requirements
 - Bi-directionality
 - Thermal requirements, etc.
 - Paper design (9/2022)
 - Breadboard Prototype Q2FY23
 - Final Test and Demonstration Q4FY23



Hierarchical Microgrids and Autonomous Power Control



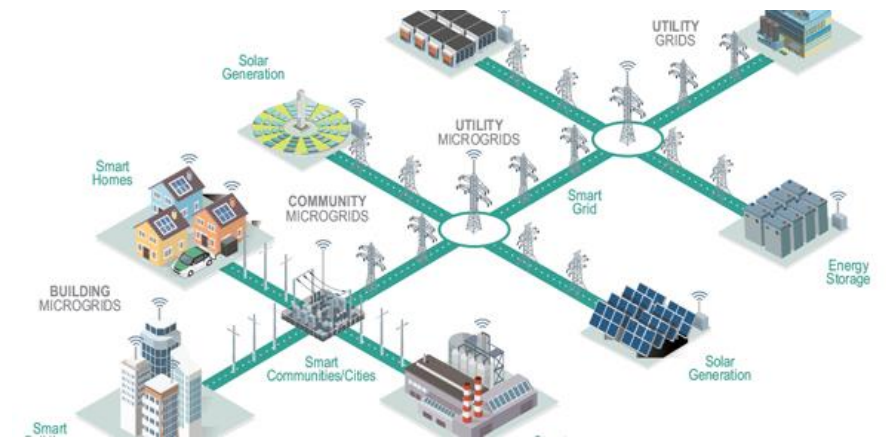
- **Power System Objectives**
 - Provide power to as many high priority loads as possible
 - Operate safely - within power system constraints
 - Power generation / energy storage constraints
 - Power distribution limits
- **Power Control Objectives**
 - Manage the power system
 - Fault Management
 - Energy Management
 - Contingency Management
- **Autonomous Power Controller Objectives**
 - Manage the power system without human intervention
 - Permit humans (Astronauts) to consent to an operations /actions during habitation



NASA Autonomous Power Controller



- **What is it?**
 - A collection of software services that interact to intelligently manage the power system without direct human intervention.
- **Why use it?**
 - Behaves like a grid operator control room packaged into software
 - Manages the grid during faults and disturbances
 - Designed for deep space exploration spacecraft but has direct applications to terrestrial microgrids
- **Key Capabilities:**
 - Energy forecasting and automatic load planning
 - Advanced fault detection and diagnostic engine
 - Contingency management
 - Distributed energy storage regulation



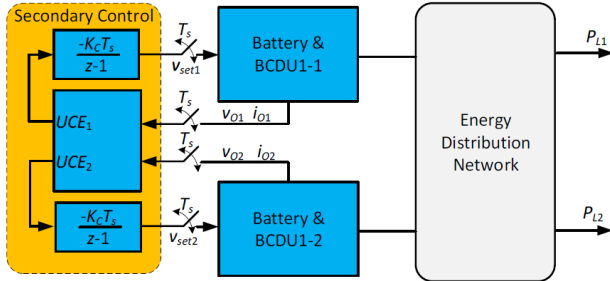
NASA Autonomous Power Controller Services



Distributed Energy Storage Control

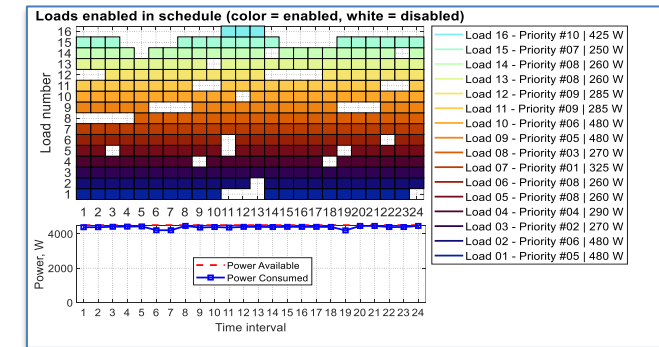
A three-level control pattern designed to:

1. Regulate bus voltage
2. Provide even load sharing across DERs
3. Balance distributed storage SOC



Power Forecasting

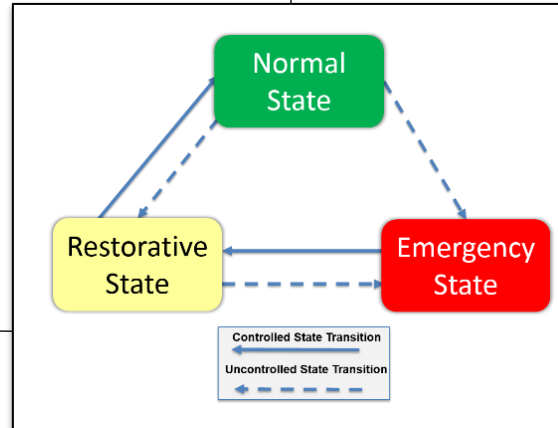
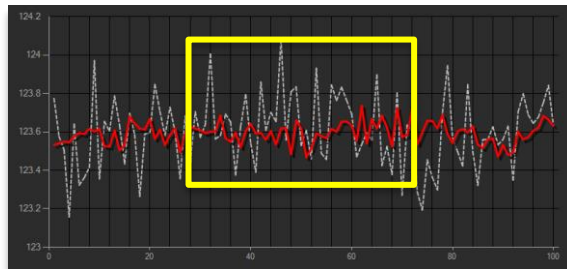
Uses projected load and forecasted energy generation to simulate future operating conditions over a rolling time horizon. This allows system vetting before new operating conditions are implemented.



Fault Detection and Diagnosis

Combines modeling techniques with expert system to detect and diagnose a wide range of fault conditions such as:

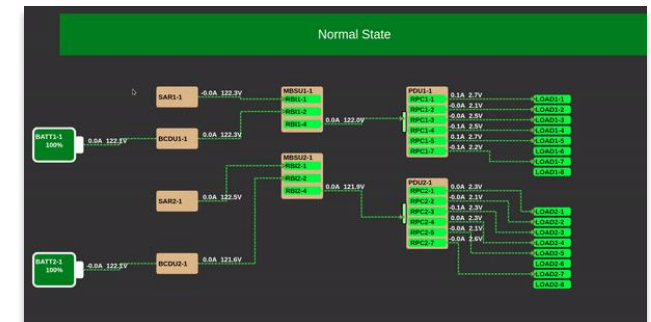
line to ground faults,
high impedance shorts,
sensor faults,
communication faults, etc.



Contingency Management

Determines optimal corrective action in the event of an unexpected event or failure.

E.g. reconfigure topology during a line outage to balance energy storage

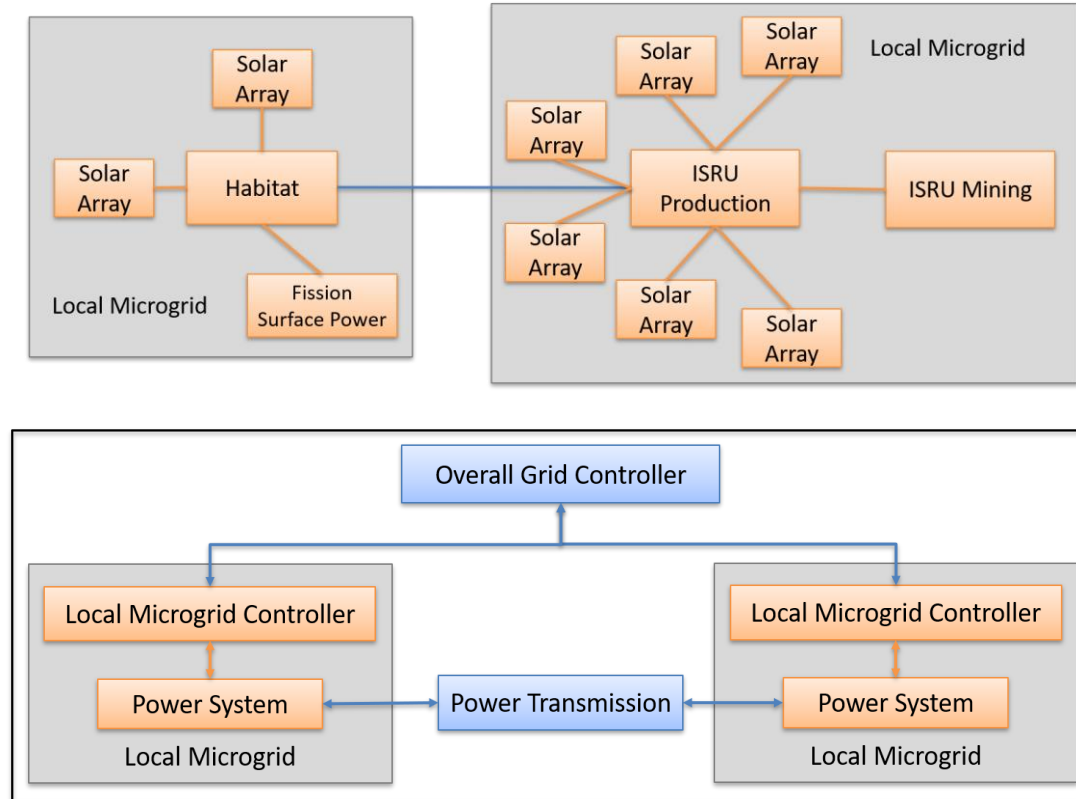


Robust, Autonomous, and Fault Tolerant DC Microgrids



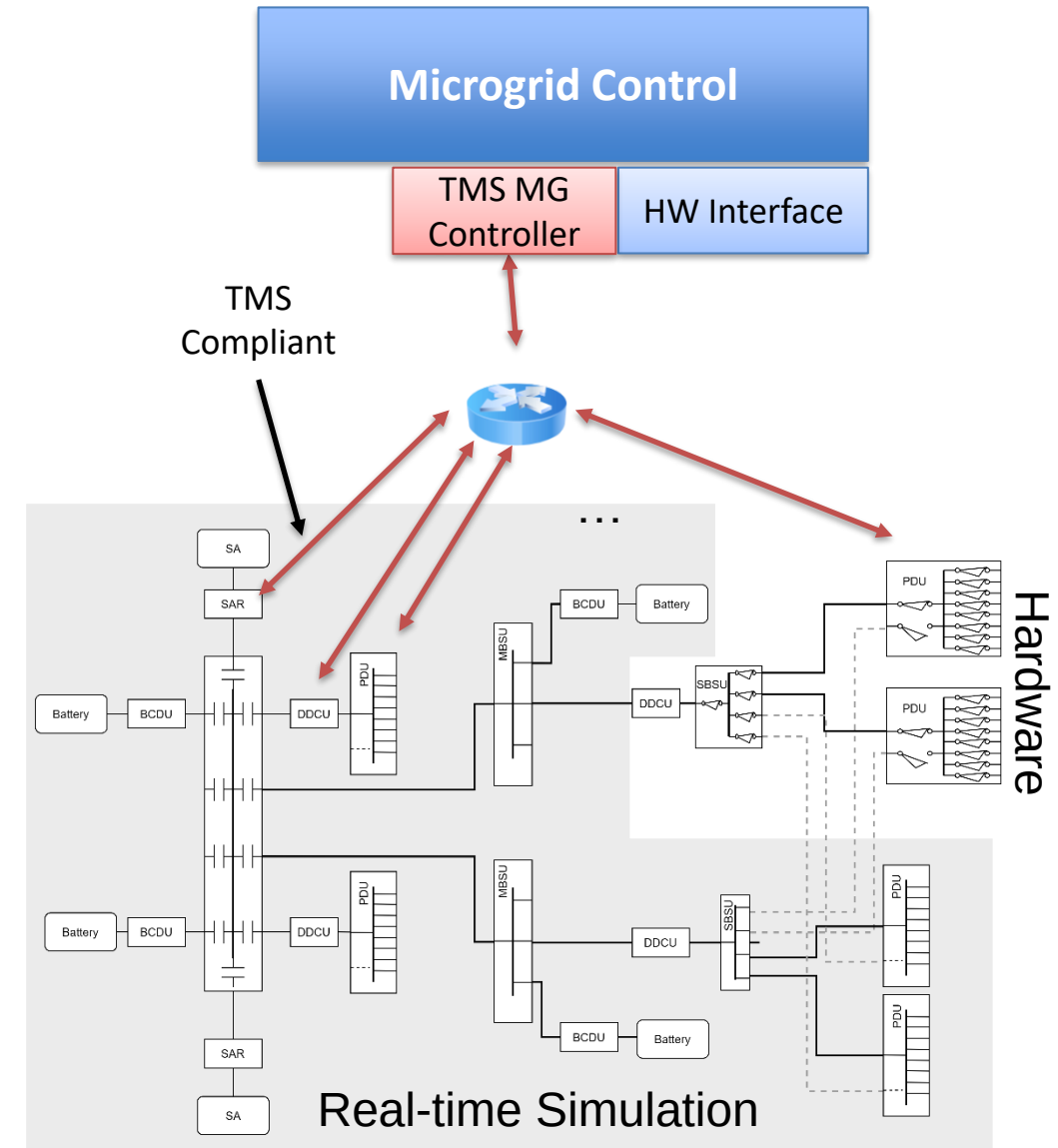
Collaboration

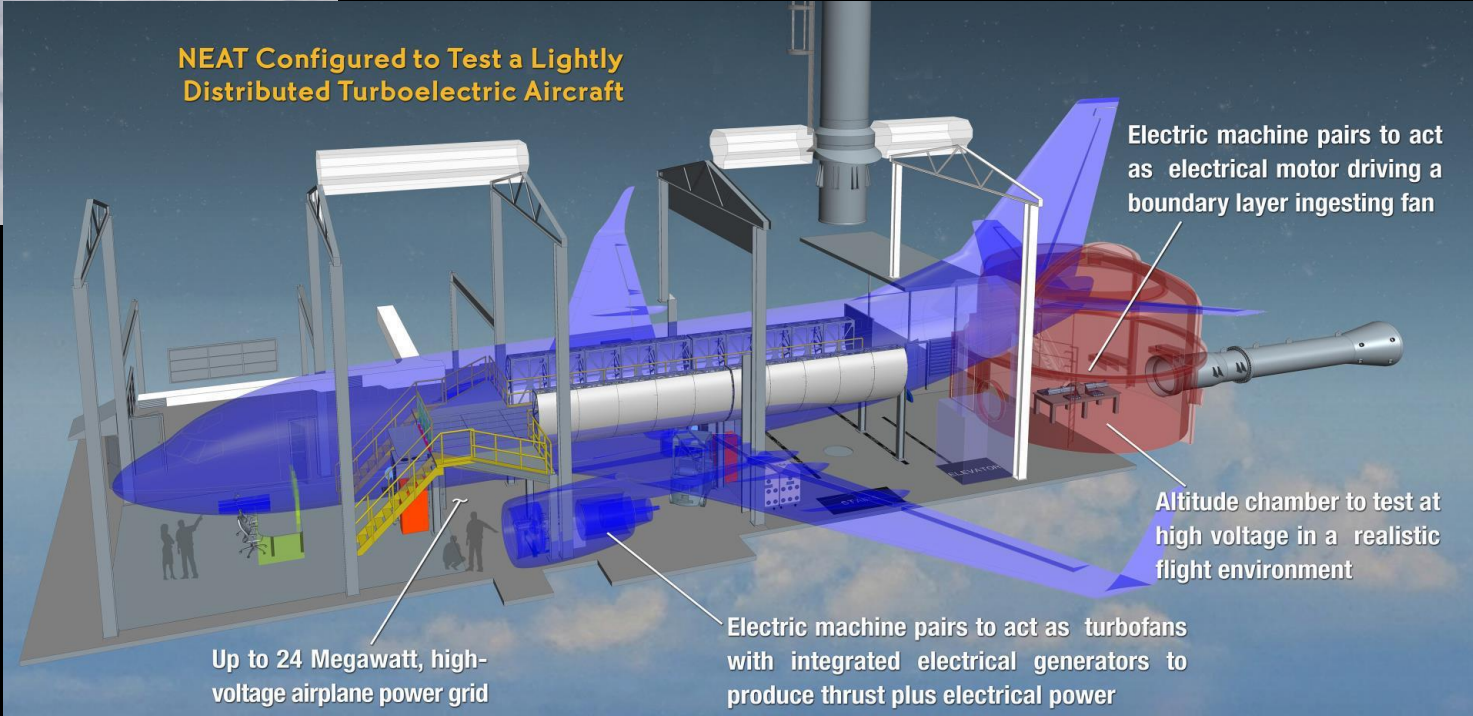
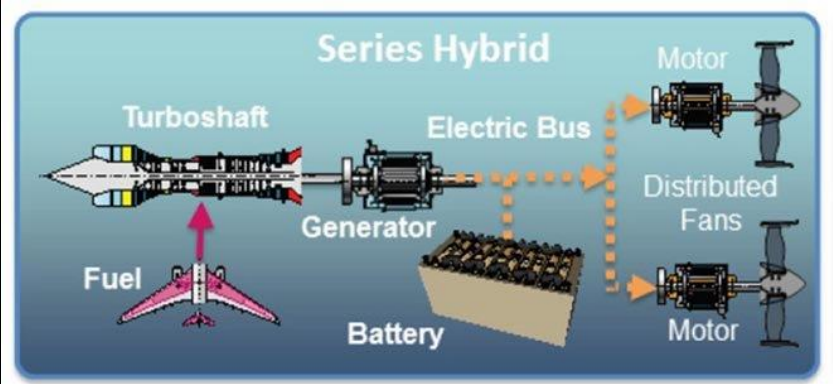
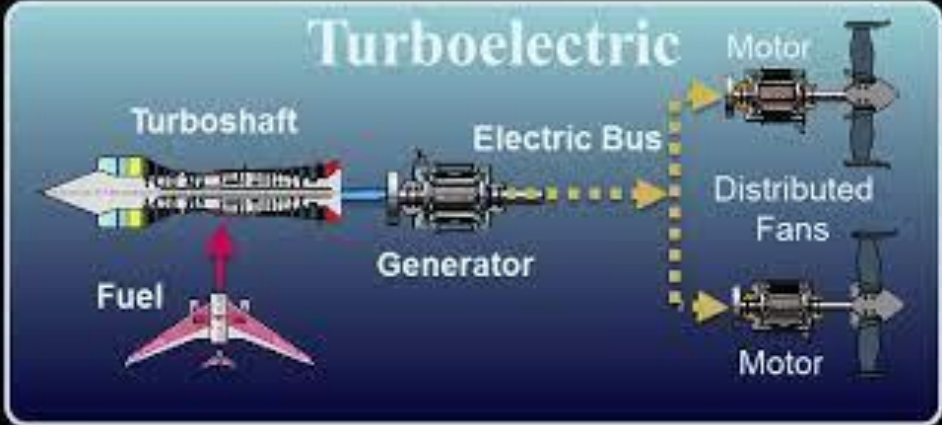
- **Problem:** Microgrids require the ability to transmit power from one island to another during peak demand periods or during a generation outage. A standardized method of communication and control is needed to manage this transfer between microgrids.
- **Objective:** Define and implement the necessary set of controls & communication needed to manage power in a network of microgrids using a system of systems approach.
- **Project Overview:**
 - Two independent controllers manage power in each microgrid
 - Power flow analysis is used to determine the energy balance (surplus/deficit) in each microgrid over a rolling time period
 - Determine when power should be shared across the grid interconnect using a global (tertiary) controller
 - The controller will be demonstrated in a real-time environment using a SpeedGoat emulator



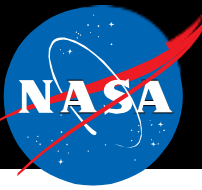
Collaboration

- **Problem:** The evolving state of the space power systems over time requires changes in the control software.
- **Objective:** Utilize the Tactical Microgrid Standard (TMS) to improve device compatibility with the APC and demonstrate device discovery using real hardware
- **Project Overview:**
 - Implement the Autonomous Power Controller with TMS communication in a Hardware-in-the-loop environment for real time demonstration
 - Streamline the message flow between devices
 - Enable new device discovery
 - Provide the basis for full plug-n-play capability
 - First step towards fully configurable control

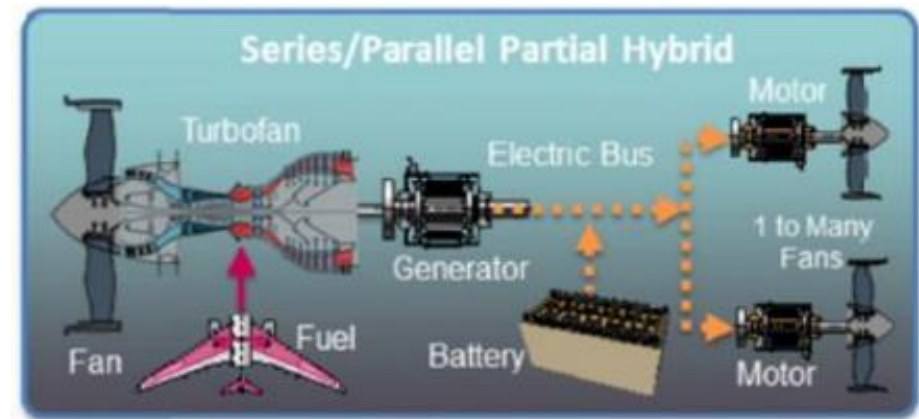




Electrified Aircraft



- **Hybrid-Electric Power Systems can act as Microgrids**
 - Power generated via turbine-driven generators & energy storage
 - Distributed loads across the vehicle
- **Nominal voltages expected from ~500V to multiple kV, >1MW of power**
- **Requires advanced power system management**
 - Fault monitoring & prevention, detection & isolation are critical in preventing loss of mission
 - Energy and power demands must balance with source capability over the duration of the flight
 - Planning
 - Islanding/Stand-alone Considerations
 - Peak Shaving
 - Pilots cannot react fast enough to reconfigure or manage the power system
 - Need for intelligence



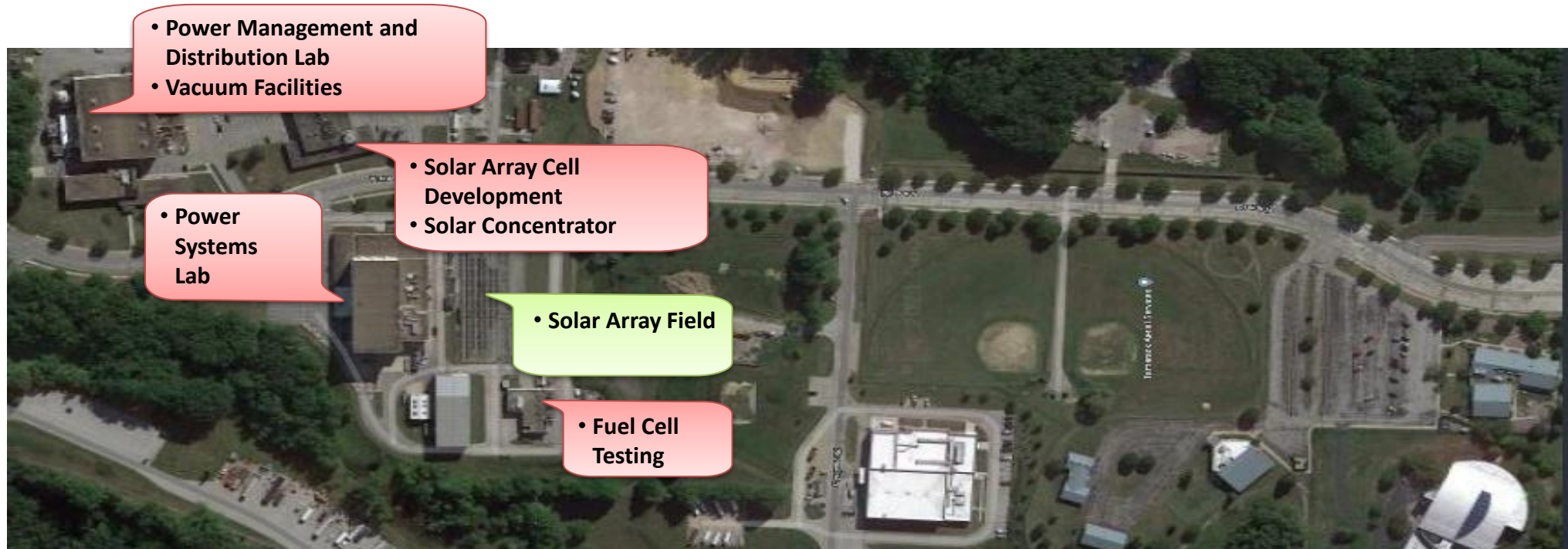
Glenn Research Center Microgrid Study



NASA Glenn West Area Microgrid Concept Study



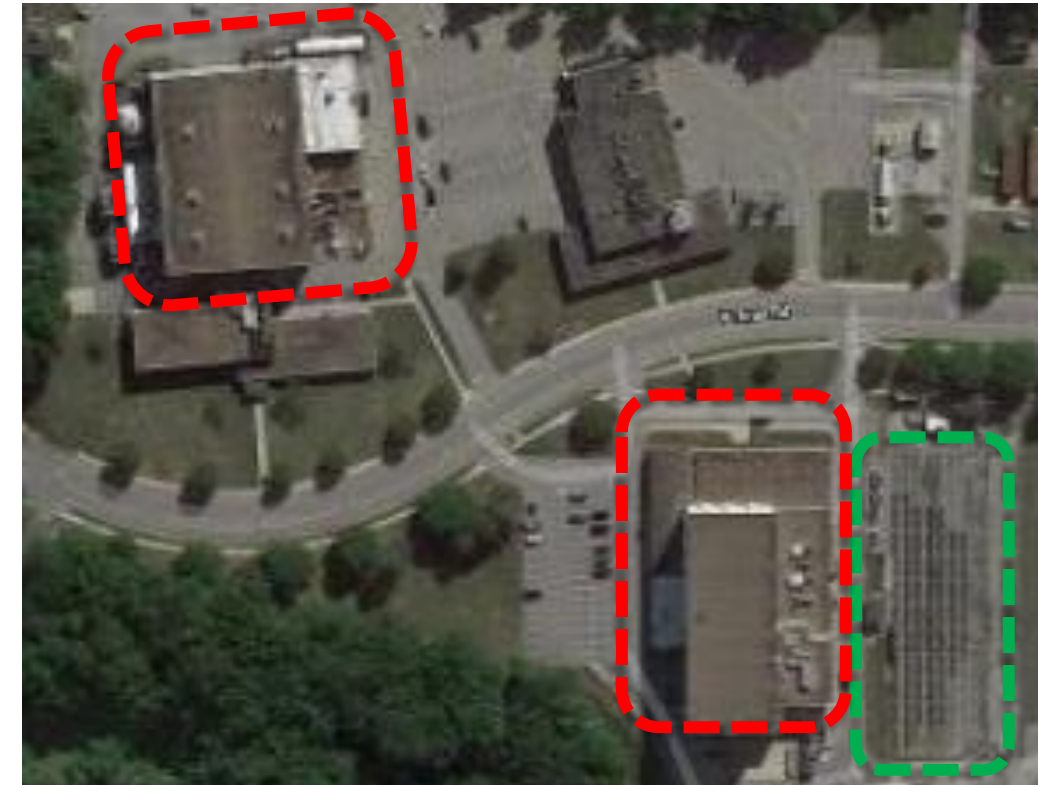
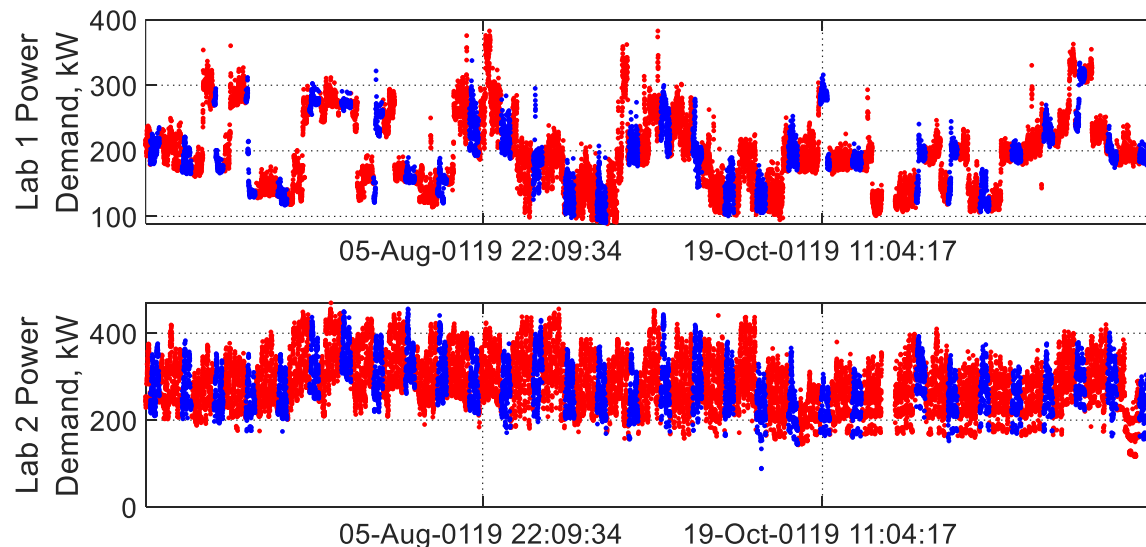
- **NASA Glenn’s “west area” consists of electrical power research facilities and some amenities**
 - Labs for hardware development, a solar array field, and a fitness center and daycare
- **NASA beginning a 6 mo project for conceptual design study of a west area microgrid**
 - Will improve reliability and availability of power for NASA’s west area by enabling integration of existing and future renewable energy sources
 - Proposed design will serve as testbed for terrestrial and lunar microgrid technologies



NASA Glenn West Area Microgrid Concept Study



- Initial phase of study to connect existing solar array to nearby power systems labs
 - Around 20 kW of unutilized solar capability maximum
 - 500 kW total loading in two nearby buildings average
- Goal is to fully utilize solar capability with energy storage
 - Power used for peak shaving during peak demand periods
 - Power stored and used as back-up power



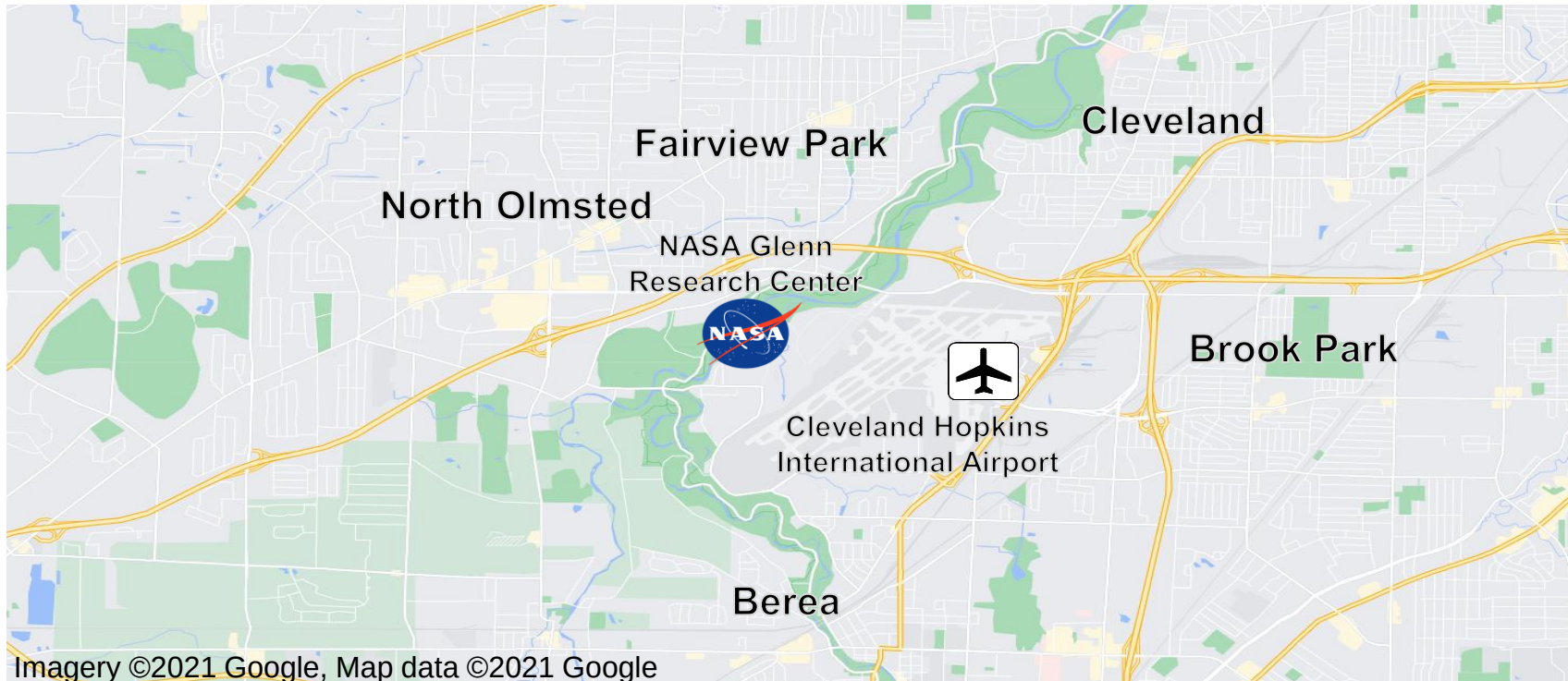
NASA Glenn West Area Microgrid Concept Study



- **Second phase, identify additional renewable power needed to supply entire west area**
 - Significant additional solar arrays or other renewables needed for full west area loading
 - Project to consider locating these on- or off-site, consider arrays owned by entities other than NASA and operated cooperatively through agreement
- **Scale of microgrid will grow in second phase as well**
 - Calculate additional energy storage needed
 - Estimate additional power transmission, distribution, and management hardware
- **At this phase, may begin considering sharing power in front of the meter**



- **Third phase, possible integration with a larger Cuyahoga County Microgrid**
 - Determine possible customers and generating assets in county to be connected in front of the meter
 - Calculate needs and capabilities (identify gaps)
 - Stakeholders (inc. NASA) may be able to add local assets where possible to close gaps for the grid
 - Aerozone Alliance, Cleveland Foundation, etc.
- **This Cuyahoga County Microgrid would be a first-of-its-kind demonstration of in-front-of-the-meter microgrid**



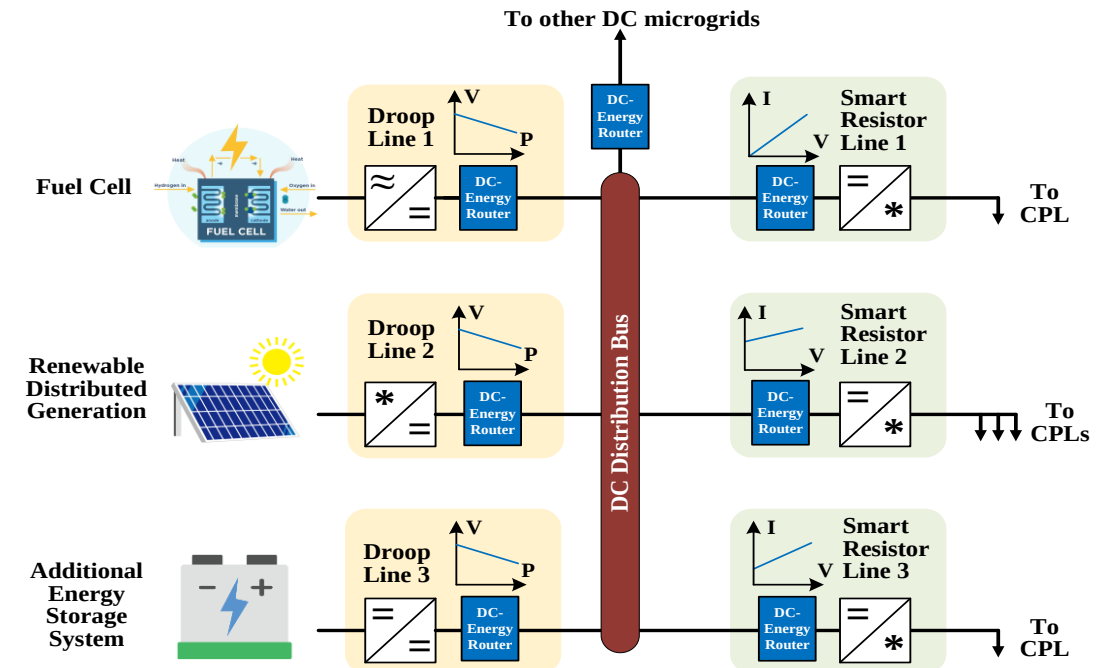
Other Efforts



- **Flexible DC-Energy Router based on Energy Storage Integrated Circuit Breaker**
 - Smart Resistor concept
 - Controller enabled by Wide Band Gap (WBG) devices and energy storage systems
 - T-Breaker concept
 - Modular and scalable dc circuit breaker, to realize a flexible DC-Energy Router between and within a wide range of lunar microgrids

- **Benefits**

- Modular design
- Co-optimization of system architecture and layered control strategies
- Flexible energy flow control and stability improvement by coordinating droop lines of energy sources and Smart Resistor lines of loads
- Fault current limiting, fast breaking, and system re-configuration with integrated energy storage devices

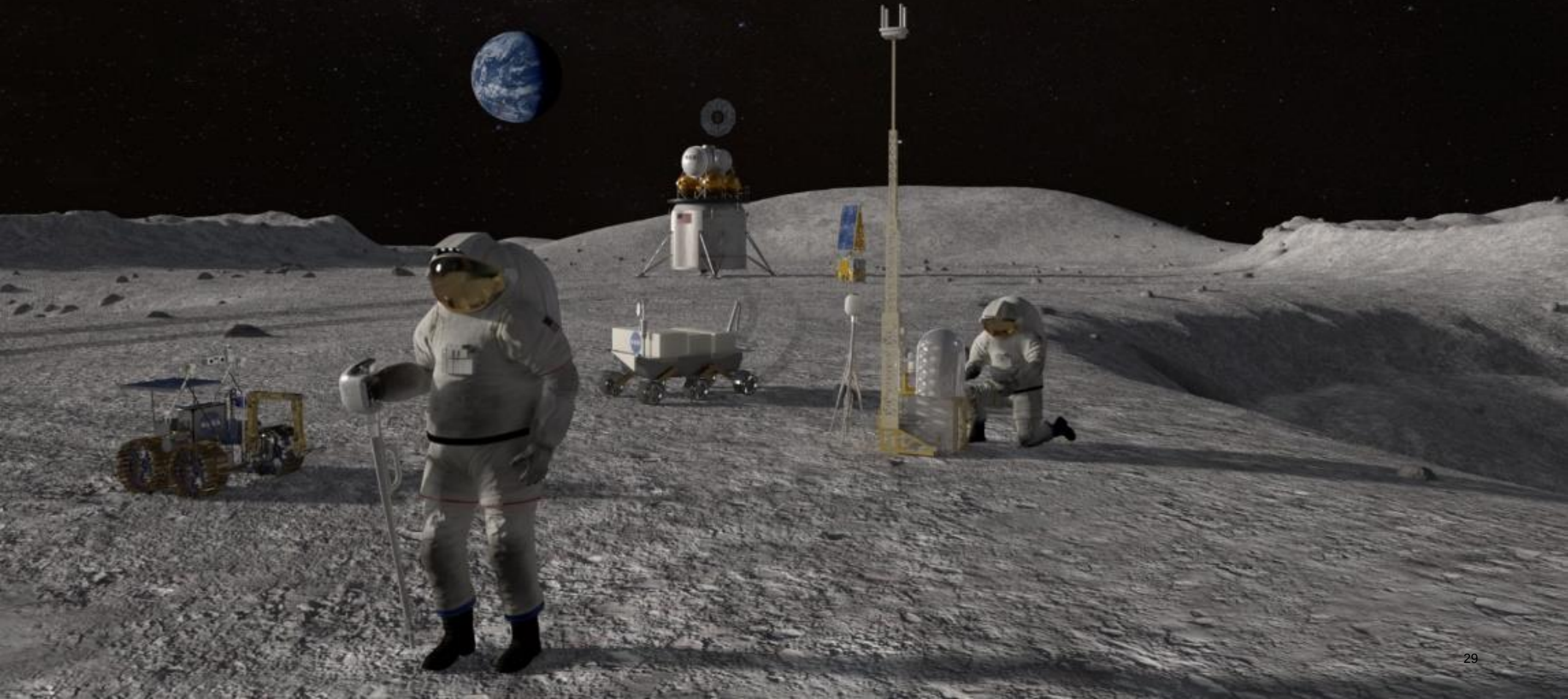


- **Several SBIRs / STTRs in recent years focused on technologies that are applicable to microgrids:**
 - Intelligent / Autonomous Power
 - PC Krause and Associates (PCKA) / Case Western Reserve University
 - PC Krause and Associates (PCKA) / Purdue University
 - Stottler Henke and Associates / Montana State University
 - Alphacore Inc
 - Integrated Thermal and Power
 - EleQuant Knowledge Innovation Data Science LLC
 - Lunar & Planetary Surface Power PMAD
 - PC Krause and Associates (PCKA)
 - Low Emission Propulsion and Power / Electrified Aircraft
 - New Electricity Transmission Software Solutions (NETSS)

- **Microgrids are becoming more popular for power distribution**
 - Space/Military Applications: Power based on available resources
 - Terrestrial/Aeronautics: Clean and efficient power
 - The attractiveness of microgrids attributed to ability to integrate dissimilar power sources (generation and energy storage) and alternative sources (renewables)
- **Many challenges still need to be addressed for microgrids**
 - Distributed architectures
 - Achieving high efficiency and high reliability
 - Integration of dissimilar or alternative power sources (interoperability)
 - Operability
 - Power quality and stability
 - Ability to reconfigure the system and switch between power sources quickly
 - Quickly detect faults/failures and reconfigure the system to avoid power disruptions

NASA GRC is interested in addressing these fundamental issues associated with microgrids

**Thank you!!
Any Questions?**



Lunar Surface Technology Research (LuSTR)

Ohio State University



Flexible DC-Energy Router based on Energy Storage Integrated Circuit Breaker

Jin Wang (PI), Giorgio Rizzoni, Mahesh Illindala, Julia Zhang, Anant Agarwal, Matilde D'Arpino

The Ohio State University

Baljit Riar

Raytheon Technology Research Center

Approach

- Modular design
- Co-optimization of system architecture and layered control strategies
- Flexible energy flow control and stability improvement by coordinating droop lines of energy sources and Smart Resistor lines of loads
- Fault current limiting, fast breaking, and system re-configuration with integrated energy storage devices
- Digital twin and prototype based validation

Development Objectives

The goal is to combine the Smart Resistor concept, which is a wide bandwidth controller enabled by WBG devices and energy storage systems, and the T-Breaker, which is a modular and scalable dc circuit breaker, to realize a flexible DC-Energy Router between and within a wide range of lunar microgrids.

A digital twin and a 120 V 10 kW GaN based high power density prototype would be built.

Impact and infusion

- Modular and flexible solution for control, protection and interoperability
- Fuel saving and reliability improvement
- Reduction in fault energy and collateral damage
- The planned digital twin, the high power density prototype and hardware platform will enable many future research
- A group undergraduate and graduate students will be trained

