National Aeronautics and
Space Administration

Lunar Microgrid Control Technology Options and Features for Interoperability

Raymond F Beach| NASA Glenn Research Center | November 6, 2020

Why go to The Moon?

Proves technologies and capabilities for sending humans to Mars

Establishes American leadership and strategic presence

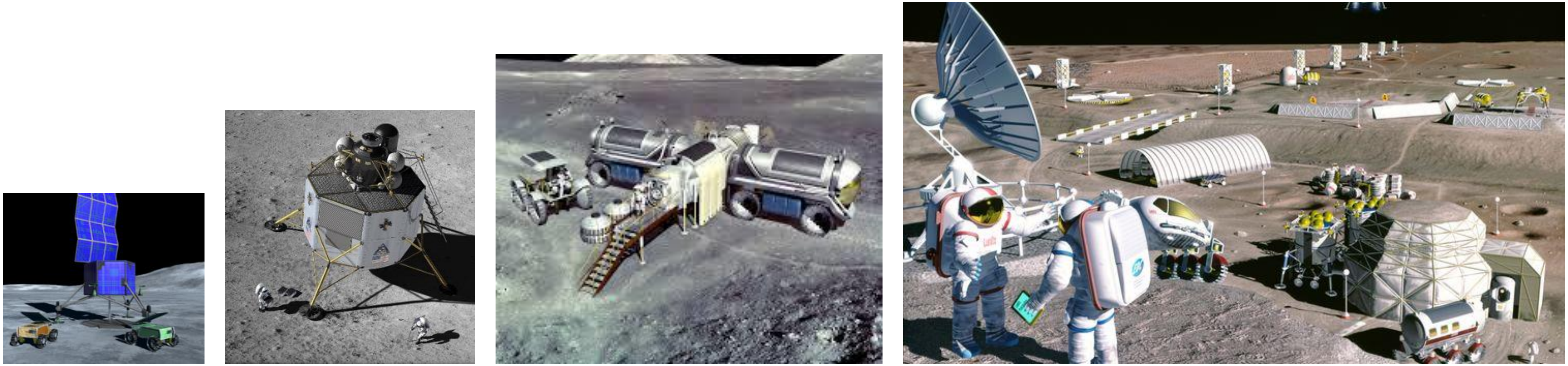
Inspires a new generation and encourages careers in STEM

Leads civilization changing science and technology

Expands the U.S. global economic impact

Broadens U.S. industry and international partnerships in deep space

Overall Mission Architecture



Scientific Landers → Rovers, Crewed Missions from Lunar Gateway → Lunar Base (habitat, charging station, ISRU plant)

MOON SURFACE

The lunar surface field station tests the fundamental capabilities required for a future Mars mission and enables world-class expeditionary science and exploration

Lunar Field Station

The scope of the lunar surface activities will borrow from the early years of Antarctic exploration, which utilized science field stations as the initial foothold on the lunar surface. Science priorities will include lunar geology, deployment of science experiment packages, deployment of initial ISRU pilot plants, mobility-enabled science, and return of samples.

South Pole Site Architecture

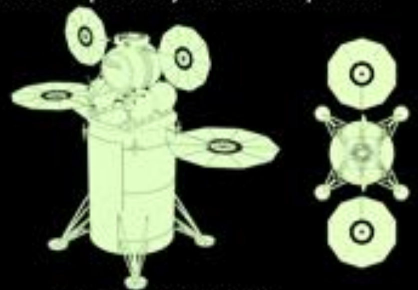
The lunar poles landing sites offer a unique mix of illumination, Earth visibility, and proximity to permanently shadowed regions and resources. The illumination conditions define narrow (km-long) field station sites that will contain areas for power generation, habitation, resource utilization, and landing zones.

PREDEPLOY ROBOTIC MISSIONS

Commercial lunar payload delivery services will be used to predeploy science and logistics payloads prior to the arrival of the initial crew, and to provide global lunar access for delivery of science and technology payloads.

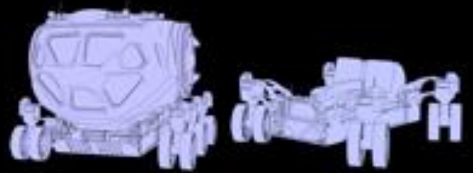
POWER AND COMMUNICATIONS

Initial surface power will be provided by solar arrays that track the sun as it circles the lunar polar horizon. A communications mast will provide



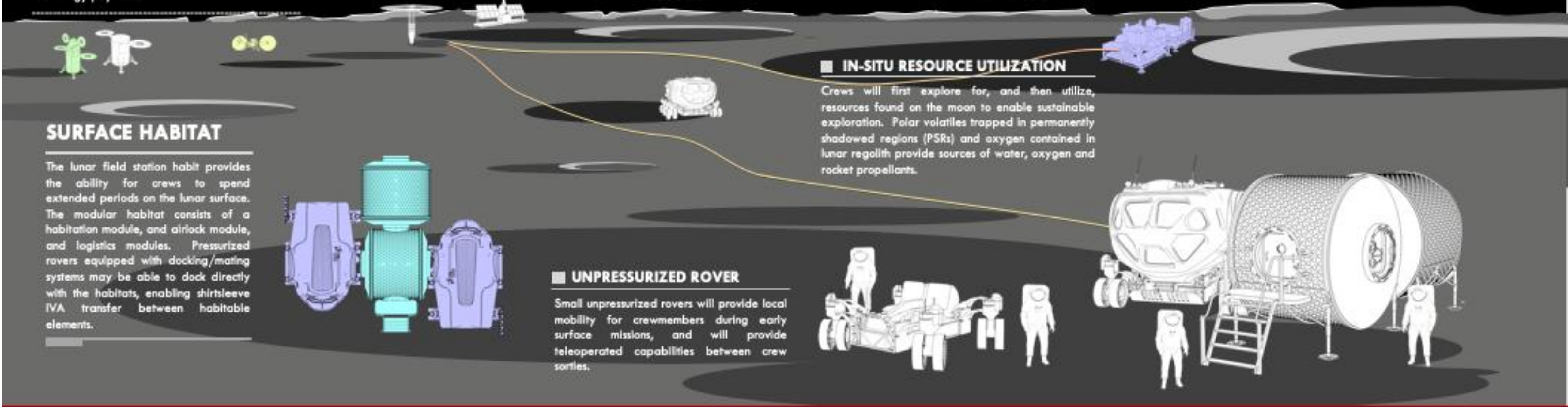
CREW LANDERS

Carries the crew from Gateway orbit to the lunar surface and returns to Gateway. Provides 6/5 days of habitation for 2-crew sorties, with the ultimate capability of delivering 4 crew to the lunar field station



2 CREW PRESSURIZED ROVER

Pressurized rovers will provide 100's of km of range for astronauts as they explore the lunar surface. The pressurized rover not only provides mobility, but functions as a short-term (up to 14 days) habitat for 2 crewmembers.



SURFACE HABITAT

The lunar field station habit provides the ability for crews to spend extended periods on the lunar surface. The modular habitat consists of a habitation module, and airlock module, and logistics modules. Pressurized rovers equipped with docking/mating systems may be able to dock directly with the habitats, enabling shirtsleeve IVA transfer between habitable elements.

IN-SITU RESOURCE UTILIZATION

Crews will first explore for, and then utilize, resources found on the moon to enable sustainable exploration. Polar volatiles trapped in permanently shadowed regions (PSRs) and oxygen contained in lunar regolith provide sources of water, oxygen and rocket propellants.

UNPRESSURIZED ROVER

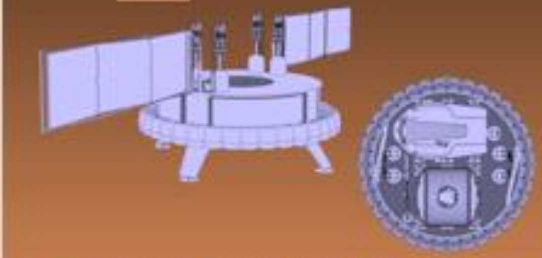
Small unpressurized rovers will provide local mobility for crewmembers during early surface missions, and will provide teleoperated capabilities between crew sorties.

MARS SURFACE

The surface systems emphasize modularity for a flexible, reconfigurable field station

Surface Infrastructure

For each expedition, three ~20 metric ton landers are required to support four crew on the surface of Mars. The first expedition's Mars surface systems will be delivered in order, from left to right below. The top-down view indicates the lander layout before the mobility system deploys the lander's payload while the other views show the landers after deployment and identify their location in the landing layout.



SURFACE POWER AND MOBILITY

Carries five Kilopower units, electrical cabling, and a power distribution box to power all surface systems. The lander also delivers a hoist, pressurized rover, mobility chassis, a crew support rover, and the initial descent module.

MARS ASCENT VEHICLE

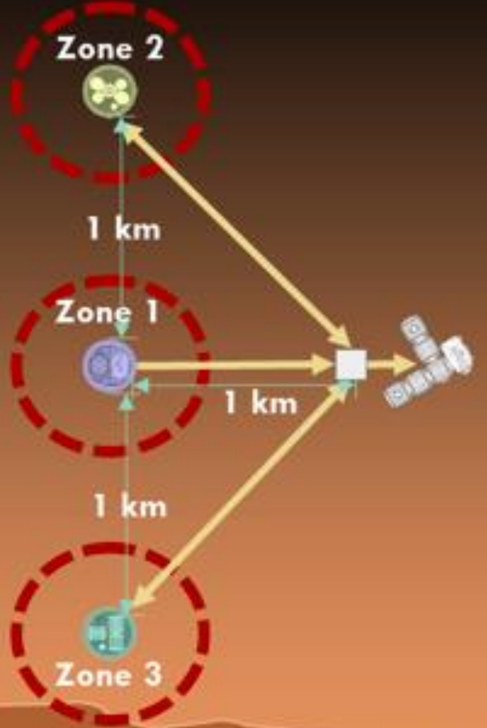
Delivered with a propellant production system to manufacture oxidizer before launching crew from the surface back to the Mars transit habit.

CREW LANDER

Carries the crew descent module with 4 crew along with an airlock, two habitable logistics modules, a second hoist, science equipment, and planetary surface suits.

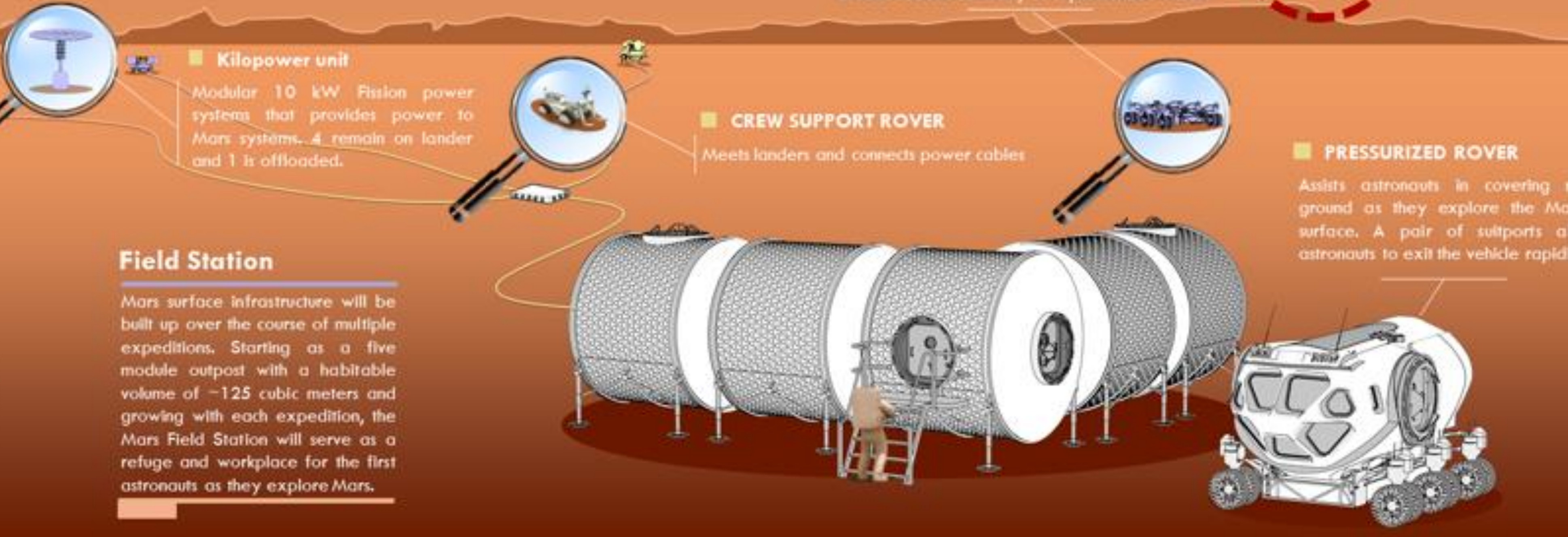
Lander Positioning Strategy

Landing zones are located approximately 1 km away from each other and the Field Station. This reduces damage from high speed debris impacts during both descent and ascent, and keeps the crew a safe distance from the Kilopower units. A mobile robotic assistant deploys the power junction box and distributes cabling between ground systems.



MOBILITY CHASSIS

Assembles the habitat pieces at the Field Station using two cargo hoists. Can be reconfigured to serve as a pressurized rover, mobile robotic assistant, or unpressurized rover.



Kilopower unit

Modular 10 kW Fission power systems that provides power to Mars systems. 4 remain on lander and 1 is offloaded.

CREW SUPPORT ROVER

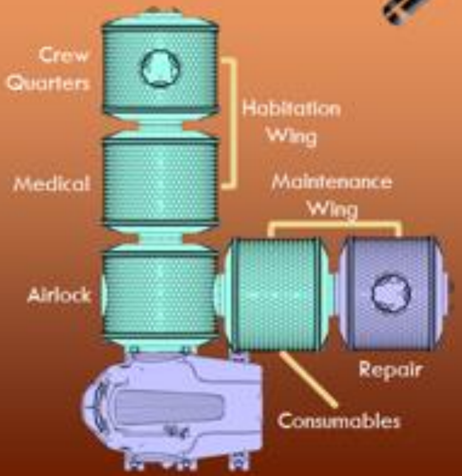
Meets landers and connects power cables

PRESSURIZED ROVER

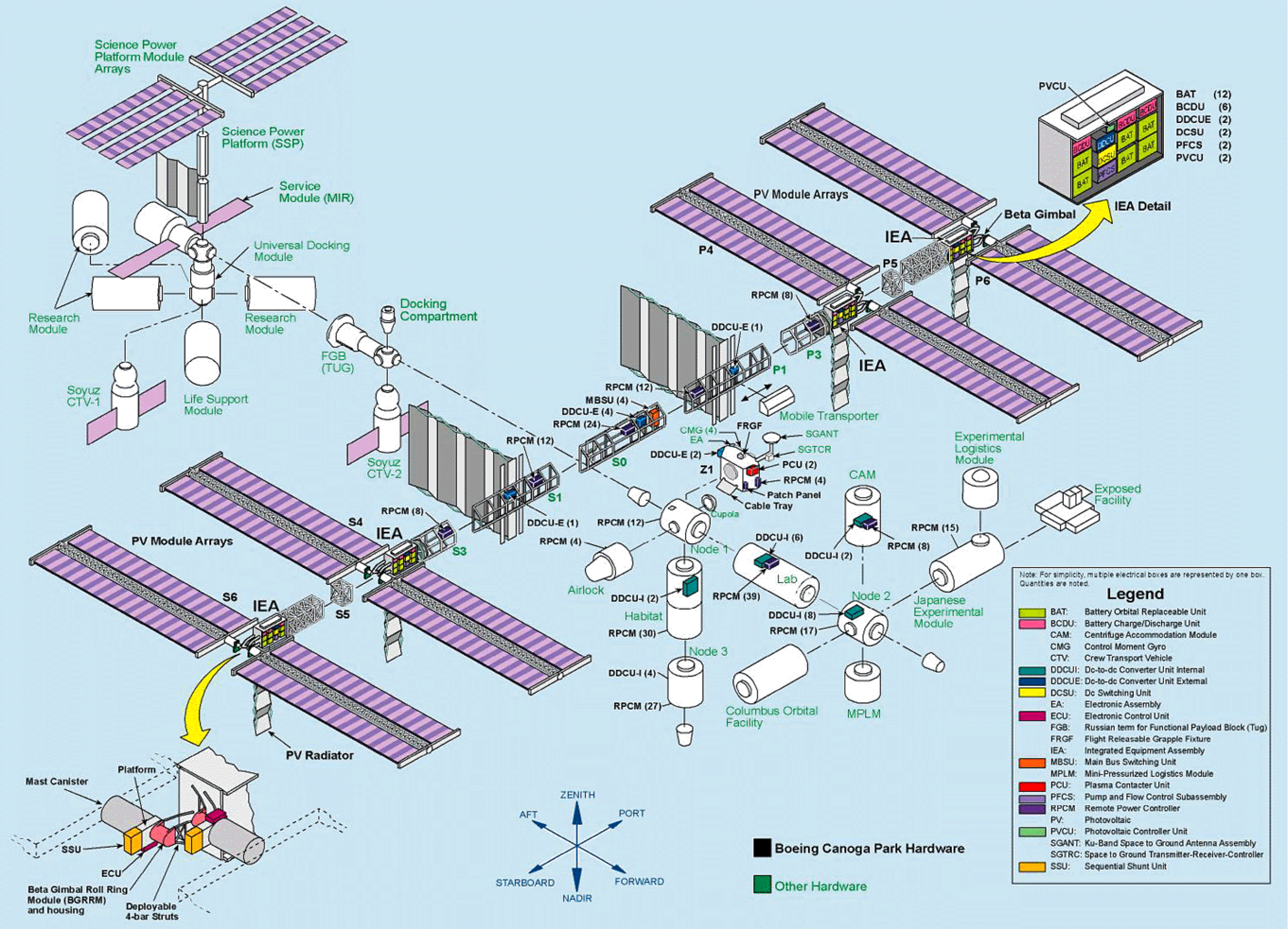
Assists astronauts in covering more ground as they explore the Martian surface. A pair of suitports allows astronauts to exit the vehicle rapidly.

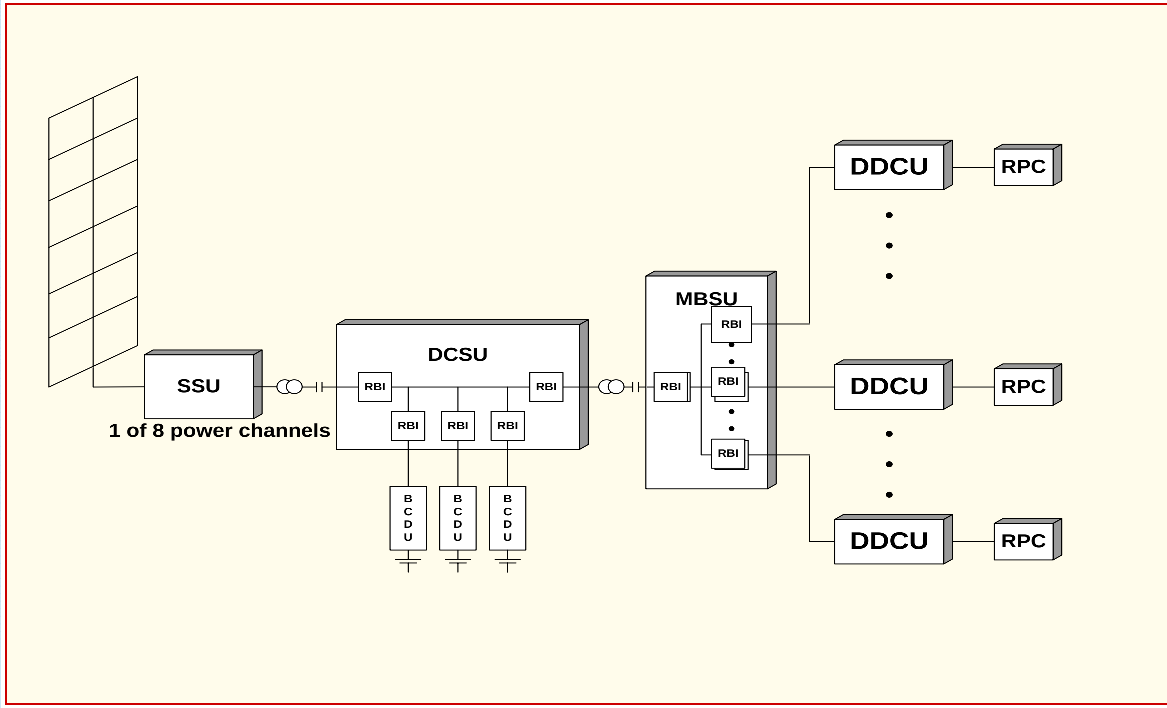
Field Station

Mars surface infrastructure will be built up over the course of multiple expeditions. Starting as a five module outpost with a habitable volume of ~125 cubic meters and growing with each expedition, the Mars Field Station will serve as a refuge and workplace for the first astronauts as they explore Mars.

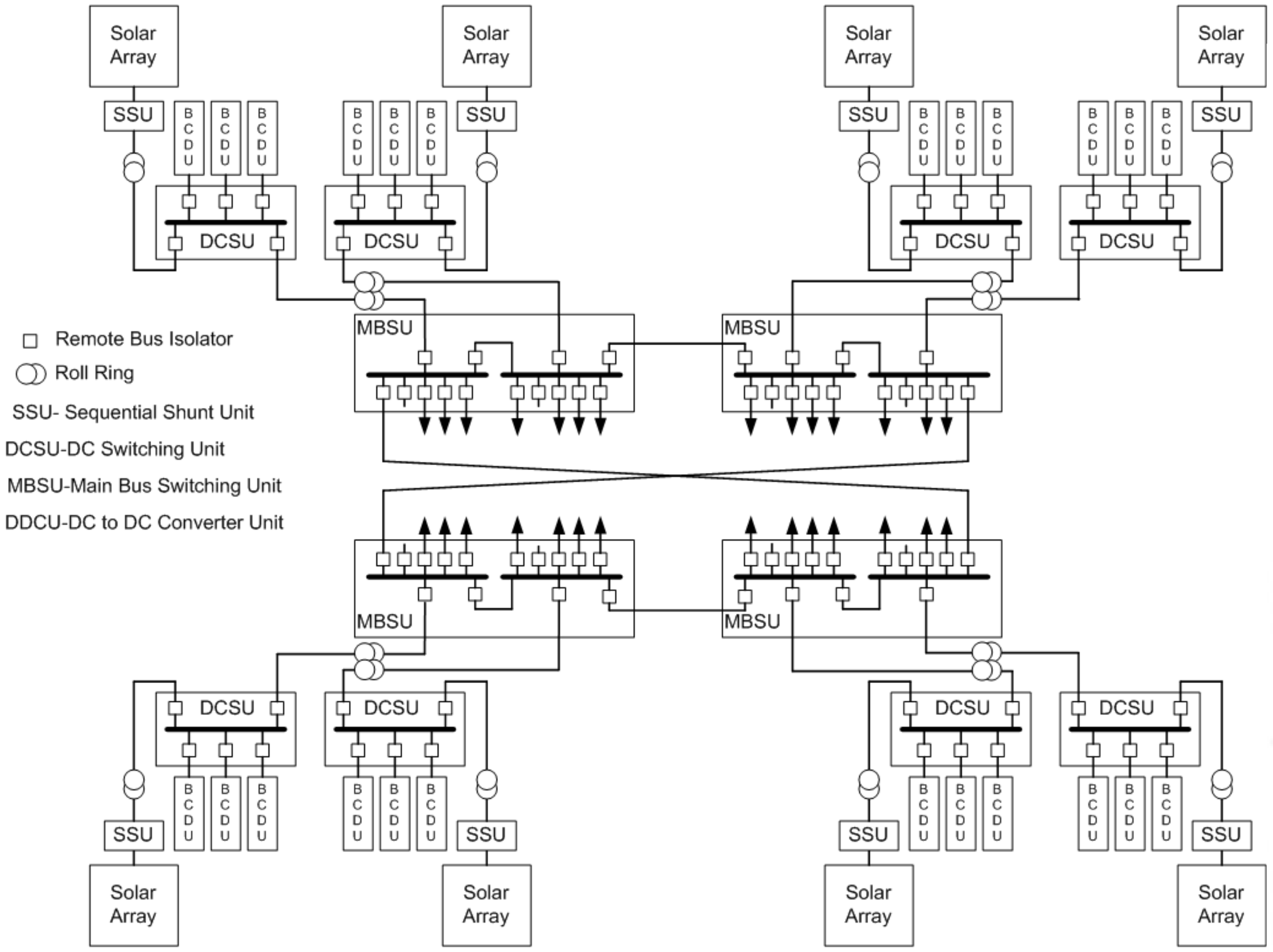


ISS Power Systemary Grid





ISS Power System Grid



☐ Remote Bus Isolator

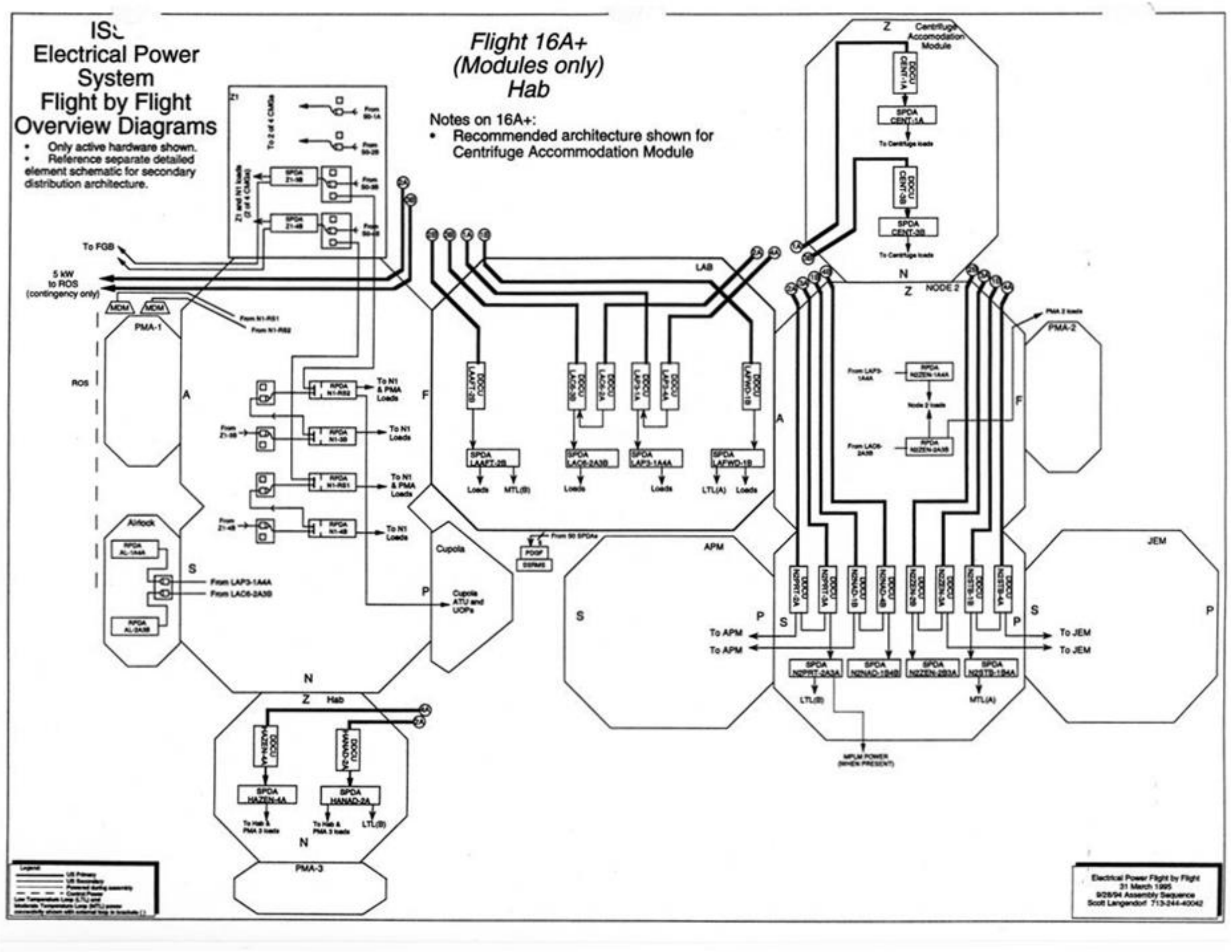
Roll Ring

SSU- Sequential Shunt Unit

DCSU-DC Switching Unit

MBSU-Main Bus Switching Unit

DDCU-DC to DC Converter Unit



Gateway Power System

Simulation Model

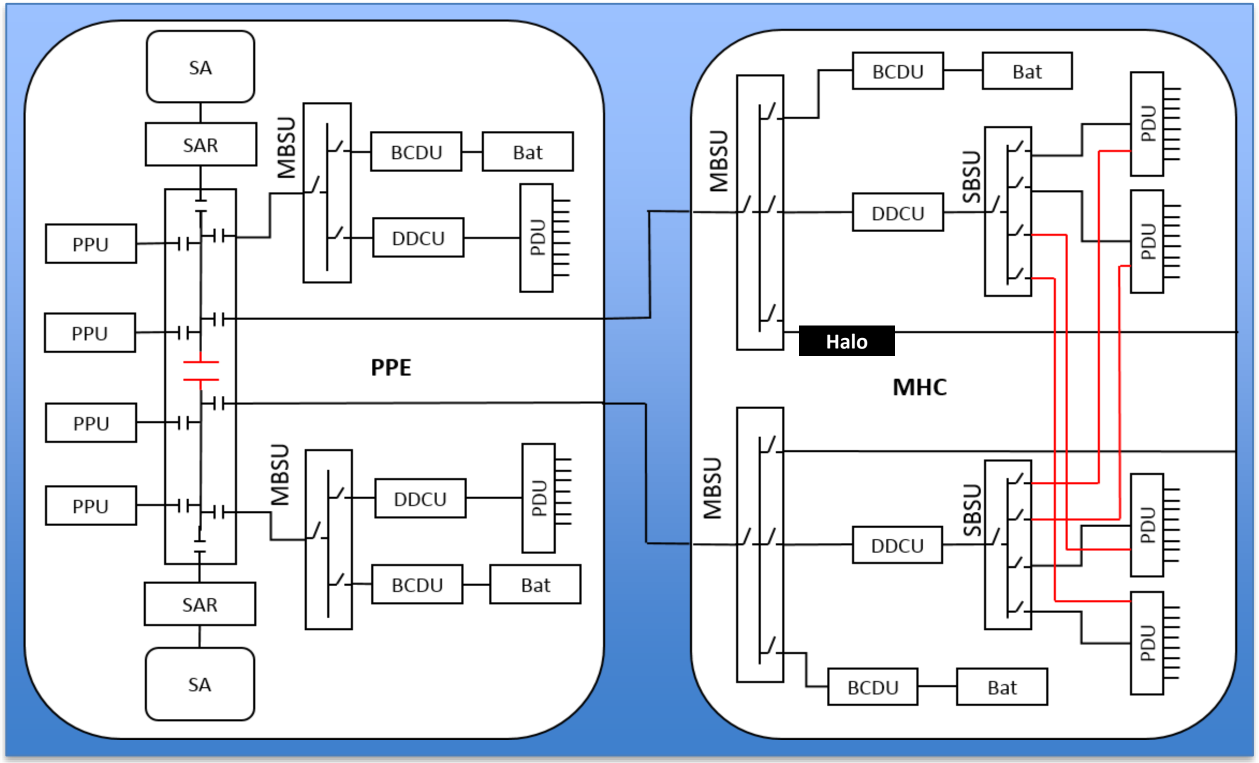
- MATLAB ® Simulink ™ based
- ISS Component Library developed by PCKA
  - On-going effort to update Simulink model for modular hardware.

Gateway architecture presents new challenges for control and integration

- Distributed battery management
  - Uniform battery SOC
- Fault coordination with Bi-directional flow
  - Trip timing changes based on power flow

EPS model integrated into Gateway in a Box (GiaB)

- Allows for in-depth analysis of power system and overall vehicle performance.
- Supports Gateway Level 2 Testing and Verification activities.



<u>Acronyms:</u>
Bat: Battery
BCDU: Battery Charge Discharge Unit
DDCU: DC-to-DC Converter Unit
MBSU: Main Bus Switching Unit
PDU: Power Distribution Unit
PPE: Power and Propulsion Element
PPU: Power Propulsion Unit
SBSU: Secondary Bus Switching Unit

Heritage Power System Control

- Analog controls for regulators and switchgear (I^2t, It)
- Nominal and Off-nominal P.Q. standards
- Power generation with field excited synchronous generators
- Separate control for real and reactive power
- Limited energy storage, but mechanical energy storage with rotating inertia and spinning reserve

- Aircraft and spacecraft followed terrestrial power systems
- Desirable power system attributes include: Power generation growth, Reliability, Safety, Interoperability
- Each desirable attribute has down-side including: Sensitive to diverse power generation, Large generation margins, Peaking inefficiency, Intensive operator involvement

Lunar Surface Technology Research (LuSTR)

University-led efforts to develop and mature technologies that address high-priority lunar surface challenges

Technical Characteristics:

- Unique, disruptive or transformational lunar surface technology development: *in situ* resource utilization, sustainable surface power, extreme access, extreme environments, surface excavation and construction, and lunar dust mitigation
- Low to mid Technology Readiness Level (TRL): TRL 2-5
- Post-award infusion opportunities

Eligibility

- Organization submitting proposal must be an accredited U.S. university
- PI must be a professor at the submitting university; co-Is are permitted
- ≥ 60% of budget must go to accredited U.S. universities
- Up to 40% paid teaming with other universities, industry and non-profits encouraged

Award Information

- Expected duration: **2 years**
- Anticipated awards (inaugural solicitation): **10-15 awards** valued at up to **$1-2M** each
- Oversight: Annual reviews and semi-annual briefings at LSIC meetings
- Award instrument: Grants
- Release Date: **July 15, 2020**

LuSTR Opportunities

For its inaugural release, 4 of 6 LuSTR topics fall under Sustainable Power!

Key Dates	
Solicitation Release	07/15
NOIs due	08/12
Proposals due	09/09
Selection Notification	Feb 2021
Award Date	May 2021

The Solicitation: https://tinyurl.com/NASA-2020LuSTR
Email questions to: hq-LuSTR@mail.nasa.gov

Topic	Area	Description
Flexible Power Distribution for Difficult-to-Reach and Mobile Applications	Sustainable Power	The goal of this topic is to promote the development of wireless energy transmission technologies to enable exploration in environments where conventional means of power generation, storage, and distribution are impractical.
Advanced, Radiation-Tolerant Power Electronics	Sustainable Power	The objective of this topic is to enable the reliable insertion of silicon carbide power components into lunar surface applications while withstanding the hazardous space radiation environment.
Low-Temperature Batteries	Sustainable Power	The objective of this topic is to provide reliable, high-performing primary and secondary battery technologies for sustained operation in low-temperature lunar conditions.
Advanced Power System Control for Interoperability	Sustainable Power	The objective of this topic is to develop the advanced power control technologies needed to enable the operation of interconnected systems with distributed and diverse energy sources.

LuSTR Topic 6 - Advanced Power System Control for Interoperability

Objective : Power control technologies and methodologies to enable interoperability of microgrid systems with diverse source and storage subsystems, formed through performance specifications that reduce reliance on static criteria and rigid compliance enforcement.

- Power control technologies and methodologies for regulators and interface converters that enable integrated and collaborative versus competitive control.
- Power control technologies that adapt to changing system operations providing a continuous system specification. This would include operation during degraded system conditions such as safe return after loss of mission continuity (Lazarus mode).
- Power control technologies and methodologies that utilize an integrated approach for system protection using regulators to reduce fault energy and provide fast detection, isolation, and reconfiguration of electrical network elements.
- Power control technologies and methodologies to reduce the influence and destabilizing effects of nonlinearities such as constant power, change to constant current, and fold back, and system bifurcation modes.
- Power control technologies to enable federated control methods to increase system reliability and mission success.
- Power control methodologies employing digital twin technologies to enable diagnostic, prognostic, and contingency analysis for autonomous power system operation.

LuSTR Topic 6 - Advanced Power System Control for Interoperability

Power control technologies and methodologies for regulators and interface converters that enable integrated and collaborative versus competitive control

- Analog control provides only ability to specify static definition for regulator control to achieve system stability
- Static definition forces competitive nature of current power system control methods
- Digital control changes perspective enabling dynamic and adaptive methods
- Data architectures provide infrastructure to enable collaborative control

Power control technologies that adapt to changing system operations providing a continuous system specification. This would include operation during degraded system conditions such as safe return after loss of mission continuity (Lazarus mode).

- Load management, dynamic/adaptive regulators and switchgear provides specification opportunity to rethink degraded system operation
- Power Quality standards need to enable energy extraction to provide continuous system operation even under worst case conditions (Lazarus mode).
- Power electronics drives most loads (motors, etc.) providing ability to tailor operation as system degrades

LuSTR Topic 6 - Advanced Power System Control for Interoperability

Power control technologies and methodologies that utilize an integrated approach for system protection using regulators to reduce fault energy and provide fast detection, isolation, and reconfiguration of electrical network elements.

- DC systems with active rectifiers or power converters provides capability to rethink approach to fault current management
- AC systems with doubly fed electric generators provides similar technology benefits to AC systems to enable new approach to fault current management and multiphase AC benefits
- Adaptive and digital switchgear provides ability to have fast detection with integrated control of sources to limit fault current energy
- Differential zones for hot and return provides fast detection and isolation for all but in-line failures

Power control technologies and methodologies to reduce the influence and destabilizing effects of nonlinearities such as constant power, change to constant current, and fold back, and system bifurcation modes.

- Power electronics at source, interface, and loads, with digital control, provides ability to rethink approach to managing system nonlinearities
- Energy based understanding of power electronic control for specification enables integrated design of distributed energy storage to enhance system control and stability
- Active and digital control enables negation of negative impedance and ability to control bifurcations under all operating conditions

LuSTR Topic 6 - Advanced Power System Control for Interoperability

Power control technologies to enable federated control methods to increase system reliability and mission success.

- Dynamic and adaptive control needs to have inherent ability to manage faults and failures within the power control data system
- Distributed energy storage for power system provides redundant power capability improving design potential for backup/redundant power to enable distributed and federated control system

Power control methodologies employing digital twin technologies to enable diagnostic, prognostic, and contingency analysis for autonomous power system operation.

- Adaptive and dynamic control will require the ability to understand system degradation for N-X conditions to enable fast reconfiguration without operator intervention
- Spacecraft, more electric propulsion for aircraft, and future terrestrial microgrids will be expected to provide continuous operation without operator oversight
- New autonomous operation for all power applications will need understanding of digital twin incorporation of technology data, design data, manufacturing data, and operational data to provide digital twin performance for control