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Megawatt HVDC Cable Power-Density Considerations for the Moon and Mars

NASA will soon be implementing a long-term presence on the Moon, with housing for 100 or more astronauts, and Mars will likely be next in the future.

Mankind will soon begin a long-term human presence on the Moon, which will initially involve housing more than 100 astronauts indefinitely. Artemis I was the first in a series of increasingly complex missions that will enable human exploration on the Moon and future missions to Mars. Let's examine Artemis II.

The Artemis II Power System

Lunar research, human habitation, and technological operations—this effort must endeavor to create advanced, adaptable, and reliable power solutions on the lunar surface projected to reach megawatt (MW) levels.

In a future mission, four astronauts will circumnavigate around Earth's Moon, on a deep space quest leading to a

The Artemis II crew is shown inside the Neil Armstrong Operations and Checkout Building at NASA's Kennedy Space Center in Florida, standing in front of their Orion crew module on Aug. 8, 2023. From left: Jeremy Hansen, mission specialist; Victor Glover, pilot; Reid Wiseman, commander; and Christina Hammock Koch, mission specialist. (NASA/Kim Shiflett) long-term presence. The four NASA astronauts, Reid Wiseman (Commander), Victor Glover (Pilot), Christina Koch (Mission Specialist), and Jeremy Hansen (Mission Specialist), will make a 10-day trip that will challenge their journey, paving the way for further lunar surface missions *(see figure)*.

Power Density with Megawatt HVDC Cables for the Lunar surface

Power density, with affordable, bipolar, MW HVDC power cables below the lunar surface, must first deal with cable electrical insulation challenges. These power cable voltages, at ±10 kV, are intended to transfer power at two different levels:

- High power (1 MW)
- Medium power (500 kW)

These specially designed cables are expected to be a viable solution for power transmission on the Moon, since they're capable of functioning effectively under harsh lunar environment conditions.

Three locations are optimal for power lines on the Moon's surface: above the surface; on the surface; and below the surface. The first two possible location methods will limit the effectiveness of power transfer on the Moon. The third location method of underground deployment offers both safety and convenience.

COMSOL Multiphysics software, for example, offers a way to design and assess affordable bipolar HVDC cables for power transmission below the lunar surface with an emphasis on its electrical insulation difficulties. At a voltage level of up to ±10 kV, these cables are intended to transfer power at medium power (500 kW) and high power (1 MW). Ultimately, such cables offer a viable solution for power transmission on the Moon.

In addition, the extreme lunar environment is characterized by factors such as:

- Temperature variation
- Micrometeoroid bombardment
- Ionizing radiation

The first two factors limit the effectiveness for power transfer on the Moon.

Mars Presents a Challenging Surface Power Generation Task

In the future, Mars astronauts will experience challenges trying to discover adequate energy for systems necessary to sustain a productive and healthy visit to the planet's surface. On top of that, when the astronauts complete their exploration, they must lift off from the surface of Mars and enter into a safe orbit that can take them home to Earth.

Mars will need high-energy-density nuclear power, either a Curiosity Rover-style radioisotope power system or fission systems, which will not be too affected by day/night cycles or even weather, and the fact that it's packaged well in a volume-constrained spacecraft.

However, current radioisotope power-system designs will only provide a few hundred watts, though they may be applicable to smaller power load applications. Higher-power crew life support or ascent propellant manufacturing needs will need fission surface power, which is scalable.

Solar power is quite limited on Mars. To address this, NASA and the Department of Energy (DOE) are collaborating on the development of a 40-kWe (1,000 W of electrical power) fission surface power system for a demonstration on the moon by late 2020s. Extensibility to Mars missions will benefit from this as well.

NASA is looking beyond solar panels. There are two other major types of solar power:

- Concentrating solar power (CSP)
- Space-based solar power (SBSP)

CSP employs mirrors that concentrate the Sun's energy to heat water or other working fluids. Generally, utility-scale CSP has difficulty in gaining traction in global energy markets because of high cost or relative plant complexity. However, solar hot water is widely used in distributed applications globally.

Utility- or industrial-scale CSP may be a challenge on Mars due to the harsh operating environment, but it could be relatively good to manufacture using local materials. Solar hot-water systems may be used to support thermal management with much less complexity.

SBSP is a proposed technology solution for terrestrial energy markets, which could use solar panels in space that will generate electricity—even during atmospheric or nocturnal conditions. It would beam the energy to Earth's surface using microwaves. Though this technique is still in the R&D phase on Earth, it may make sense for Mars, especially for the higher northern latitudes. If we select optimal orbits, SBSP could lead to year-round solar usage for most locations. Nevertheless, dust might still pose a challenge, especially with receiving equipment on the surface.

Mars Dust Storms

Dust storms on Mars range from small, local "dust devils" to harsh regional storms covering thousands of square kilometers. Mars has global dust storms that encircle the planet and can last for weeks or even months.[3]

Since the atmosphere is so thin and dry, it will take much longer for fine dust particles to settle out of the atmosphere. This will place solar-array-powered systems at particular risk.

Data collected by the Mars Opportunity rover, in its fatal encounter with a global Mars dust storm in 2018, proves just how quick and furious the weather can change: from clear skies to as dark as the Opportunity had ever previously recorded (4.9τ), within three Martian sols (a solar day on Mars). There was a virtual blackout of 4 sols after this occurrence—the Curiosity rover, on the other side of Mars, experienced powerful optical degradation. Curiosity's radioisotope nuclear power system wasn't overly affected by that storm, as it still kept transmitting data to Earth.

The Exploration Systems Development Mission Directorate (ESDMD)

The ESDMD manages and defines systems development for programs that are highly critical to NASA's Artemis program. The ESDMD is planning for NASA's Moon to Mars exploration approach. The ESDMD manages the human exploration system development for the lunar orbital, lunar surface, and Mars exploration.

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