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Electricity Generation & Power Distribution on Moon & Mars

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ABSTRACT

Energy systems that are dependable and efficient are essential as interest in sustaining human presence and exploration on these celestial bodies grows. The study examines several energy-generating techniques, such as nuclear power, solar power, and possibly ground-breaking technologies like regenerative fuel cells. Problems unique to each environment are covered, including radiation exposure and dust buildup on solar panels, along with possible solutions. Space engineers work on satellites, the exploration system, and the conceptual design of space habitats for interplanetary missions. In those missions, the state of the art depends on solar panels connected to batteries for power storage or radioisotope thermoelectric generators, both of which have drawbacks. For example, the efficiency of the solar panel's energy collection decreases when a spaceship moves away from the Sun. Moreover, the performance of solar arrays is negatively impacted by the unpredictable degradation of individual solar cells at temperatures below -100°C. In order to support crew members and make use of in-situ resources, future human exploration missions to the moon and Mars will need a new generation of power sources. Long-term human missions to the lunar and Martian surface are probably going to involve pressurized rovers, large-scale landers, crew homes, and in-situ propellant manufacturing plants.

Keywords: Traditional Power Generation Method, Mars Surface Power Generation Opportunities, Risk Analysis

INTRODUCTION

Maximizing the use of indigenous resources on the Moon while reducing the number of supplies that must be brought from Earth will become crucial to ensuring sustainability in our upcoming lunar expeditions. It will be crucial to construct adequate energy generation and storage facilities on the Moon for the Moon from the Moon in terms of lunar infrastructure development. The requirement for a delta-v of 3.3 km/s for launch from the lunar surface to geostationary equatorial orbit (GEO) around Earth places a premium on sourcing propellant/oxidizer from lunar resources to return humans and cargo to Earth and lower the cost of human missions.

The moon's south pole offers various benefits over other locations, making it the perfect place for a lunar settlement. It is said that colonists on the south pole can enjoy year-round sunshine (which means they can generate power and experience minimal temperature fluctuations), permanent visibility to Earth (which means they can communicate from the surface continuously), and exciting resources like water ice, regolith, and other building materials like FeO, SiO_2, and TiO_2.

On the other hand, the first human explorers will have to overcome the difficulties of getting to and landing safely on Mars before tackling the problem of obtaining enough energy to run the systems necessary for both their ascension back into orbit and a healthy and productive stay on the planet. Depending on the length of time each crew intends to spend on Mars, the goals of their surface mission, and the support services their surface and ascending vehicles will need, surface power requirements may differ from one human Mars mission to the next.

More recently, manned missions to Mars have been discussed by NASA, various national space bureaucracies throughout the world, foundations, and other organizations. Power generation will be one of the main issues that must be resolved for any future human colonies on Mars. "Ion harvesting" is taken into account as a power source in this report. The terms "ion harvesting" and "ion power" here allude to the use of electricity generated by the Mars Global Electric Circuit (GEC) or charge separation during dust storms.

The 21st century has seen a significant increase in the need for power due to advancements in technology. There are many different ways to generate electricity to fulfil the growing demand for electricity from the world's population, and nuclear power plants are the least expensive option [1]. yet, "There are at present serious doubts that nuclear energy can be relied upon to fill a continuously larger percentage of energy requirements since there are no known ways as yet to provide complete insurance against environmental pollution by nuclear energy plants [2].

The Traditional Power generation Method

When fossil fuels burn, the conventional way of producing power releases a lot of carbon dioxide [3]. Contemporary nuclear, photovoltaic, wind, hydro, and other power plants are examples of alternative techniques. When combined, they can produce and supply power to much of the planet continuously.

In 2020, the global output of electricity reached 26,823.2 terawatt-hour, meeting the needs of both families and business. Along with other greenhouse gases, 32,284.1 million tonnes of carbon dioxide were released during production [4]. The ozone layer surrounding the Earth is seriously harmed by these substances. causing the temperature to rise daily as a result. As a result of the growing need for renewable energy, numerous nations and companies have increased their solar energy plant construction quickly.

Key points to the power generation subsystem are as follows:

- Investigating and evaluating the energy source(s) at the South Polar Region of the Moon.
- Create an ISRU-compliant power generation system that is doable and satisfies the SMART criteria (Specific, Measurable, Attainable, Realistic, and Trackable).
- Create a primary and backup system that can supply the manned base with a steady supply of electrical energy.
- Reduce the transfer losses that occur during the production and transmission of power by optimizing the power budget and efficiency.
- Create a system that is small, scalable, simple to start up, and easy to use for greater comfort and ease of access.

Moon

In order to investigate and establish a permanent habitat station for future interplanetary travel, the Moon is crucial. In an effort to find water, the People's Republic of China, the Russian Federation, the United States of America (USA), and the Republic of India launched rovers to the Moon's surface. Of these, Moon Mineralogy Mapper (M3), a component of Chandrayaan-1, was able to find OH/H2O on the Moon's top surface [5]. These data indicate that the polar regions and craters are the most Livable areas on the Moon. The majority of craters, however, remain only in the shadowed areas for a few months at a period, if not permanently.

As a result, the crater's temperature is lower than that of other areas of the surface. Using the Lunar Exploration Neutron Detector (LEND) on the Lunar Reconnaissance Orbiter (LRO) spacecraft, which collected data to be sent back to Earth, the Lunar Crater Observation and Sensing Satellite (LCROSS) mission was designed to determine the concentration of hydrogen. The South Pole of the Moon has the highest hydrogen concentrations, with estimates of 0.5 to 4% water in the form of ice based on measurements gathered in the Cabeus crater using an impactor [6].

Mars

Operational difficulties on Mars are much more severe than those on the Moon. The solar system's fourth planet is called Mars. The solar irradiance on Mars is roughly 590 W/m2, and the photonic energy on the surface and in orbit is much decreased because of the planet's distance from the Sun, which is approximately 210.96 million kilometers. Furthermore, the PV cell's peak power generating period is limited to two hours. For this reason, the majority of Mars missions depend on RTG, which provide enough power to power the avionics of tiny research-based rovers or landers. For instance, the Multi-Mission RTG (MMRTG) is used by the RTGs on Mars2020's Perseverance rover to supply 110 W for its operations. Because radioisotope is used as fuel, Curiosity uses 100 W, which has a lifespan of 10 to 15 years and a decrease of a few percent annually. Additionally, the solar panels on Mars are often covered by sandstorms, which lowers the rover's power generating efficiency.

MARS SURFACE POWER GENERATION OPPORTUNITIES

Surface Power Generation Technologies

Though Mars faces numerous obstacles, there are promising power generation systems either developed or available. High energy density nuclear power, like as fission systems or radioisotope power systems a la Curiosity rover, package well in volume-constrained spacecraft and are independent of weather or day/night cycles. Even though the designs of contemporary radioisotope power systems only provide a few hundred watts, they might be useful for situations with lesser power loads. Fission surface power is easily adjustable for purposes such as ascending propellant manufacturing or higher power crew life support.

While surface dust removal would not solve the issue of suspended atmospheric dust during protracted storms, limited solar power may be possible if combined with robotic dust wipers, pressurized gases, mechanical array tilting, or electrodynamic or piezoelectric dust removal to clear accumulated dust from the solar arrays. However, this would only be possible for applications that do not pose a risk to crew safety. Mars would require special operating issues to be assessed, such as radiation keep-out or big array off-loading.

Although they are frequently suggested, fuel cells do not trade effectively for mass because they either need the mass of the landed reactant or more energy and mass of production to create reactants in-situ than the fuel cells can offer. Another option for power generation technology is bio generation, which depends on microorganisms to transform organic feedstock directly into heat or another commodity like methane that may then be utilized to generate power.

However, planetary protection limitations may make the introduction of microbes more difficult. Furthermore, because Martian soil contains perchlorates and other chemicals and their byproducts, further safety and processing precautions might be required if feedstock or biomass replenishment entails using Martian soil.

It should be noted that several power systems could be integrated as needed to meet increased power needs, regardless of the power source chosen. This would enable the power system to be customized for a particular mission as more ambitious exploration progresses from more basic beginning efforts.

The Moon as a Testbed for Mars

Due to the Moon's greater vicinity, there is a great chance to test potential Mars surface power generation technology with fewer failure modes. Systems for the lunar surface that are meant to be extended to Mars would have to take into consideration the planet's different environment, which includes its low-pressure atmosphere of carbon dioxide, increased gravity, shortened day-night cycle, decreased solar insolation, wind loads, dust storms, and a greater distance from Earth that means longer communication times between Earth and Mars.

The difficulty lies in maintaining Mars-forward lunar power generation systems without significantly increasing the expense or complexity of the journeys to Mars or the Moon. The use of solar and fission surface power technology in demonstrations could pave the way for the autonomous deployment, landing, maintenance, and continuous operation of power systems in demanding and dynamic situations.

For Lunar Surface Different Technologiesfor Power Generation Based on Different Sources of Power

Nuclear Energy

One benefit of nuclear technologies is their extremely high power to weight ratio. Nuclear power raises safety concerns, but there have been encouraging advancements in this field in recent years. Nuclear systems are now safe, dependable, and economically viable thanks to extensive research and development. NASA's Kilo-Power Project, depicted in Figure 1, is one such device. It is a fission-based nuclear reactor the size of a three-meter garbage container ability to produce 40kW or more.

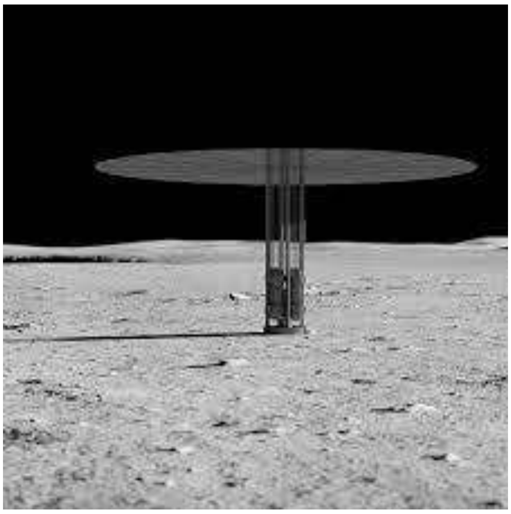

Fig1. The Kilo power Project (NASA) [7].

Nuclear Fusion

Another possibility for producing electricity on the moon is nuclear fusion. The moon, in contrast to Earth, receives a plentiful supply of Helium-3 via solar winds. Fusion is not a technologically feasible option at this time, but it may be in the future. Helium-3 nuclear fusion reactors have the potential to provide extremely efficient nuclear electricity with almost little waste or radiation [8].

Radioisotope Thermoelectric Generator
Another rather safe alternative power generation technology is the thermoelectric generator powered by radioisotopes. The heat produced by radioactive material decay is converted by these generators using a set-o thermocouples. These systems have previously been deployed on a number of deep space missions, including Cassini Huygens [9]. The power generation capabilities of these systems are limited to a few hundred watts, notwithstanding their high level of safety and dependability.

Solar Energy
The Shackleton Crater offers the perfect setting for solar-powered power plants, as was previously mentioned. Solar panels can be used to harness the areas around the crater rim that are always lit to produce electricity. In terms of the resources on the crater, solar energy offers a dependable and safe source of electricity.

Thermoelectric Generator
Another device that can be used to consistently and safely harvest solar energy is a thermoelectric generator (TEG). These generators have an ideal platform thanks to the temperature difference that exists between the crater's sunlit and shaded areas.

Risk Analysis
An important component of any space mission is risk assessments. It assists in locating probable failure points early in the development process and devising countermeasures. The Power Generation sub-system was identified with a number of risks, each of which has a presentation of its mitigation strategies below.

Table 1. Risk Analysis Factor

S No.	Risk	Probability	Severity	Mitigation
1.	Radiation Damage	High	High	Using radiation hardened components and providing shielding for the subsystem
2.	Damage from Micrometeoroids	Medium	High	Shielding using IR Transparent Glass
3.	Sunlight Blockage by Lunar Regolith Deposit	Low	Medium	Setting up Multiple Working Units for Redundancy and Providing Periodic Maintenance for Dust Removal
4.	Eclipse	Low	Low	Using Stored Energy from the fuel cells/battery
5.	System Failure	Low	High	Providing Load Monitors Switching to Backup Power Generation Units

CONCLUSION

To sum up, research into power distribution and generating technologies for Martian and lunar communities is essential to the search for long-term, viable alien life. Using a wide range of technologies, including as solar, nuclear, and maybe geothermal energy, in conjunction with developments in energy storage, smart grids, and in-situ resource utilization, offers viable ways to address the particular difficulties that each celestial body poses. The establishment and long-term sustainability of human presence on the Moon and Mars depend on resilient, scalable, and sustainable energy solutions, which can only be achieved through cooperative efforts between space agencies, commercial businesses, and academic institutions.

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