Niels Clayton
ENGR 201

A Case Study of Surface Power Systems for Martian Colonisation

1. Introduction

The establishment of surface power systems will be an integral part of any manned Martian colonisation mission. This surface power system will provide all of the power that is required to recharge and repair equipment, grow and prepare food, synthesize oxygen for life support and fuel, and ensure a stable climate is maintained within the colony over the two-year re-supply period. This system must encompass a safe and stable power source for the colony, as well as a means of storing excess energy for later use.

This study looks to provide a recommendation on the best possible design of this surface power system, looking at the options of nuclear power reactors and photo-voltaic (PV) solar cells. This will take into consideration the power outputs of the suggested systems, as well as their transport feasibility and any safety considerations that accompany them.

2. Background

In the NASA Design Reference Architecture [1][2], it is estimated that a surface power system built to support a crew of 4 to 6 inhabitants will need to handle a continuous 40kWe load per day/night cycle. Of this load, nominal outpost operation, including habitat maintenance, logistics systems and rovers will account for 12kWe [2]. The remaining 28kWe load will be used to operate In-Situ Resource Utilisation (ISRU) plants, which will convert the Martian atmosphere into 0_2 for use as a propellant, and life support [1][2].

The power system must also be accompanied by a power storage solution, either batteries, or regenerative fuel cells [3], allowing for stable operation of the colony during output power fluctuations. The size of this storage system will be dependent on how reliable the output of the power system is.

All further evaluation and calculations of potential surface power systems will be done based upon these conditions of a continuous 40kWe load and a crew of 4 to 6 people.

3. Solar Based Surface Power Systems

Any implementation of a solar based surface power system will involve a network of individual PV panels chained together. This form of power system is well documented and reliable, being currently used on Martian rovers. Its simplistic setup due to a lack of moving parts, and its safety make it a viable power solution for a Martian colony [1] [3].

Solar based surface power systems do however suffer from a wide range of external factors. These include dust build-up on the panel surface, drastically decreasing panel efficiency. Dust concentration within the Martian atmosphere, limiting the total available light resource, and decreasing solar irradiance. And most importantly, the need for external power storage during the night cycle when the system is inactive [1] [4] [5] [6]. This leads to the system needing a much higher continuous power output of 98kWe per day, in order to achieve the required average output power of 40kWe [1] [3].

3.1. Solar Power System Electrical Storage

Due to this non-continuous, and unstable power output, an external storage system must be employed to provide power during panel inactivity [3]. This storage system will also help lessen the effect that fluctuations in temperature, season, and sun position will have on the output of the PV system, ensuring that the colony will remain powered. The storage system must also have the capacity to support the colony for extended periods of time, as weather events such as dust storms can render the solar power system inoperable [4] [5].

There are two electrical storage systems that are currently under consideration within the NASA Design Reference Architecture, conventional Li-ion batteries, or regenerative fuel cells [1]. Li-ion Batteries feature a mass-specific energy density of 150 Wh/kg and a volume specific density of 270kWh/m^3, while regenerative fuel cells feature a mass-specific energy density of 250 Wh/kg and a volume specific density of 200kWh/m^3 [5].

3.2. Solar Power System Transportation

Due to the requirement of a continuous power output of 98kWe per day, a solar surface power system will require substantial space and have a substantial mass, incurring substantial fuel costs. The NASA Design Reference Architecture 5.0 states that in conditions such as a dust storm, a total mass of 8,000 kg of panels will be required, totaling for a 4,300 m^2 panel area [3]. This large array of panels will also require an equally large power storage system to accompany it.

4. Nuclear Surface Power Systems

Within nuclear power systems, there are two major concepts under consideration by the NASA Design Reference Architecture 5.0, the Pellet Bed Reactor system (PeBR), and the Potassium Rankine System (KRS) [1] [6] [7], the detailed operations of which are beyond the scope of this study. Both systems rely on the production of alpha radiation, which is then absorbed, producing the temperature potential difference required to generate electricity. The most common alpha generating radioisotopes in used are ^{238}Pu and ^{241}Am, due to their long half-life of 87.5 and 458 years respectively [3] [6]. Both systems are also easily scalable between outputs of 10kWe and 100kWe, increasing their versatility.

4.1. Nuclear Power System Transportation

When transporting a nuclear power system, safety of the crew is the major concern. Any sort of nuclear power system will require a large amount of shielding during the transportation to Mars, as well as a large amount of external shielding for the final setup on the Martian surface [3].

Fuel will also need to be included and transported with these systems. The PeBR system has an overall specific mass of 3.29 Kg/kW, the KRS system an overall specific mass between 4-10 Kg/kW [3]. However due to their continuous operation, a nuclear-powered system is only required to output 40kWe per day/night cycle. Because of this, they can afford the lower energy density when compared to a solar array, still outputting the same total power. This continuous output also means that the Nuclear system will require very little external storage in terms of batteries, decreasing its overall mass and volume [4].

4.1. Nuclear Power System Safety

Nuclear surface power systems must be accompanied by an external shield to protect the crew from radiation emitted by the reactor. In the Design Reference Architecture 5.0, a radiation dosage of 5 rem/yr from the reactor is considered to be acceptable [1]. To achieve this while maintaining low mass, semi-circular shaped shield is employed. This will limit radiation in the direction of the colony to the required 5 rem/yr (at 1 km), and 50 rem/ye in all other directions. This will limit the required total mass of the reactor but will also reduce the total habitable area of the colony. It is also advised that the reactor be buried beneath Mars' surface or encased in water, as this will also help with the shielding of radiation. These options will help greatly diminish the radiation output of the reactor [3].

5. Wind Surface Power Systems

Wind based surface power systems are generally not considered to be a feasible approach to the issues of power generation in a Martian environment [1]. When compared to both solar and nuclear based surface power systems, wind lags far behind in both its output and its efficiency [1] [8]. Wind based surface power systems are also bulkier, incurring greater transportation costs [3], and have moving parts which allow after greater points of failure [8]. Because of this, wind-based surface power systems will not be considered for the final recommendation.

6. Recommendations

Based on the information gathered within this study, for a surface power system to be effective and successful, it must be robust. The system should be able to supply the colony with a continuous 40kWe per day/night cycle, while being feasible to safely transport to Mars. To be able to achieve the robustness required by this system, it is recommended that a hybrid photo-voltaic and nuclear system be developed. This system would allow for the use of a solar surface power system initially upon landing, allowing for immediate setup of the colony without having to spend days setting up the nuclear power system. This will increase the safety of crew in the initial landing phase, and during this period it is only required to power the colony, meaning a total load on the panels of 12 kWe. Once the nuclear power system is set up, the required 40 kWe per day/night cycle can easily be established and the operation of ISRU's can begin.

This system will be more reliable and robust, allowing for the possible failure of one of the power systems, without endangering the lives of the crew members. This system will also easily allow for repairs of any damage to either system as there will always be sufficient power to maintain the colony.

References

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