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Power Sources for Rovers

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Abstract: ***Planetary rovers are small unmanned vehicles equipped with cameras and a variety of sensors used for scientific experiments. They must operate under tight constraints over such resources as operation time, power, storage capacity, and communication bandwidth. Moreover, the limited computational resources of the rover limit the complexity of on-line planning and scheduling. The rover requires power to operate. Without power, it cannot move, use its science instruments, or communicate with Earth. The power source aboard the robotic space probe will have to be strong and versatile enough to meet the requirements of the mission. The main source of power for each rover comes from a multi-panel solar array. Their purpose is to provide energy. This paper deals with the use of alternate resources for power supply of rovers other than solar arrays.***

Keywords: Rovers; Power system; Energy; Communication; Alternate resources

1. Introduction

Space Agencies are exploring ideas for future missions to send robotic spacecraft to harsh and distant places that hold great promise for major new discoveries. Landers, rovers, orbiters and flyby craft could be sent on pioneering missions to some of the coldest, hottest, and darkest environments imaginable beyond Earth.

Space exploration missions require safe, reliable, long-lived power systems to provide electricity and heat to spacecraft and their science instruments. Planetary exploration spacecraft and their electrical power sources must be built to withstand extremes in temperature, radiation, pressure and dust that would quickly disable or destroy most hardware and software on Earth. In addition, these spacecraft often must function continuously in such environments, sometimes for many years, to accomplish their goals.

The energy to power systems can be provided by using various energy resources like solar energy, wind energy, hydrogen energy, nuclear energy, geothermal energy etc. This paper describes some of these forms of energies and their shortcomings in space exploration missions due to which the rover becomes dead and is not able to communicate on earth. It also describes the methods by which these shortcomings could be removed and the rover is made more efficient so that sample return can be made possible.

1.1 Solar Energy

Solar energy is most widely used to power rovers and spacecrafts. As the heat of the sun is most widely available in Terrestrial planets (Mercury, Venus, Earth, Mars). So, the spacecrafts and rovers sent to these planets can use solar energy by implanting solar cells and arrays. Rovers like Spirit, Opportunity, Phoenix, Mars exploration rover etc used solar power.

The advantages of solar power are its renewability (as compared to a primary battery), its low cost, and availability of sun for charging batteries in Terrestrial planets.

1.2 Wind Energy

One of the alternate for rover is the use of wind energy to generate power for the functioning of rover. A wind turbine is a device that converts kinetic energy from the wind into electrical power. The speed of wind on planets like Mars and Jovian gas giant planets (Jupiter, Saturn, Uranus, and Neptune) is high enough to produce energy needed by the rover.

1.3 Geothermal Energy

Geothermal energy is thermal energy generated and stored in the Planet. Thermal energy is the energy that determines the temperature of matter. The geothermal energy of the Earth's crust originates from the original formation of the planet (20%) and from radioactive decay of minerals (80%). A Planet's internal heat is thermal energy generated from radioactive decay and continual heat loss from its formation.

1.4 Nuclear Energy

Radioisotope Power Systems (RPS) are long-lived sources of spacecraft electrical power and heating that are rugged, compact, highly reliable, and relatively insensitive to radiation and other effects of the space environment. This makes them an excellent option to produce power or heat for a variety of potential missions to some of the most extreme space and planetary environments in the solar system.

1.5 Hydrogen Fuel Cells

A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent. A fuel cell combines hydrogen and oxygen to produce electricity, heat, and water. The fuel cell will produce electricity as long as fuel (hydrogen) is supplied.

Fuel cells, consist of an anode, a cathode and an electrolyte that allows charges to move between the two sides of the fuel cell. Electrons are drawn from the anode to the cathode through an external circuit, producing direct current electricity.

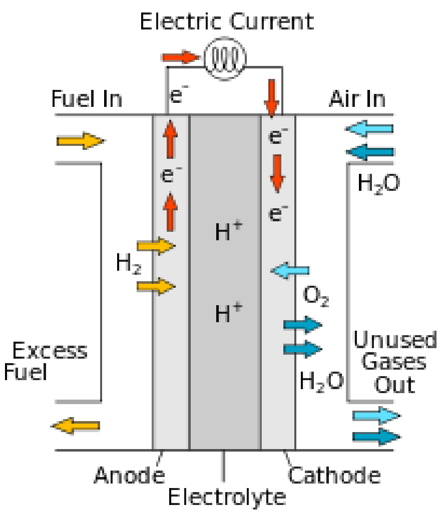

Figure 1

2. Related Work

A lot of research in the area has been taken up so as to develop an efficient source of power for rovers. Some of the work which has contributed for the enhancement of power sources is discussed here:

Kennith A. Bruke discussed in his paper about fuel cells. According to his work Fuel cells can provide "added value" as energy storage devices for space science missions. This added value could take the form of mass savings, volume savings or more power or energy at the same mass and volume.

The current fuel cell technology development emphasizes high-power and high-energy applications. A new fuel cell development thrust is needed for applications that are "power dense" and "energy dense". Space science and terrestrial applications that currently use high energy batteries (either primary or secondary) could potentially use these kind of fuel cells. Generally, the power levels and energy levels need to be scaled down by one or more orders of magnitude for these new fuel cell applications [3].

Gerald Halpert, Harvey Frank, and Subbarao Surampudi discussed about batteries and fuel cells. According to them Planetary landers require rechargeable batteries that can provide high specific energy (> 100 Wh/kg) and long active shelf life (> 10 months). In addition, these batteries must be capable of operating at temperatures as low as -40°C. Cycle life requirements of these missions are modest, less than 300 cycles, at moderate depth of discharges. Ag-Zn batteries manufactured by BST were used in the Mars Pathfinder mission. Li-ion batteries are being considered for future Mars Landers.

Battery requirements for planetary rovers are similar to those of the landers. Silver-zinc batteries were used on the Moon Rover vehicle. The Sojourner (Mars Rover launched along with the Mars Pathfinder) employed primary Li-SOCl2 batteries manufactured by SAFT. Low temperature rechargeable Li-ion batteries are being developed for future Mars Rovers.

Planetary probes require primary batteries that can provide high specific energy and energy density and possess long active shelf life (six to eight years). In addition, some of the missions require batteries to operate at temperatures as low as -80°C and withstand 80,000 G shock/acceleration. Li-SO2 batteries were used for the probe on the Galileo mission to Jupiter. The probe of the Stardust mission has also employed Li-SO2 batteries. Li-SOCl2 batteries, capable of operating at -80°C, were used on the two penetrators that were launched along with Mars 98 spacecraft [2].

Matt Roman, David P. Miller, and Zac White did a field experiment to test rover for its functionality and power. The result was that the current system allowed the rover to operate for about three hours. Late in the day the rover would become starved for power because the batteries had been drained making it difficult for the rover to climb over rocks. It is apparent that the batteries were being used as the primary power source. While in the field, the surface of the solar panel was approximately 30’C higher than originally planned for. The average power output of the panel was less than 35 watts. The lack of power from the solar panel is due to the decrease in voltage as the solar cells heat up. In the event that the voltage dropped too low the rover put itself into sleep mode without any complications [4].

3. Existing Power Source Used in Rovers

The rovers designed today are experimented with different forms of energy sources. Some of which are successful while other are not able to meet the expectations. Some of the energies used in existing rovers with the shortcomings in their power system are discussed here.

3.1 Solar Energy

Rovers like Spirit, Opportunity, Phoenix, Mars exploration rover etc used solar power. When fully illuminated, the rover solar arrays generate about 140 watts of power for up to four hours per sol. The rover needs about 100 watts to drive. The power system for the Mars Exploration Rover includes two rechargeable batteries that provide energy for the rover when the sun is not shining, especially at night. Over time, the batteries will degrade and will not be able to recharge to full power capacity. Also, by the end of the 90-sol mission, the capability of the solar arrays to generate power will likely be reduced to about 50 watts of power due to anticipated dust coverage on the solar arrays (as seen on Sojourner/Mars Pathfinder), as well as the change in season. Mars will drift farther from the sun as it continues on its yearly elliptical orbit, and because of the distance, the sun will not shine as brightly onto the solar arrays. Additionally, Mars is tilted on its axis just like Earth is, giving Mars seasonal changes. Later in the mission, the seasonal changes at the landing site and the lower position of the Sun in the sky at noon than in the beginning of the mission will mean less energy on the solar panels.

3.2 Shortcomings

The batteries will degrade overtime and will not be able to recharge to full power capacity. If rovers are solar powered, they must land and operate within a fairly narrow latitude band near the equator where enough sunlight shines to provide adequate electricity. Further, the sand storms, dust storms, unavailability of sun, landing rovers in colder regions of planet etc makes the use of solar power inappropriate. And it appeals for the search of alternate sources of power.

Using solar power limits the places on Mars and other planets especially Jovian planets (Jupiter, Saturn, Neptune, and Uranus) that landed rover missions can explore. They are restricted to landing and travelling around the equatorial region where they can get enough sunlight to re-energize their batteries. For future missions, alternate power sources are being considered to increase the area that might be studied, opening up the whole planet to exploration.

3.3 Nuclear Energy

Radioisotope Power Systems (RPS) are long-lived sources of spacecraft electrical power and heating that are rugged, compact, highly reliable, and relatively insensitive to radiation and other effects of the space environment. A flight-proven capable source of power is the Radioisotope Thermoelectric Generator (RTG)–essentially a nuclear battery that reliably converts heat into electricity.

RTGs work by converting heat from the natural decay of radioisotope materials into electricity. RTGs consist of two major elements: a heat source that contains plutonium-238 (Pu-238) and solid-state thermocouples that convert the plutonium's decay heat energy to electricity. Plutonium-238 (abbreviated as Pu-238) was selected as the heat source to power these missions by the Department of Energy (DOE), which develops and provides RPS to NASA for use in space exploration. Plutonium-238 is a special material that emits steady heat due to its natural radioactive decay. Pu-238 is an ideal radioisotope fuel for RPS applications because it generates heat that declines in output by only one half after 88 years. As a result, the ability of an RPS to produce electricity decreases slowly in a highly predictable manner; today the typical RPS is designed for at least 14 years of operation. This allows deep space missions to function for extremely long durations in places where alternatives such as solar panels would be impractical or ineffective. Pu-238 also has a high heat density, which means that heat sources can be made compact and that the fuel transfers its heat effectively to power conversion devices and heater units.

4. Proposed Work

My work shows the use of alternate sources of energy for rovers so that the rovers may be able to explore a celestial body for longer period of time and may be able to give more information about the planets. As, the cost involved in space missions is very high so reliable and efficient sources of power are required which lasts for longer period of time. Some of such power sources which may be used in future can be thought upon.

4.1 Wind Energy

A wind turbine is a device that converts kinetic energy from the wind into electrical power. The speed of wind on planets like Mars and Jovian gas giant planets (Jupiter, Saturn, Uranus, and Neptune) is high enough to produce energy needed by the rover.

The speed of wind on Mars ranges from 10 mps to 30 mps or 20 miles/h to 60 miles/h. Currently, the windmill employed on Earth produces 70% of energy at 12 mph and the power produced by windmill is 250 W to 1.8 MW. On Jovian planets like Neptune the speed of wind is 1,100 kph to 2,100 kph. The rover needs 140 W of energy to operate. So, windmill employed on rover can complete its power requirements.

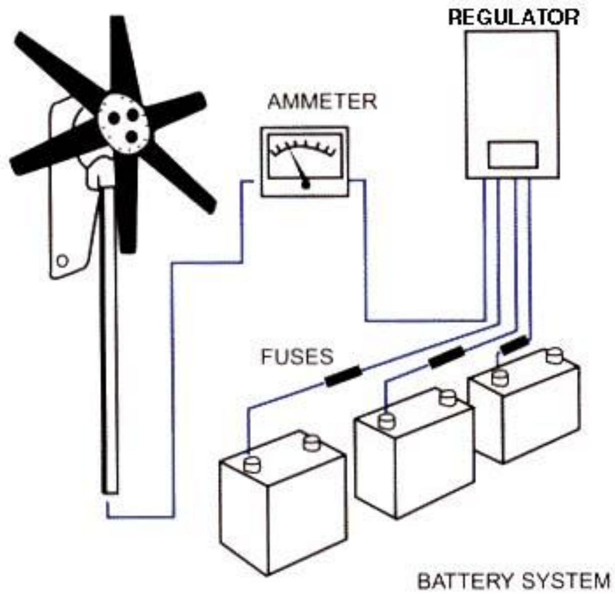

Figure 2

4.2 Proposed Working

The windmill could be placed on the back of the Rover. The wind energy will turn the blades of the windmill around the rotor. The rotor would be connected to the main shaft, which would spin a generator to generate power. This generator would be connected to battery which will store power generated.

The main purpose here would be to connect the rover to a solar cell as well as battery, and the energy generated by the solar cell could be used as and when sun is available, simultaneously generating the energy by the wind mill that could be stored, so as to be used at that time when there is no sunlight. In this way the efficiency of the rover could be increased.

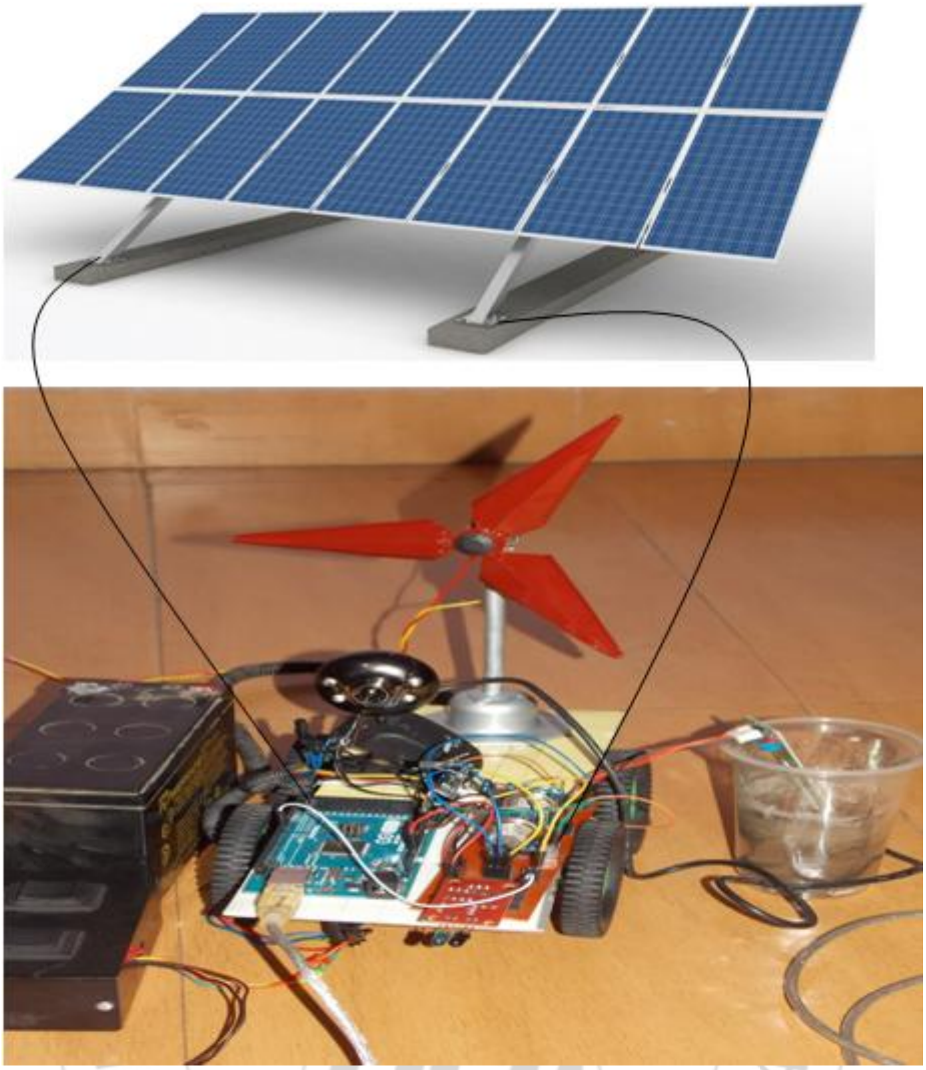

Figure 3

To prevent damage, the windmill could be made so as to stop functioning when the speed of the wind exceeds 25 mph. Rover can be installed with small windmill which can generate energy and at the same time it may not interfere with the working of rover because of its weight or other constrains. As, the speed of the wind is more than 25 mph, so, the wings of the windmill must be strong enough to tolerate the pressure of the high speed wind. So, small changes made in the windmill can be helpful and installing it on rovers, can act as a good alternate source of energy for rovers.

If this technology is successfully implemented, then it could save a lot of energy and money spent in sending the rovers again and again over the planet's surface to do research and in near future sample return projects may also be possible. Scientists may also be able to carry out manned space missions and to establish colonies on Mars. Windmills can also be thought of as the best technologies to be implied on planet's surface to generate power.

4.3 Geothermal Energy

Geothermal energy is thermal energy generated and stored in the Planet. A Planet's internal heat is thermal energy generated from radioactive decay and continual heat loss from its formation.

The energy is generated by Power plants. Power plants need steam to generate electricity. The steam rotates a turbine that activates a generator, which produces electricity. Geothermal power plants, use steam produced from reservoirs of hot water found a couple of miles or more below the Earth's surface.

In future when humans will think of setting up colonies on other planets then geothermal power plants can be set up to satisfy the energy needs. Various planets which are a platform for setting up geothermal power plants are:

Mars

Upon first glance, the surface of the red planet appears to be dead. While boasting the largest volcanoes in our solar system, the crimson globe apparently changes little, aside from a "global-cane" that covers the surface every six (earthen) years.
The Martian depths may be more active than we think beneath the surface, as its semi-active core may be generating a "lumpy magnetic field" that barely pops up above the surface.

Mars also is known to host geysers in its southern pole, which may indicate that the red planet may a lot warmer underneath than we can imagine. Combined with the abundance of water, Mars may become fertile ground for future geothermal power plants.

Ganymede

Orbiting almost 780 million kilometres away from the Sun, solar power is not an option for any future colony settling on Jupiter's largest moon. Boasting a global magnetic field which is ironically three times larger than the planet Mercury, a future outpost on Ganymede may be a prime candidate for a geothermal plant. While future "Jupiterans" would have to live within "aquarium houses" in order to survive the intense radiation surrounding the moon, their ability to "tap" into the Jovian moons centre, providing enough energy to turn this frozen globe into a second Earth.

Saturn's Icy Moons

Despite its size, the tiny ice world of Enceladus contains geysers that are spewing icy crystals above its surface. It can become a prime candidate for a geothermal power plant (by tapping into the "warm crevices" beneath). But Enceladus is not the only ice world orbiting Saturn with geysers. Last year scientists discovered that both Tethys and Dione are also spewing ice particles into space, which may hint toward a warmer than anticipated core underneath.

Triton

Often known for its retrograde orbit around Neptune, Triton may become a major settlement in the future by harvesting helium-3 from the atmosphere of its paternal planet. But before colonists can exploit the blue gas giant for profit, they will need to find a way to acquire energy upon that frozen world. Fortunately, Triton does boast nitrogen geysers, whose erupting pressure may help keep an advance turbine engine spinning for a future colony.

Charon

Pluto's moon Charon may also have geysers on its surface, which could point towards a warmer core underneath.
Even though off world colonies will probably have to adjust their technology in order to make geothermal power plants feasible, future settlements may consider it more reasonable to power their cities from energy below, rather than importing it from afar.

Although geothermal energy cannot be used to power a rover until and unless geothermal power plants are created on planet's surface but geothermal energy can be thought of as an alternate source of energy for powering colonies in future.

4.4 Nuclear Energy

Radioisotope Power Systems (RPS) are long-lived sources of spacecraft electrical power and heating that are rugged, compact, highly reliable, and relatively insensitive to radiation and other effects of the space environment. This makes them an excellent option to produce power or heat for a variety of potential missions to some of the most extreme space and planetary environments in the solar system.

Long-duration missions to the high latitudes of the surface of Mars and to the surface of the Moon (which is naturally in darkness for two weeks out of every month) are also considered extremely challenging, if not impossible, for power systems using solar arrays and batteries alone.

Sunlight may also be too weak to supply enough electrical power for a given mission when it is highly intermittent, or obscured by an opaque or especially dusty planetary atmosphere. For example, the vast distance from the sun to Saturn means that sunlight received in the neighbourhood of the ringed planet is already 100 times less intense than the sunlight that reaches Earth orbit.

The thick, hazy atmosphere of organic chemicals on Saturn's moon Titan absorbs another 60 percent of this already faint incoming energy. On Mars, the ever-present red dust has cut the amount of energy produced by the solar panels on the Mars Exploration Rover Opportunity in half, despite several serendipitous cleaning events from local winds and random "dust devils" that can help clean the panels.

Space exploration missions require safe, reliable, long-lived power systems to provide electricity and heat to spacecraft and their science instruments.

Hence, with radioisotope power systems, years of operation are possible. Radioisotope power systems do not require any sunlight to operate, permitting spacecraft to land at more diverse locations regardless of season, time of day or latitude. Because of the number of moving parts, rovers and other mobile explorers require more power than landers. If rovers are solar powered, they must land and operate within a fairly narrow latitude band near the equator where enough sunlight shines to provide adequate electricity. For rovers, radioisotope electrical power systems could provide the capability to land and operate at a greater variety of scientifically important locations.

Hence, if RTGs replace solar panels used currently then the problem of energy needs can be satisfied and space programs can be made more efficient.

4.5 Hydrogen Fuel Cells

Fuel cells if employed successfully can serve as a good source of fuel for long years. It may also help to minimise the costs incurred in production of space probes. The disfunctioning of probes due to dust storm, unavailability of sun, temperature changes etc may not interfere in the working of rovers because of fuel cells.

Fuel cells have been in use in space explorations since very long time. But they are not very successful in rovers and probes. The reason behind it is their high cost and efficiency. The fuel cells are efficient till mars in our solar system but they are not efficient to travel distant planets. So, by making changes in them and by further innovations in technology and design can make them efficient and probably one of the best source to power our Extraterrestrial Vehicles.

5. Conclusion

As we are moving on with time our technology is also moving with the same pace. With changing technology our power requirements also change. Now, we are moving towards Cheap, Efficient power which can satisfy our needs in all ways and may be able to cope up with all environmental changes.

The past few decades remind us of Thomas Edison who lighted our lives. At that time the concept of bulb and light were hard to be understood and believed, but later advancements in our power system by the use of steam energy, fossil fuels, solar energy, wind energy, fuel cells, RTGs etc developed us a lot. Later the use of these energies in our space exploration programs added to the success of mankind.

Our continuous research will help us to continuously evolve our power sources for rovers. Now moving from solar cells to RTGs and further to Fuel cells we will search for more reliable, cheap and efficient source of energy, which may help us to enhance our space missions and may help us to peep deep inside the universe and open its secrets.

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