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The Interaction of High Voltage Systems with the Environments of the Moon and Mars

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THE INTERACTION OF HIGH VOLTAGE SYSTEMS WITH THE ENVIRONMENTS OF THE MOON AND MARS

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Abstract

High voltage systems designed for use on the lunar and Martian surfaces or in orbit will interact with environmental components such as electrically charged dust, low pressure atmospheres, ionospheric plasmas and neutrals, and chemically reactive species. As the Space Exploration Initiative (SEI) advances from the realm of feasibility study to that of conceptual design, guidelines will be required to ensure that these effects are properly accounted for. A first step in providing such guidelines is the prioritization of interactions for each of the space or surface environments that will be encountered. For those issues that are identified as high priority, the state of environmental knowledge, emphasizing essential data, must be determined. This report describes possible means of obtaining such information, including ground tests, modeling and analysis, and flight experiments. The development of computational tools which will enable engineers to simulate and thereby quantify the interactions will be especially considered. Our analysis is drawn from various study and workshop activities undertaken within the last two years.

Nomenclature

LMO	Low Mars Orbit
LEO	Low Earth Orbit
SSF	Space Station Freedom
EMI	Electromagnetic Interference
NASCAP/LEO	NASA Charging Analyzer Program for Low Earth Orbit

Introduction

Historically, power systems on US space vehicles have operated at the nominal 28 V dc inherited from the aircraft industry. At such low voltages, plasma interactions effects are negligible and, except for certain scientific spacecraft, have not been a consideration in spacecraft design. High power systems now under development for space applications will operate at higher voltages in order to reduce power loss and system mass. The emergence of such systems is motivated primarily by a desire to optimize

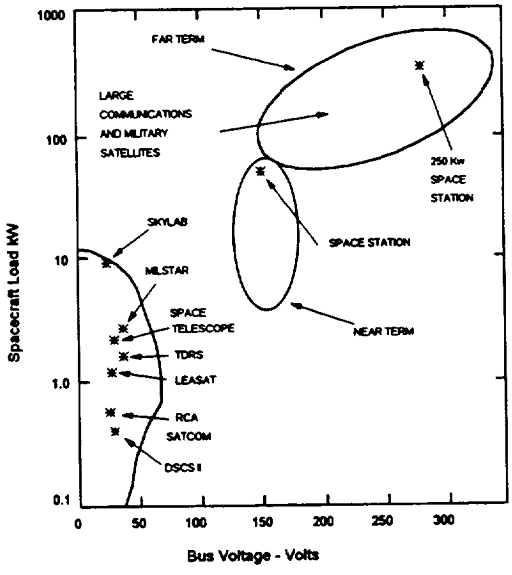

Figure 1 - Future Trends in Space Power, reproduced from "Space Vehicle Design", by M.D. Griffin and J.R. French, copyright© 1992 American Institute of Aeronautics and Astronautics.

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weight. Since the resistance of the necessary cabling is a strongly decreasing function of mass per unit length and cable losses are proportional to current squared, it is desirable to furnish power at higher voltages and lower currents. A further consideration is the reduced effect of magnetic interactions (torque and drag) that follow from low current operation.

Figure 1 shows past space power levels as well as some future trends. The tendency toward higher power/higher voltage is clear. Going even beyond the figure are proposed power systems for orbit transfer which have been predicted to require thousands of volts. Vehicles for the SEI, which will experience plasma conditions in LMO qualitatively similar to LEO, may require very high voltage systems which can be expected to undergo plasma interactions similar to those experienced in LEO.

High voltage power systems for planetary surfaces will be subject to a variety of interactions involving charged, chemically active dust, and electrical breakdown of natural and/or induced low pressure atmospheres. Small robotic precursors may well use low voltage systems, as they have in the past, but the inevitable requirement for high power will force mass conscious designers to high voltage systems.

The sections that follow discuss how this move to high voltage opens a new realm of environmental interactions not previously faced by the power system designer.

Mars Orbit

The composition of the Martian ionosphere has long been a subject of research[1]. Table 1 shows a basic comparison between some of the parameters of interest in LMO and LEO.

Table 1 - Comparison of LEO vs LMO

	LEO	LMO
Electron temp (eV)	.1 - .2	.1 - .2
Dominant Neutral species	O	CO_2
Neutral density cm^{-3}	10^9	10^{10}
Dominant Ion	O^+	O_2^+
Magnetic Field (G)	.4	~ 0
Electron density	10^6	10^5

Much of what can be said about plasma interactions in LMO follows from the considerable attention paid to these effects in LEO. In particular, while high voltage systems are clearly desirable to the power system designer, they suffer the drawback of interacting with ionospheric plasma[2,3] in several different ways. Conductor/insulator junctions whose electrical potential is highly negative with respect to the plasma undergo arcing. Such arcing not only damages the material but results in current disruptions, significant EMI, and large discontinuous changes in the array potential. Furthermore, inbound ions, accelerated by spacecraft generated fields, will cause sputtering from conductors with which they impact.

Solar arrays and conducting surfaces which are biased positively with respect to the plasma collect electrons. Since the mass of an electron is much less than that of an ion, the magnitude of electron current density is much greater than the ion current density (by the square root of the mass ratio). These electron currents act as parasites on the system and result in electrical power loss. For insulators at potentials greater than about +200 volts, sheath formation and secondary electron emission can lead to the insulator surface behaving as if it were a conductor. Specifically, when a small conducting area collecting electrons at low positive bias is surrounded by a larger insulating area, increasing the bias leads to an effect called "snapover" in which the current collection area abruptly shifts from that of the conductor alone to the entire insulating area. The magnitude of the collected current may jump by several orders of magnitude.

Besides producing a power loss, currents collected by biased surfaces significantly affect the potentials at which different parts of the spacecraft will "float." As explained earlier, because of their large mass and low mobility, ion currents to a spacecraft surface are much smaller in magnitude than electron currents. Since, by definition, the spacecraft equilibrium potential distribution results in a net collected current of zero, for equal ion and electron collecting areas, the spacecraft negative potentials must exceed the positive potentials. Ram and wake effects further complicate the picture. Ram energy is considerably higher than ambient thermal energy so ram flow enhances ion collection relative to that of surfaces which are oblique to plasma flow.

Real systems usually involve unequal collecting areas. The worst situations occur when the spacecraft power system uses a negative ground. In such a configuration, large surfaces are negative and must collect slow moving ions to balance the current from electron collection which now occurs only from relatively small areas of positive surface. In the worst case, parts of the spacecraft will be biased with respect to the ionosphere to a level very near the maximum voltage used on the solar arrays. This situation occurred in the design of Space Station Freedom. As a result of selecting a negative ground, SSF was predicted to float at about 140 volts negative with respect to the ionosphere. It has been necessary to add a plasma contactor to the baseline design as an active spacecraft potential control measure.

To assist the power systems designer in accounting for plasma interactions in LEO, a number of large computer codes have been developed. Chief among these is NASCAP/LEO[4]. NASCAP/LEO is a finite element Poisson's equation solver. As such, it is capable of dealing with complex geometries and can realistically model the arbitrary configurations of typical spacecraft. The code requires a specification of plasma conditions, spacecraft orientation and velocity, materials, and electrical biases. The code then calculates the equilibrium potential distribution on all surfaces and in the surrounding space, as well as the perturbed plasma conditions resulting from the interaction. Charge flow to the spacecraft and its effects are especially important and are readily calculated.

NASCAP/LEO has been under development since 1982 under a contract managed by the Lewis Research Center and will be released for public use in mid-1993. It is anticipated that NASCAP/LEO can be applied to spacecraft interactions in LMO without requiring extensive modification. Given the appropriate specification of environmental conditions. one can do design trades for a hypothetical Mars mission.

Mars Surface

High voltage power systems operating on the Martian surface may avoid most of the effects of environmental interactions simply by potting the entire system. This traditional approach may be practical for small robotic precursors. For large systems, however, encapsulation is impractical. Such systems operating on the surface of Mars face two main environmental factors[5] which will significantly influence their design: the low pressure Martian surface atmosphere, and dust.

The atmosphere is nearly pure CO_2 with a surface pressure varying from 7 - 9 torr (7.6 torr = .01 bar). Exposed high voltage surfaces may be expected to undergo Paschen discharge to the local atmosphere.

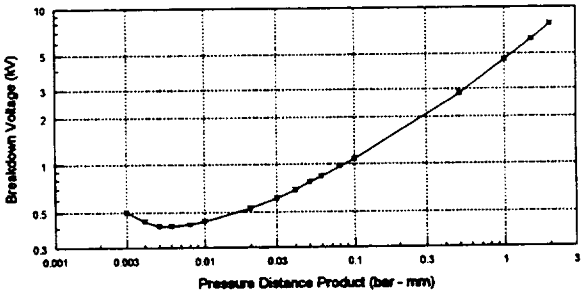

Figure 2 - Paschen curve for CO_2. Source: CIGRE committee 15.03

Figure 2 shows the Paschen curve for CO_2. As can be seen, the minimum for 1 mm distance occurs close to the pressure typically encountered on the Martian surface. Reports from the Mars Surface Wind Tunnel (MARSWT) indicate that video equipment which operates normally under 1 atm must be completely enclosed when operating under Martian surface conditions[6] to prevent the effects of Paschen discharge in the equipment. At this pressure, millimeter to centimeter long discharges are possible at voltages up to a few hundred volts, and centimeter to meter discharges from a few hundred to a few thousand volts.

Paschen breakdowns in the form of diffuse glows are most probable at the surface. These glows are relatively easy to produce, and will almost certainly occur around exposed high voltage surfaces. Paschen discharge represents a power loss to electrical generating equipment, and to electronic instruments operating even at moderate voltages (< 100 volts). It is a source of electromagnetic and optical noise which interferes with sensitive instruments and support system electronics (e.g., mobile life support). It is also a damage mechanism, particularly where the local electric field enables ionic bombardment of the surface.

While Paschen breakdown is reasonably well understood in a stationary pure gas or gas mixture, the process is poorly understood in the presence of dust and/or wind. It is certain that blowing dust will alter the atmospheric breakdown potential. Furthermore, dust on a high voltage surface may act like a microscopic lightning rod. Experiments in simulated Martian winds or dust storms will help to quantify this effect.

The long-term effects of charged dust, which may cover high voltage surfaces more or less permanently once exposed, is also not known but is almost certain to alter local electrical potentials.

Ideally, one would like to define measurable parameters to describe dust accumulation as well as moving dust. One then would seek to experimentally determine a family of breakdown curves as function of these parameters and thereby quantify these processes. Such an experimental program would be time consuming but could be done with existing facilities at reasonable cost. Computer models capable of predicting breakdown under such conditions do not exist and should be developed and validated as part of such a program. Although no such program is currently funded, it is our opinion that the expected results are essential if space power systems are to be confidently designed for operation in dusty, windblown, low pressure environments.

Lunar surface

The principal environmental threat to high voltage systems operating on the lunar surface has long been recognized to be dust. Lunar dust has a well known reputation for being pervasive and sticky. One area of immediate concern has been identified as dust covering of solar cell coverslides. Once polarized by strong electric fields, such dust is very difficult to remove as anyone who has removed dust from a CRT screen can testify.

Two additional problems become of concern when power systems move into the high voltage arena: induced local environments, and grounding. "Induced environments" refers to transient atmospheres created by outgassing, gas jet operation, or any process which results in a temporary increase of local pressure. If high voltage surfaces are exposed to such induced environments, the same problems discussed above under breakdown and discharge can occur. As with the Martian surface, the presence of a dust layer will almost certainly lower the discharge potential. Again, if the system is small, encapsulating will eliminate the problem. Otherwise, designers of high voltage systems must pay great care to the breakdown characteristics of all gases and vapors that their system may encounter. Ideally, the overall operation of high voltage power systems in transient atmospheres and dust should prove amenable to modeling. Practically, this ability has yet to be demonstrated.

Lunar soil is extremely dry and nonconductive. It offers little potential for grounding in the traditional sense. The implications are considerable if high voltage surfaces must "float" at high potential relative to humans, structures, and vehicles. At this time, little is being done to prioritize and quantify the issues in this area. Solving problems with system grounding will undoubtedly be an area of active research before high voltage systems are deployed on the moon.

Summary

Over the past ten years or so, it has become increasingly recognized that environmental interactions are a fundamental consideration in spacecraft design. Just as one would never think of designing a spacecraft without a complete thermal analysis, an environmental analysis is now becoming recognized as an essential part of the design process also. We have argued that this process must be extended to surface systems as well. The chief concern is the presence of high voltage. Materials and design practices that have a long history of successful use at low voltages must be reevaluated for high voltage use as a host of new interactions come into play. It is hoped that such a reevaluation will become standard practice in baselining future SEI systems.

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