Arcing and Discharges in High–Voltage Subsystems of Space Station

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Abstract

Arcing and other types of electrical discharges are likely to occur in high–voltage subsystems of the Space Station. Results from ground and space experiments on the arcing of solar cell arrays are briefly reviewed, showing that the arcing occurs when the conducting interconnects in the arrays are at negative potential above a threshold, which decreases with the increasing plasma density. Furthermore, above the threshold voltage the arcing rate increases with the plasma density. At the expected operating voltages (~200V) in the solar array for the space station, arcing is expected to occur even in the ambient ionospheric plasma. If the ionization of the contaminants increases the plasma density near the high–voltage systems, the adverse effects of arcing on the solar arrays and the space stations are likely to be enhanced. In addition to arcing, other discharge processes are likely to occur in high–voltage subsystems. For example, Paschen discharge is likely to occur when the neutral density $N_n > 10^{12}$ cm^{-3}, the corresponding neutral pressure $P > 3 \times 10^{-5}$ Torr.

1. Introduction

The purpose of this paper is to report on the possible effects of contaminant gases on the arcing and other discharge processes occurring near Space Station subsystems operating at relatively high voltages. The subsystem which is of primary concern here is the solar cell array, which is the heart of the Space Station Power System (SSPS). Under normal operating conditions the SSPS will operate at 160V, but during the cold starts the operating voltage is likely to double to about 320V. One of the main concerns here is, whether or not, at such voltages arcing and other discharge processes will occur in the array. These processes are likely to produce several unwanted effects on the power system and the space station, some of which are: (i) degradation of the solar cells, (ii) transients in the power system, even leading to the power disruptions, and (iii) electromagnetic interference, which can be detrimental to communications and telemetry.

In the following section we briefly review the existing knowledge on arcing in solar cell arrays and then we use it to predict the allowable contaminant densities near the arrays.

2. Arcing in Solar Cell Array

The information on arcing in solar cell arrays has been obtained from both ground and space–flight tests. However, the latter tests are limited to only two flights known as

PIX–1 and PIX–2, where PIX stands for Plasma Interaction Experiments. Results from both ground–based and space–flight experiments have been summarized by Stevens [1986], and Ferguson [1986] and Purvis et al [1988]. Some of the questions which have been attempted to be resolved using the experimental data are as follows: (i) Is there a voltage threshold for arcing? (ii) How does this threshold vary with the local plasma density?, (iii) How does the arcing rate for voltages above the threshold vary with the plasma density and other plasma parameters?

Figure 1 shows a summary plot of threshold potential as a function of the ambient plasma density. PIX–1 data are limited and they show that arcs occur at potentials between −700 and −1000 volts for all plasma densities [Purvis et al, 1988]. On the other hand, the more complete PIX–2 data set shows that threshold voltage decreases with the increasing plasma density. Furthermore, a comparison of the ground test data with the PIX–2 data shows that both the data sets predict the general trend of decreasing threshold voltage with the increasing plasma density, but the threshold voltages for the former set are higher than those for the latter data set based on space experiments.

The above conclusion drawn regarding the arcing threshold voltage is based on a very limited data set. Unfortunately, there are no theoretical basis so that the applicability of the data set can be extended to conditions for which the measurements have not been performed.

We use here PIX–2 data to decide whether there is a possibility of arcing in Space Station solar cell arrays. Barring transients, and cold starts after eclipse, the maximum voltage on solar cells will be near −160 volts, for which arcing is likely to occur at densities $N > 2 \times 10^5$ cm^{-3} (see Fig. 1).
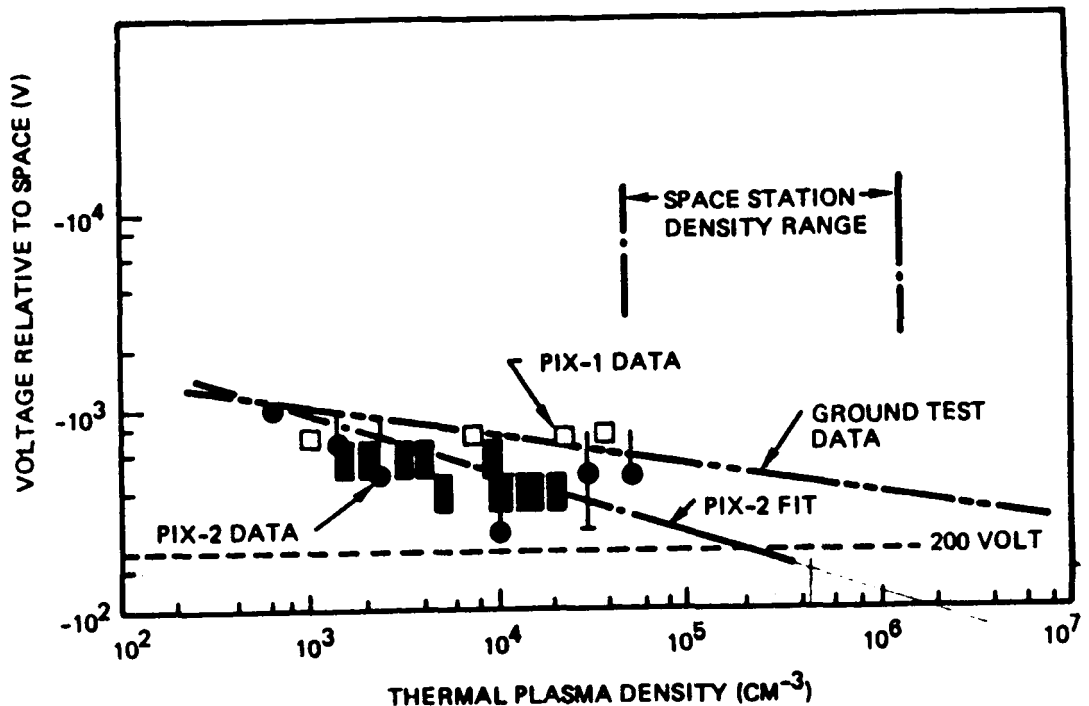

Fig. 1.   Threshold voltage for arcing versus plasma density. The ground test data show a higher threshold than the PIX–2 data from a flight experiment (Steven, 1986).

In the altitude range of the space station the <u>ambient</u> plasma density is likely to be in the range $10^4 - 10^6$ cm^{-3}, indicating the possibility of arcing even in the ambient plasma. The ionization of the contaminant molecules and atoms is likely to increase the plasma density above the ambient density. This may further aggravate the arcing problem.

The contaminant molecules and atoms are generated by outgassing, leakage, venting and thruster firings. In addition, the phenomenon of ram pile–up enhances the neutral density in front of the vehicle. This enhancement can be as large as 20 times the ambient neutral density.

The neutral densities of the contaminants and that associated with the ram pile–up have been calculated by the <u>S</u>cience and <u>E</u>ngineering <u>A</u>ssociates (SEA) contamination model [Rantanen, 1988]. For example, Table 1 shows the total density of the neutrals in the ambient environment and the enhanced density due to the ram pile–up.

The production of plasma from the neutrals depends on the efficiency of the ionization processes, which include photoionization and charge exchange processes, and also on the transport of plasma. Thus, the determination of the total plasma density around the vehicle is a difficult task. However, at the altitude range of the space station it can be roughly assumed that about one out of 10^4 molecules or atoms are ionized. Thus, the ram plasma density can be as high as 10^7 or more and Fig. 1 shows that arcing is quite likely to occur.

Since the solar arrays for the space station are likely to have very large surface areas, the ram effects can be very pronounced. Thus, if the solar cells are exposed to the ram plasma, the arcing is expected to occur at smaller voltages (and over a larger portion of the array) than those at which the solar cells arc in the ambient plasma.

Recent analysis of data from both ground and space experiments show that the arcing rate (R) depends on the plasma properties as follows [Ferguson, 1986]:

$$R \; \alpha \; n(T/m)^{1\backslash 2} \tag{1}$$

where n and T are the plasma density and (ion) temperature, respectively, and m is the ion mass. The proportionally constant and the dependence on the voltage is found to vary from one set of experiments to another. From space data, it is empirically found that

$$R \simeq 2.8 \times 10^{-13} |V|^{3.1} \, n(T/m)^{1\backslash 2} \tag{2}$$

where V is in volts, n is in cm^{-3}, T is in eV and m in amu. The above relation is found to be true above a threshold at about -230V. However, this threshold is true for the prevalent ionospheric plasma densities. When the plasma density is enhanced either by ionization of the contaminants or by ram pile–up the threshold is likely to be reduced and the arc rate is likely to go up. However, <u>a quantitative estimate of the plasma density enhancement associated with the enhancement in the neutral density remains an unsolved problem, and its solution must include both ionization and transport processes.</u>

There is another issue involved here dealing with the effect of neutrals on the high voltage systems. At very low pressures nearing vacuum conditions discharges are difficult to occur. However, when the pressure increases so that the mean free path for the electron collision with the neutrals become of the order of the inter–electrode spacing d, the Paschen discharge occurs. For the Space Station sub–systems at high voltages the inter–electrode spacing is roughly the sheath size, which is roughly of the order of 10 cm or so at the voltages of about hundred volts. Thus, the condition for Paschen discharge becomes

$$N_n > \frac{1}{d\sigma} \qquad (3)$$

where σ is the collision cross section. Since the molecule size r $>>$ size of an electron, $\sigma \simeq \Pi i r^2$. Assuming r $\simeq$ 3 × 10^{-9}m, we find

$$N_n > 10^{12} \, cm^{-3} \qquad (4)$$

This neutral density amounts to a neutral pressure $>$ 3 × 10^{-5} torr, which is two order of magnitudes or more larger than the ambient neutral pressure. But such enhancements of the neutral pressure have been observed aboard space shuttle during thruster firings [Wulf, 1986].

Since Paschen discharge and associated plasma processes may lead to arcing, it is recommended that neutral pressure must be controlled to $<$ 10^{-5} torr or equivalently $N_n < 10^{12} \, cm^{-3}$.

3. Summary

At the operating voltages for the space station solar cell arrays, arcing is expected to occur even with the ambient plasma. If the plasma density is enhanced by the ionization of the contaminants, the voltage threshold for arcs is likely to be reduced, causing arcing over a larger portion of the array. Furthermore, the arcing rate goes up with the plasma density. Thus, the detrimental effects of arcing on the array and the space station are likely to be enhanced by increase in the plasma density due to the ionization of the contaminants.

High neutral densities ($N_n > 10^{12} \, cm^{-3}$) near high voltage systems are likely to cause discharge processes other than arcing. Such discharges generate plasma and are likely to create conditions for increased arcing. The ram pile—up (Table 1) at low altitudes (~200 km) appears to generate neutral densities comparable to this value.

Finally, we state that our theoretical understanding of arcing and discharges is far from complete. Thus, it becomes very difficult to draw general conclusions from the limited set of data from laboratory and space tests on arcing of solar cell arrays. It is recommended that systematic investigations involving both theory and experiments be carried out so that arrays characterizations be carried out with confidence. Such an investigation warrants a global model of space station based on generation and transport of both neutrals and plasma

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