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Project:

High-Voltage High-Power Solar Array For Exploration Missions

Title of Document:

D6 Executive Summary Report

Document Number:	Issue:
HVHP-ADSO-TN-1000204161	**2**
	Issue Date:
ESA Contract No. 4000113120/14/NL/FE	**26.10.2017**

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This study was carried out under a programme of, and funded by, the European Space Agency.

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Notes, Keywords: High Power/Voltage Solar Array								

CHANGE RECORD

Document Identification Number: **HVHP-ADSO-TN-1000204161**

Title of Document: **D6 Executive Summary Report**

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1 SCOPE

This D6 Executive Summary Report summarizes activities and results of the High-Voltage High-Power Solar Array For Exploration Missions project conducted between February 2015 and March 2017 by Airbus Defence and Space GmbH as prime contractor together with Airbus Defence and Space SA and ONERA.

2 REFERENCES

2.1 Applicable Documents

The following publications were applicable with their respective scope:

	Document Number	Document Description
AD 1	AO/1-8019/14/NL/FE	Invitation to Tender
AD 2	Appendix 1 to ESA ITT AO/1-8019/14/NL/FE	Statement of Work
AD 3	4000113120/14/NL/FE	ESA Contract
AD 4	HVHP-PP-DG0181686-ASTR	Proposal Ref.: A.2014-4412-9-1
AD 5	05.12.2014	Minutes of Meeting
AD 6	ECSS E-ST-20-08C rev.1	Space engineering - Photovoltaic assemblies and components
AD 7	HVHP-ADSO-TN-1000123952, Issue 2	D1 Technical Note
AD 8	HVHP-ADSO-TP-1000133576	Electrical Test Procedure for HVHP ESD Coupons and Material Samples
AD 9	ECSS-Q-ST-40C	ECSS Space Product Assurance - Safety
AD 10	ECSS-Q-ST-40-02C	ECSS Space Product Assurance - Hazard Analysis
AD 11	ADS.E.0422 Issue 2	Product Safety Assessment Guide
AD 12	EN62368-1	Audio/video, information and communication technology equipment - Part 1: Safety requirements

2.2 Reference Documents

The publications listed below were used in the preparation of this document and contain background information relating to the subjects addressed.

	Document Number	Document Title
RD 1	ECSS-E-HB-20-05A	High voltage engineering and design handbook
RD 2	EN 50191:2000	European Standard: “Erection and Operation of Electrical Test Equipment”
RD 3	DuPont H-38492-2	Summary of properties for Kapton Polyimide Films
RD 4	NASA Technical Memorandum 105753	High temperature dielectric properties of Apical, Kapton, Peek, Teflon AF, and Upilex polymers
RD 5	NSAT.SP.GPMO.00000949	NEOSAT Next Generation Solar Cell Specification
RD 6	NGSA-AN-DG0184376-ASTR	NGSA Power Performance Analysis
RD 7	Technical note 01	Angular dependence of Sputter yield of almgsc alloy Foil (ko8242) and stainless Steel 1.4310 foil

3 ACRONYMS AND ABBREVIATIONS

AC	Alternating current
AD	Applicable Document
BO	Blow off
BOL	Beginning of life (in terms of degradation by particle radiation)
CFC	Carbon Fiber Compound
CMX100AR	Cover glass 100µm with Anti Reflective coating
DC	Direct current
DC93500	Dow Corning 93500 cover glass adhesive
EOL	End Of Life (in terms of degradation by particle radiation)
EOR	Electrical Orbit Raising
EOT	End Of Transfer (into Geostationary Earth Orbit GEO)
ESD	Electrostatic discharge
FO	Flash over
GaAs	Gallium Arsenide (cell)
GEO	Geostationary Earth Orbit
GFO	Grace-Follow-On
HIHT	High Intensity High Temperature
HVHP	High Voltage High Power
Imax	Current at max power produced from the generator
IPG	Inverted Potential Gradient
NASCAP	NASA/Airforce Spacecraft Charging Analysis Program
NEOSAT	Next Generation European Telecommunication Satellite
NGSA	Next Generation Solar Generator
NSA	Non Sustained Arc
PA	Product Assurance
PM	Project Manager
Pmax	Maximum power produced from the generator
PSA	Permanent sustained Arc
PVA	Photo Voltaic Assembly
RD	Reference Document
RMS	Root mean square (Measure for AC-voltage)
RTV	Room Temperature Vulcanizing
S/A	Solar Array
SAA	Solar Aspect Angle
SAS	Solar Array Simulator
SCA	Solar Cell Assembly (with cover glass and interconnectors)
SEEE	Secondary Electron Emission by Electron impact
SEEP	Secondary Electron Emission by Proton impact
SOW	Statement Of Work

SPIS	Space Plasma Interaction System (Software)
TJ	Triple Junction (cell)
TSA	Temporary Sustained Arc
Vmax	Voltage at max power produced from the generator
Voc	Open circuit voltage

4 INTRODUCTION

To extract and conduct high amount of electric power from a solar array, it is preferable to increase the voltage rather than the current in order to keep the wiring within acceptable weight. The study presented herein was initiated to investigate critical materials and effects that could pose upper limitations to the voltage that could be handled safely on a space solar generator.

The baseline for this study was the NGSA solar array under development within an ARTES program by Airbus Defence and Space. The hybrid solar array concept, consisting of rigid backbone panels in combination with lightweight lateral panels and the new generation of solar cells as a baseline is especially attractive for missions with high power consumption e.g. using electric propulsion.

The work was divided into four main tasks and one successive that then were allocated to work packages.

Task 1: Overview of the technology status-of-the art for HIVO-HIPO solar array:

The materials used in the NGSA design and their suitability for a high voltage and high power solar array were reviewed within WP110. Preliminary test were performed on samples of main insulator materials. In WP120 concepts and alternatives for the panel layout were developed and compared against the power and electrostatic requirements or constraints in WP320. The designs were implemented in the modelling and simulation within Task 2 and 3.

Task 2: ESD issues in HIVO-HIPO solar array:

The charging behavior of the solar array concept was modelled and simulated in WP210. In parallel the electrostatic behavior, in particular secondary arcing, was experimentally studied in WP230 on two coupons, representative for the semi-rigid and the rigid panel design (WP220).

Task 3: Interaction between HIVO-HIPO solar array and Electrical Propulsion (EP)

was studied in WP 310 and reviewed against the two design options in WP320

Task 4: Safety issue of HIVO-HIPO Solar Array:

The final design was evaluated in WP 410 for hazards - especially high electrical voltage - it poses on ground personnel during manufacturing assembly test and transport. In WP 420 corresponding safety measures are proposed for implementation both in the design and in the handling procedures

Task 5: Identification of future developments

Along the whole study and within each WP, needs for further investigation, testing and development were gathered and summarized in WP510.

Using the baseline concept developed in WP120 and WP320, the solar array performance at high intensity and high temperatures was evaluated against the envisaged power requirements in WP520.

5 WORK PACKAGES

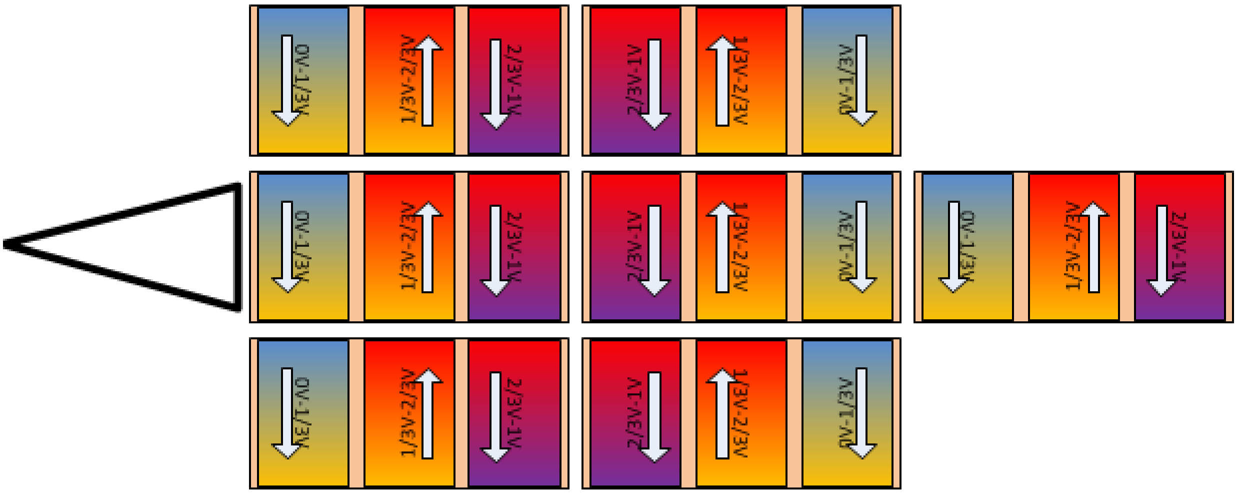
5.1 WP110 Material Properties

The main elements for a high voltage high power solar array design have been derived from existing configurations. The main insulating materials are Kapton HN and RTV-S691. The available literature for Kapton indicates good stability of its insulative properties also under environmental conditions in space. However, these properties are typically derived from alternating current conditions which are not necessarily covering the direct current case applicable for solar array operation. Therefore longterm high temperature high voltage tests have been performed on Kapton HN in representative configurations. Also the longterm behavior of RTV-S691 under temperature and 1000 Volt was tested. The test with duration of two months demonstrated stable resistances in the insulating range.

A design with a semi-rigid substrate with surface resistivities down to MΩ/sq represents a special case since the RTV-S691 bonding spot underneath the solar cell is not completely isolating the solar cell against the substrate. The development of a substrate material intended to be used for a solar array with 100V is still ongoing, therefore any preliminary conclusion on the suitability for a high voltage application is out of the scope of this study.

5.2 WP120 Design/Layout

A draft design for a high voltage solar generator was derived from existing solar generator designs along with the development still ongoing for NGSA. Taking the target operating voltage of 350V as a starting point, a fairly straight forward layout was developed that would readily provide 370V while preserving proven basic design rules. However to provide such high operating voltage, the open circuit voltage of the corresponding generator could reach more than 800V under worst case never the less realistic mission conditions and depending on the type of power conditioning on space craft level, the corresponding voltages must be taken into consideration and may pose certain limitations on the applicability of certain power distribution circuits. The power analysis also demonstrated the necessity to balance the length of solar cells strings within each section which could increase the amount of cabling on each panel significantly, depending on the layout and the need for mechanical support structures that intercept with the solar array layout.



5.3 WP210 Simulation Charging/Coupling With Environment

As the voltage of the solar panels increases, the potential of the exposed interconnectors relative to the spacecraft ground increases as well. When the potential difference between the interconnectors and the solar cell cover glasses is much larger than the thermal electron energy, the effective collecting surface of the interconnectors becomes much larger than their geometrical surface, to this point where it collects all of the electrons or all of the ions.

This may represent a threat because of several effects:

(1) The Electrostatic discharge risk: the large voltage of the interconnectors is relatively close to the Electro Static Discharge (ESD) threshold voltage;

(2) The current leakage: the effect of the increased current collection by interconnectors is equivalent to a current leakage in the solar panel circuit, which may lead to a reduction of the solar generator power
(3) The erosion risk: the increased collection of ions by high voltage interconnectors leads to an increased erosion of the thin interconnectors.

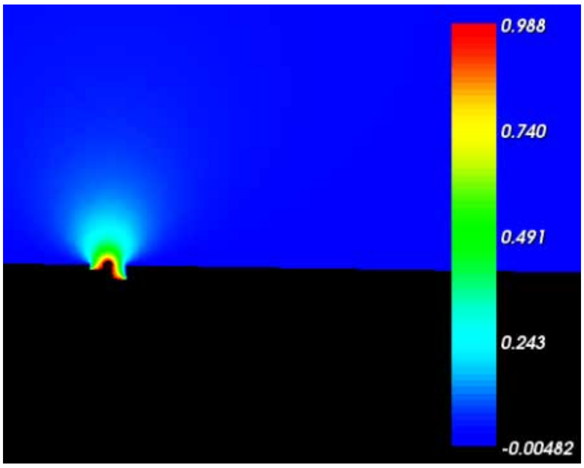
In order to evaluate the risk, a semi-analytical model of the current collection by interconnectors was developed as a function of their voltage. This model takes into account the geometry of the interconnectors and the space charge saturation at high voltage and while it appears consistent with a 3D OML model for moderate voltage, it gives more realistic results at high potentials. This semi-analytical model was defined on physical basis and validated against small scale particle-in-cell simulations of the plasma species collection by interconnectors with different geometries and voltages performed with the Spacecraft-Plasma Interaction Software (SPIS). The comparison between the model and the simulation showed a very good match.

This model shows in particular that the interconnector voltage plays a sensitive role only if it leads to potential differences between the cover glasses and the interconnectors that are much larger than the electron temperature. As this is not the case in GEO, it was concluded that the use of high voltage solar panels do not increase sensibly the risk of ESDs in GEO. But the conclusion is quite different for spacecraft in LEO or using electric thrusters.

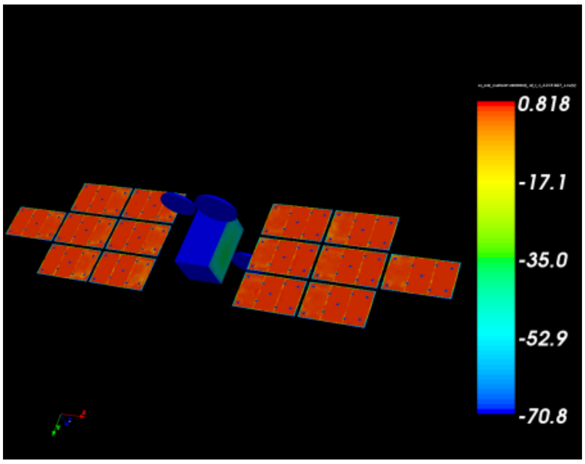
SPIS simulations were also used to study the details of the processes occurring in the gap between solar cells, in particular the effect of secondary electrons created by the collected species impacts. While this seems to have little effect for positive polarized interconnectors (which then recollects the secondary electrons), the effect may be more threatening for negative polarized interconnectors. In this case, the electrons generated by the ion impacts on the interconnectors are collected by the cover glass edges with a high energy that leads to the re-emission of secondary electrons with a yield larger than one: although the positive cover glasses collect a relatively large electron current from the interconnectors, they re-emit even more electrons so that the potential difference is increasing. This may lead to an increased ESD risk, but because of the relatively large current and densities involved, this may also lead to continuous discharges much alike the corona discharges. In the latter case, the potential differences and currents would be limited and would less probably cause destructive secondary arcs, but the thermal effects and the particle collection may accelerate the ageing of the cells.

The semi-analytical model was implemented as a surface collection model in SPIS in order to perform large scale simulation of the electrostatic charge of telecom spacecraft. As the effect of high voltage in GEO was deemed negligible in the first part of the study the effects in a LEO environment (which is close to that obtained using electric propulsion) were investigated. The model of a Eurostar 3000-like platform was established with 14 solar panels and a design corresponding to that developed in the current project. Simulations at different local time were performed.

The outcomes of these simulations are consistent with experiments performed at ONERA: the overall potential of the spacecraft is driven by the current collection by interconnectors, and for a voltage of 350V, the spacecraft potential is comprised most of the time between -150V and -180V. These potentials are very large in a cold and dense ionospheric environment, and may impact the erosion of the whole platform by ionosphere’s oxygen ions.



Potential close to the interconnector at +1V



Surface potentials of Eurostar 3000 platform with 14 high voltage solar panels

The total amount of current collected by the interconnectors is limited: our model shows that although the most polarized interconnectors may collect all of the electrons reaching the solar cell, the space charge effect imposed by the small Debye length limits the current to a few nano-Amperes by interconnectors. This is a negligible current leakage at the spacecraft scale (less than 1% of power loss). Nonetheless its effect on the solar generator circuit may not be negligible for the high voltages occurring out of eclipse with an open circuit.

5.4 WP220 Coupon Design & Manufacture

Two different types of coupons have been built with to pieces each type. Every coupon has two strings with two 3G30 solar cell assemblies (80x40 mm) in serial connection and a shunt diode stripe for the last cell of each string. The gap between the strings is 35 mm (+1.5 mm tolerance). The difference between the coupon types is the substrate used and the presence of a corrugation between the strings. Coupon type 1 is made out of an E3000 representative substrate without a corrugation, coupon type 2 of a semi-rigid Kevlar substrate and a corrugation between the strings.

5.5 WP230 Coupon Experiment

Two kinds of coupons have been tested to evaluate the possibility to prevent arcing between two sections on a high voltage solar array: a classical coupon on honeycomb (rigid coupon) with a gap of 35mm between cells and a semi-rigid coupon whose substrate was Kevlar with the same gap size but with a corrugation of Kevlar between cells.

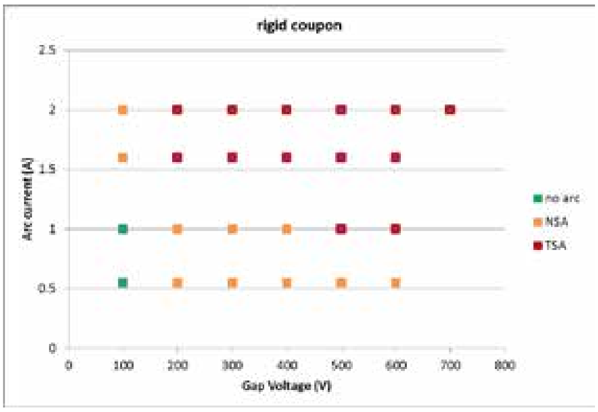
The coupons were placed in an Inverted Voltage Gradient representing the most critical situation in space where a large electric field is created at cell’s level due to an absolute negative charge of the spacecraft and a less negative charge of the cover glasses. In this situation, electrostatic discharges can occur on the solar cell’s edge, interconnectors etc. everywhere there are triple points (highly charged conductor, less negative dielectric and vacuum) The most critical is when a discharge occurs where there is also a difference of potential between cells i.e. where a secondary arc can occur and be fed by the solar array power.

The test performed in this project followed the classical method using an electrical circuit representing first, the absolute charging of the spacecraft initiating the primary electrostatic discharge, then, the differential charging of the cover glasses (even the missing ones) with a flashover simulator and finally, the secondary arcing circuit with a solar array simulator reproducing the power provided by the solar array (even the missing cells) when an arc is triggered.

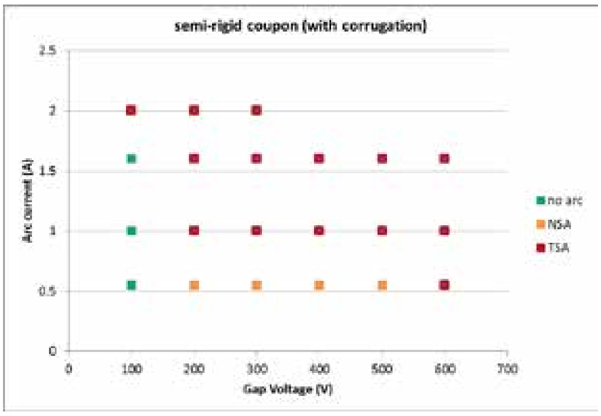
Different steps have been performed changing the settings of the solar array simulator from 100V to 600V and with an available current from 0.55A to 2A. The first conclusion for these tests is that a gap of 35 mm (flat or with corrugation) can prevent secondary arcing only for a gap voltage up to 100V and current I <1.6A.This was confirmed by the fact that the arc voltage which was measured was about 100V. Secondly, the tests have shown that the corrugation did not work as a protection since the results were the same (or worse) with the corrugation than without.

A more detailed evaluation of results (see figure) however reveals that the arcs that were measured last longer than they ignition discharge only for a current at least equal to 1A and very critical arcs inducing damages in the cells were observed for a current at least equal to 1.6A.

Rigid coupon



Results obtained for both rigid coupons SN01 and SN02



Results obtained for both semi-rigid coupons SN01 and SN02

5.6 WP310 Simulation Of Interaction Of Hv Sa &Eps

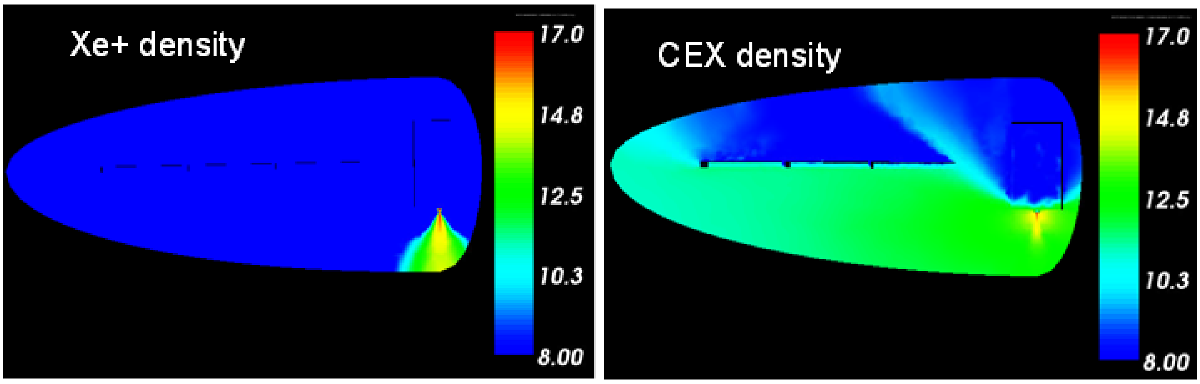
Electric propulsion is a key enabling technology, in particular for missions where mass saving constitutes a decisive advantage, like geostationary telecom missions, planetary exploration and low thrust mission. Mounting electrical propulsion on-board needs to master all the related system aspects, some of them being quite new with respect to those induced by classical propulsion systems. In particular, the interactions between the highly energetic and charged plume and the surrounding spacecraft raise several issues at system level that have to be predicted during the design phase of the spacecraft: partial pressure, dynamic effects, erosion, contamination, interactions with RF beam and spacecraft charging.

Among the different spacecraft components, the solar array is one of the most critical ones for what concerns interactions with electric propulsion systems. This is due to several specific aspects:

- The solar array is a large spacecraft appendage potentially significantly exposed to the thruster plume.
- The solar array includes polarized surfaces (interconnectors…). Their interactions with the charged plasma plume can modify the distribution of potentials of the overall spacecraft and drain parasitic currents.
- The solar array integrates thin elements (interconnectors, cover glass coating…), which can be significantly eroded by the plasma plume. In particular, erosion of interconnectors is known to be one of the major constraints for EP implementation.

In this context, it is proposed to make a detailed assessment of the interactions between electric propulsion systems and HIVO-HIPO solar array: SA and SC charging level, induced current, pressure levels and SA erosion. Several spacecraft and thrusters configurations are studied in order to draw a large picture of plasma interactions impacts.

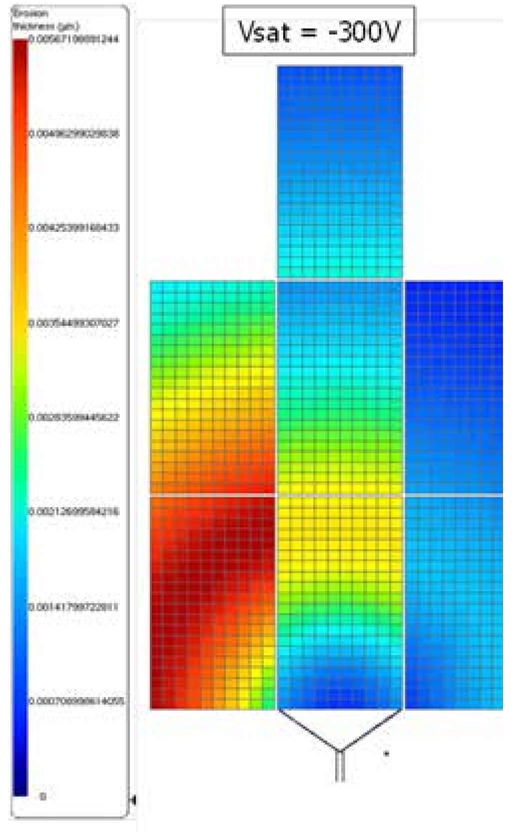
In particular, two thruster technologies are simulated, using SPIS software: Hall Effect Thruster (SPT100) and Ion-gridded Thruster (T6). The main difference between both technologies is the grounding configuration: cathode is floating in hall effect thruster whereas it is grounded for ion-gridded thruster. Moreover, two solar array voltages (300V and 900V) and two string layouts are studied in order to assess impact of solar array key parameter.



Xe+ and CEX densities in T6 thruster plume

Spacecraft potentials and collected currents on solar array are then outputs from SPIS simulation and are used as inputs for erosion simulations, using CIONIC software. Regarding erosion, both silver and aluminum alloy materials are studied, aluminum alloy showing lower erosion thickness and thus better performances.

Paschen/arcing risk related to electric propulsion is not critical in the studied configuration, pressure due to Xe density being low at solar array level. Nonetheless, in different spacecraft configuration (plasma thrusters closer to solar array for example), the conclusion could be different. It is also recalled that arcing risk due to outgassing (with air) could exist, at SADM level for example.



example of CIONIC output considering silver IC

As a conclusion, plasma interactions between thruster plume and the surrounding spacecraft are obviously highly dependent on the chosen configurations. This study allowed showing that key design features (thruster technology, thruster power and grounding, spacecraft design) can lead to slightly different results.

- Concerning spacecraft charging, it is shown that spacecraft absolute potential may vary in the range from some tens to some hundreds on negative volts. This is due to electric propulsion which tends to neutralize potentials. Hence, such potential level is not critical from a spacecraft charging point of view but it shall be assessed as it is a key parameter for erosion.
- The collected current on solar array, which participate to spacecraft equilibrium potential, may vary from some tens to some hundreds of negative milli amperes, which remains negligible compared to the thruster emitted current but can be taken into account into design.
- Considering the different pressure levels, no arcing risk is identified with regards to the thruster plasma interaction with the solar array in the studied configurations.
- Finally, erosion is identified as being the most critical aspect. Indeed, it is shown that erosion levels, which are directly linked to the absolute spacecraft potential, can reach around 10µm which is not acceptable considering interconnectors design. However, use of aluminum alloy instead of silver tends to improve the situation.

Different thruster configurations in terms of both geometric and electrical integration in the spacecraft showed a significant impact on the behaviour of the overall spacecraft potential with consequences to ESD risks, current dissipation and erosion. It may become a major design criterion for certain missions in order to avoid detrimental effects.

5.7 WP320 Solar Array Design Options

Based on the simulation results design options are considered that are most promising to handle, mitigate or avoid critical interactions of the solar array with the plume of the EPS. Their impact on the design and implementation of the generator is evaluated.

Within this study two main design concepts were considered to achieve the desired output voltage: The combination of three separate panels in series versus panels comprising three sections in series each. While the first concept would utilize a straight forward panel design, the second would be more flexible concerning the adaptation to power requirements.

It turned out, however, that separating the parts of the solar generator which are located electrically close to the satellite ground from of the parts that are on the positive pole of the electrical subsystem enhances the attraction of thruster plume towards the low voltage areas, which in turn results in higher erosion rates on these parts of the generator.

New materials under consideration for the application in NGSA/ENeo showing lower sputter rates help reducing the erosion but enough to withstand a typical mission length without other mitigation techniques.

The design using three sections in series per panel shows lower erosion rates due to the more intermixed potential geometry it presents to the thruster plume.

During the coupon experiment it became clear, that the 35mm large gap between the sections at different potential was no unsurmountable barrier for a sustained arc: Even at 200V and 1.6A a temporarily sustained arc TSA of 2.8ms was observed and at 300V and the same current the duration exceeded 28ms which slightly degraded one cell already.

While on the front side the current available will be limited to one string thanks to blocking diodes, this current could exceed 1A when larger cells are implemented such as the LARS being under qualification.

Whereas on the rear side of the panel there are conductive parts of the harness carrying the combined current of several strings or the whole section, which may exceed 20A in certain cases. As the coupon experiments showed, covering conductive parts of the coupons, such as bus bars and cell edges does effectively prevent these areas from arcing and therefore provides a valid way to protect against arcing.

Covering parts on the rear side is a common practice, although mainly for mechanical purpose as to prevent parts of panels from sticking together while the generator is in stowed condition. It may easily be implemented.

5.8 WP410 Identification Of Hazards

A hazard analysis was performed for the nominal ground operations until launch according to the applicable European rules amended by company rules.

The main hazards that were identified in the formal Hazard report sheet are:

- At the positive string terminals a DC voltage of 300V may be present in open circuit mode. Contact to uncovered electrical conductors (e.g. at bus bar; diode boards) of different electrical potential can cause electrical shock when touched, leading to lethal shock. Personnel’s reaction caused by electrical shock can result in damage to the Solar Array or other parts of the spacecraft.
- Build-up of static electrical charge may discharge to persons or equipment, producing sparks. Inadequate grounding of electrically conductive surfaces leads to ESD. In presence of an explosive atmosphere during launch preparations this may lead to damage of ground facilities. Personnel’s reaction caused by electrical shock can result in damage to the Solar Array or other parts of the spacecraft.

5.9 WP420 Mitigation Strategies

The following strategies were considered applicable to mitigate hazards arising from high voltages that may be present on the solar array.

In general the personal shall be trained w.r.t the risk of high voltages present on the solar array.

1st safety inhibit:

- As defined within previous hazard analysis for solar arrays insulating gloves must be used.
- It must be ensured that in use lint free gloves are insulating.

2nd safety inhibit:

- Parts with hazardous voltages on the panel rear side (diode boards, crimp terminals, bus bars, etc) and the c-springs shall be insulated with black Kapton.
- For AIT and on ground handling signs shall clearly warn personal that hazardous voltages may be present on the solar array.
- Personal should be trained to use only safe areas for handling

5.10 WP510 Identification Of Future Development Needs

Future needs for research and development were identified in the field of

- Material properties:
  - Dielectric robustness, specifically under aging conditions
  - Methods for aging insulating materials
  - Sputter yields of conductor materials at high incident angles (>60°)
- Secondary arcing
  - Thresholds versus distances
  - Effect of barriers
  - Covering of conductor paths
- Operation under LILT conditions
  - was considered out of scope of this study
  - may be questionable due to lower operating current

5.11 WP520 High Temperature Extension

The extension of the high voltage solar generator design for operation at high intensity and high temperature corresponding to up to 3 solar constants appears straight forward as long as thermal control is allowed. By changing the solar aspect angel SAA to higher values the incident power is reduced due to Lambert's cosine law and thus the temperature can be keept within qualification range.

Even then the resulting power still could be higher compared to 1 solar constant.

6 CONCLUSIONS

The study "High-Voltage High-Power Solar Array For Exploration Missions" was initiated by ESA to investigate the feasibility of increasing the operation voltage of a space solar generator to a level that would allow to be directly feed into an electric propulsion system. Electric propulsion is one key element to further exploration of the solar system. As a side effect, the conduction of electrical power at higher voltages could reduce the weight of wiring thus adding to the payload capacities.

From a materials point of view, there appeared no limitation to increase the voltage up to at least 1kV, although the long term aging behaviour under such high voltages will have to be further investigated. The dielectric breakdown tests indicated a DC behaviour that is in line with manufacturers data at AC.

Higher voltages impose an even higher attention to safety precautions that are already in place during manufacturing for today’s 100V array production. Some of the applicable regulations request for additional measures that may have to be adopted appropriately. It may appear opportune to implement design elements that allow separating parts of the array from each other to minimize the need for handling solar array components bearing high voltage.

Concerning electrostatic discharges it was shown that even today's solar arrays routinely operating at 100V already dominate their electrostatic environment in a way that would not be changed significantly by higher voltages. Therefore another increase of the voltage will only be reflected in a corresponding shift of the spacecraft potential towards more negative potentials, which has its own consequences.

In contrast to these encouraging findings, the interaction of the plume ejected by an electric propulsion system was shown to be increased by increase of voltage up to such an extent that further attention must be paid to the erosion of exposed electric conductors. Namely the cell interconnectors on the panel front side are threatened to be dissolved at areas where the most negative potentials apply. It was also demonstrated, that both, geometric arrangement of panel and thruster and electric layout of the solar generator panel can significantly help to improve the situation.

Until today there was a correlation between the distances of two facing conductors forming a triple joint each and the voltage difference between them that could be handled without risk of arcing. The wider the "gap" was, the more voltage it withstood until arcing occurred. For instance it has been proven in several campaigns that 5 mm of distance would clearly avoid arcing up to 200V.

This appeared no more valid when exceeding this limit: As soon as there is more than 1A of current available, arcing appears to be able to bridge distances that are almost 10 times larger than these safe up to 200V. On the semi-rigid coupon temporarily sustained arcs were observed at 200V already. On the front side of the panel, applicable design rules may prevent arcing by limiting the available current to one string, but with the emerging of large solar cells this threshold will be shifted beyond 1A. On the rear side of the panel, additional measures must be foreseen. However there are measures at hand such as covering by insulating foils, yet their effect on large areas has to be further investigated.

Ideas how to improve the robustness against secondary arcing at higher voltages have been mentioned by CNES and ONERA, that are worth further investigation.

It was found difficult to obtain primary discharges on the semi rigid substrate, because of its considerable conductivity. It may provide a feasible way to mitigate primary ESD on any kind of panel substrate thus diminishing the need for measures against secondary arcing.