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Behavior of arc current waveform on satellite solar panels and its dependence on arc location, dissipated charge and irradiation time

Rashmi S. Joshi and Suryakant B. Gupta

***Abstract*—Risk of arcing in space plasma environment on satellites solar arrays has always been an issue of major concerns in aerospace community. The outcome of round robin tests performed in various laboratories has resulted in finalization of the guidelines for the ground test of solar panels. This is documented as ISO -11221 standards.**

Authenticity of arc plasma flashover parameters are still under debate. In this paper we discuss some GEO arc experimental findings which support the perimeter theory to validate arc flashover parameters. It has been observed that behavior of arc current waveform is dominated by its location on the solar coupon, bias charge (charge due to bias voltage and external capacitance) and the total charge dissipated during the arc discharge. For the arc occurring at any location on the solar coupon, if the dissipated charge is lesser than the bias charge, the energy of the arc is insufficient to discharge the complete coupon. In this case a smooth rise and fall of the current waveform is observed. If the bias charge is lesser than the dissipated charge, then the location of arc dominates the shape of the arc current. For the arc occurring near corners or edges, a drop in the current waveform is observed when the arc plasma flashover effect reaches nearest possible edge of the solar coupon. These experimental results show good repeatability and reproducibility in this common trend of arc current behavior.

It is also observed that the duration between the two consecutive arcs is directly proportional to the dissipated charge. Coverglass and the CFRP sheet above the honeycomb structure hold the charge during irradiation by the electron gun resembling an internal capacitance. Arc energy is governed by the internal and external capacitance. It is observed that if intermittent arc duration is sufficient longer then the gradual accumulation of charge on the internal capacitance may lead to a major arc. In some experiments conducted on ATJ solar panel coupon, charge accumulated in the internal capacitor exceed the charge due to external capacitance which results into a higher current value even after the external capacitor is completely discharged. In this particular case arc current does not obey the perimeter theory. Such behavior is observed for AZUR and UTJ solar panel coupon as arc current gradually decreases with time.

Keywords—ESD on solar panels, arc behavior and flashover, perimeter theory

I. INTRODUCTION

Arcing on solar panel is the most common phenomenon for its degradation in space environment. In adverse space conditions, different materials on the satellite surface charge differently. When the potential difference between them increases above the threshold voltage, the stored energy is dissipated in the form of an arc. The duration of such arcs may lie between few microseconds to few milliseconds. In this paper arc occurring on the satellite solar panels parked in geo-synchronous earth orbit is studied under simulated environment in laboratory. A dedicated stainless steel vacuum chamber of 1 meter length and 1 meter diameter is designed to create the desired environment. Flood beam type electron gun is used to irradiate solar coupon kept at the center of the chamber to conduct irradiation studies thus simulating GEO conditions. Filamentary plasma source is used to create artificial LEO environment inside the chamber. A data acquisition system is developed which automatically detects the arc, captures its location using the camera and process the information according the pre-defined protocols. Integrated facility is discussed in brief in [1]. This paper focus only upon the results obtained during the experiments. Here, shape of arc current waveform is discussed for various types of solar panel coupon which includes ATJ (Advanced Triple Junction) solar cell, UTJ (Ultra Triple Junction) solar cell and AZUR solar cells. Difference in the behavior of these cells during the arc is discussed in this paper.

Figure 1: Experimental setup for testing arcing phenomenon on solar coupons

The experimental setup is designed according to the ISO-11221 standards for spacecraft charging experiments [2].

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II. Theoretical and Experimental Survey

It is known that the shape of the arc does not follow a definite pattern thus the concept of a 'standard pulse' does not exist in this case [3]. Still various parameters affecting arc current behavior can be summarized through theories and experiments [4]. Figure 2 shows the expansion of arc from the center of the solar coupon towards its edges.

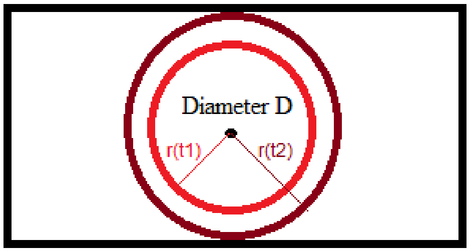

Figure 2: Arc plasma bubble expands towards the edges symmetrically. Here, arc location is defined by the black dot at the center. Here r(t1) and r(t2) are the plasma bubble radius after time t1 and t2 where t1<t2

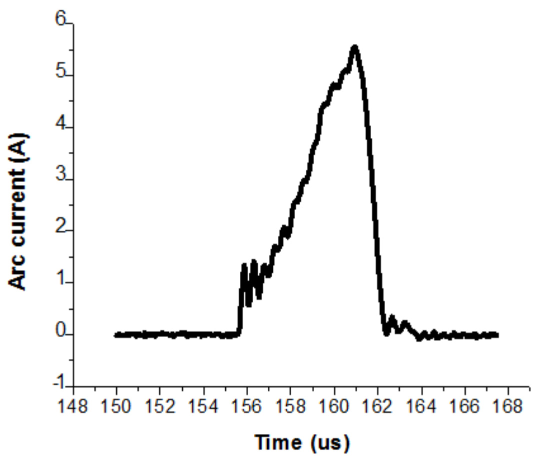

Figure 3: Current waveform for the arc occurring at the center of the solar coupon

It is clear from figure 2 that arc plasma expands symmetrically in all directions until it reaches the nearest edge. Figure 3 shows the real time measured waveform of arc current. Location of the arc is confirmed the image captured by the camera which is synchronized with the digitizer used for measuring the current (A) values. This situation is simple to analyze as arc plasma neutralizes the surface radially outwards. Arc current rises up to its peak value gradually and falls smoothly. Here, total charge on the coupon's surface is not neutralized and arc quenches before it reaches the nearest end.

Some arcs with higher energy value are capable to neutralize charge in the complete coupon. In such case, arc plasma expands unevenly after reaching the nearest edge. Figure 4 shows the schematic of the arc expansion region phenomenon with time. The waveform corresponding to this phenomenon is shown in figure 5. A plateau type region is observed before the arc quenches completely. The mathematical formula of such event is described in [3] by Boris Vayner.

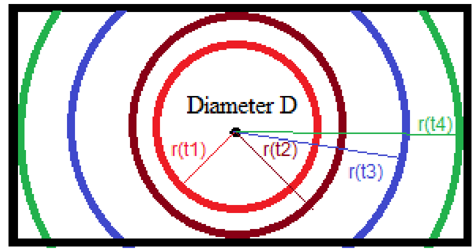

Figure 4: Arc plasma bubble expands beyond the nearest edges asymmetrically. Here, arc location is defined by the black dot at the center. Here r(t1), r(t2), r(t3) and r(t4) are the plasma bubble radius after time t1, t2, t3 and t4 where t1<t2<t3<t4

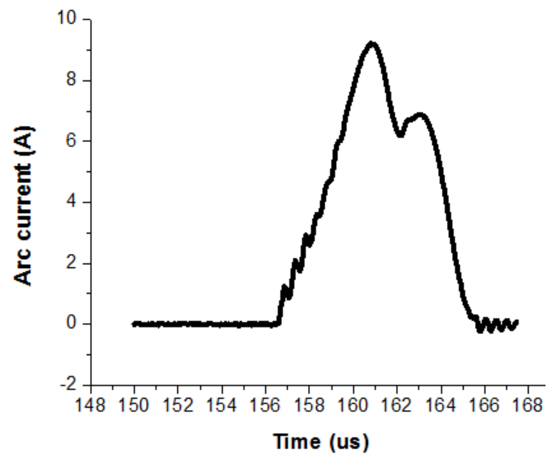

Figure 5: Current wavefore for the arc occuring at the center

III. Experimantal Results on Various Types of Solar Cell Coupons

Arcing test is performed on three types of solar panel coupons. Current waveforms for all the arcs occurring on AZUR solar cells obey the perimeter theory. It is also observed that the time interval between two consecutive arcs is directly proportional to arc duration. AZUR solar cell coupon biased at 1 KV was irradiated with electrons energy of 1 KeV. No arc was observed even after 20 minutes of irradiation. It is evident from the waveforms that the arc current does not quench unless complete charge on the solar coupon (C-int) is not washed-out. Even after irradiating the solar coupon for 20 minutes no arc was observed. Various solar panel assembly layers like CFRP at the top of honey-comb structure and adhesives between CFRP and solar cells behave as charge storing element during irradiation. This could be defined as internal capacitor. The role of charging of internal capacitor cannot be avoided as it plays an important role in intensification of arc amplitude and elongation of its duration. This accumulated charge forms internal capacitor. On occurring of an arc, both internal and external capacitor (connected to simulate missing solar cells) gets connected in series and jointly contributes in arc current. In all the experiments, external capacitor was kept constant. The charge dissipation is initiated by the external capacitance and continued by the internal capacitance. The charge dissipated

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during the arc on an AZUR solar panel coupon is calculated as 25 µC from the arc current waveform shown in figure 5. This energy is almost two times compared to the arc occurring at higher rate that is with 10 minutes of the previous arc. It is also clear that the arc waveform follows the perimeter theory.

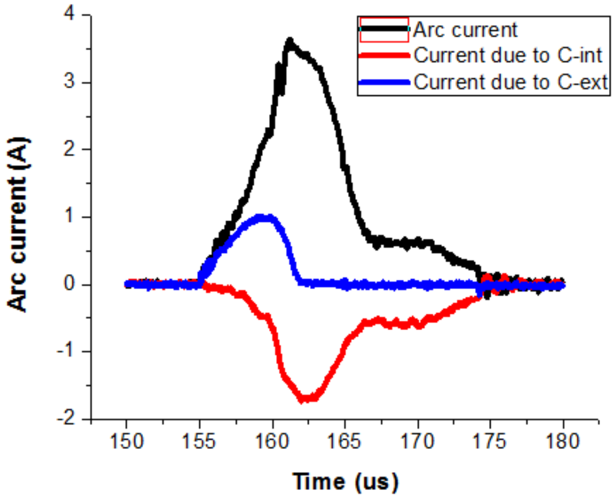

Figure 6: Current waveform for an arc on an AZUR solar panel coupon biased at -1KV and irradiated with electron gun with 1 KeV energy for 20 minutes. Arc duration is elongated due to combined effect of external capacitor (C-ext) and internal capacitor (C-int)

Few arcing experiments were conducted on ATJ solar panel coupons with different bias voltage and electron gun energy. In certain cases, it was observed that the internal capacitance charged very fast and greater than the external capacitance. Such internal charging results into a peak overshoot of the arc current even after the external capacitor is dissipated completely. Thus, two peaks are observed in the arc current waveform as show in figure 7. Here the ATJ solar cell coupon is biased to -1 KV and irradiated by electron shower of energy 1 KeV.

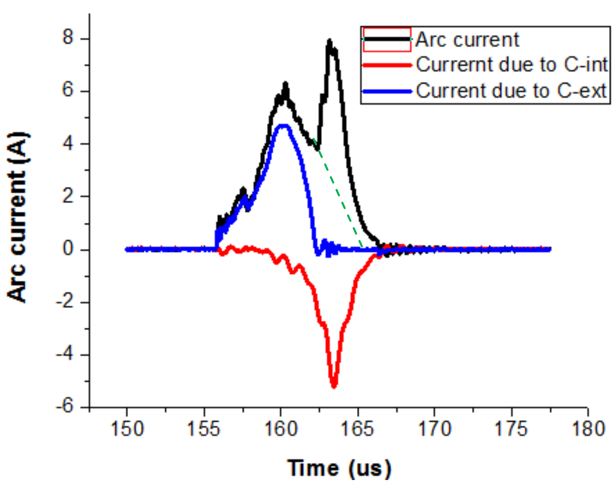

Figure 7: Current waveform for an arc on an ATJ solar panel coupon biased at -1kV and irradiated with electron energy of 1 KeV for 13 minutes. Arc duration is elongated due to combined effect of external capacitor (C-ext) and internal capacitor (C-int)

If the internal charging of the solar coupon can be avoided, arc current would follow the path indicated by the dashed green line. The second peak overshoot increases the duration and amplitude of the arc current. The waveform does not obey perimeter theory. Also the phenomenon has a good repeatability. Figure 8 and figure 9 shows current waveforms of different arcs occurring on ATJ solar cells. Such type of arc occurs only on the ATJ solar cell coupons. Experiments carried out using UTJ solar cells indicate that arc current follows the perimeter theory.

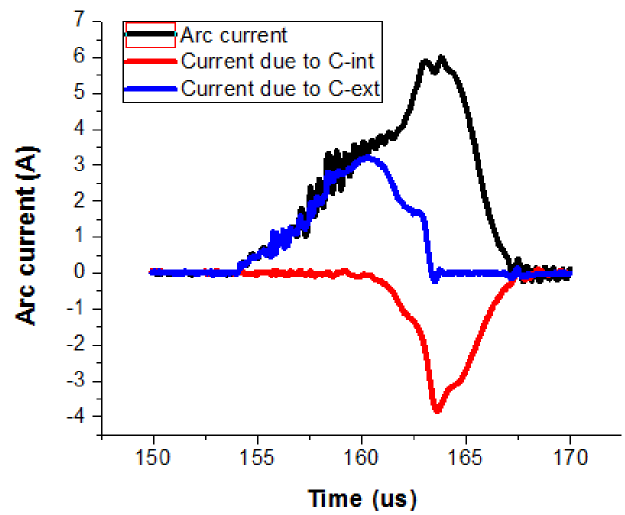

Figure 8: Current waveforms for different arcs occurring on ATJ solar cell biased at -1KV and irradiated with electrons having 1keV energy. Here arc current continues even after charge in the external capacitor is dissipated. Arc current's amplitude and duration increases due to C-int.

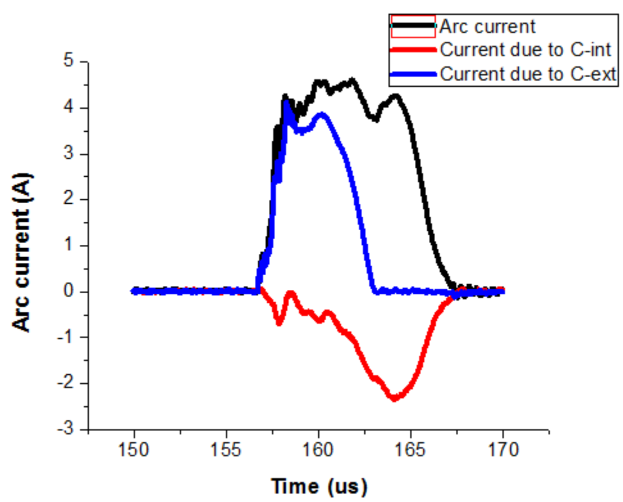

Figure 9: Current waveforms for different arcs occurring on ATJ solar cell biased at -1KV and irradiated with electrons having 1keV energy. Here arc current continues even after charge in the external capacitor is dissipated. Graph depicts the effect of internal charge in elongation of the arc current waveform duration

It is clear from the ISO 11221 that during arc, external capacitor and internal capacitor (due to solar coupon's charge) get connected in series with each other. The former initiates the discharge and the latter follows it. If the arc continues even after charge in both capacitors is dissipated, it is called a

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sustained arc. In our case, arc terminates when complete internal capacitor is dissipated. This is termed as primary arc. Extended primary arcs make the region prone to elongated arcs once sustained arc conditions are faced by the solar coupon.

IV. Dependence of Arc Current on Internal Capacitance and Irradiation Time and Location

Few postulates can be derived from the experiments discussed above.

- Time duration between the two consecutive arcs is directly proportional to the energy released during the latter arc.
- The rate of charging of the solar cells is also dependent upon the internal capacitance. The internal capacitance is formed by charging of solar coupon body (which includes everything except solar cells) due to electron irradiation.
- If the arc occurs near to any of the edges of solar coupon, arc plasma reaches the nearest end earlier which makes the shape of arc plasma bubble expansion non-uniform. Often, two peaks are also observed in arc current waveform.

The energy released during the discharge is also dependent on the internal capacitance. The arc continues until both the capacitors are not discharged. Thus the severity of the arc can be controlled by controlling its internal capacitance. This creates the need to find a method for measuring the internal capacitance of the solar coupon (panel) which can be used to anticipate the detrimental effects of an arc. Dissipating the charge from the surface before it reaches near to threshold charge holding capacity of solar panel coupon, could maintain uniform charging in the solar panel coupon surface. A charge controlling method can be thought of as arc mitigation technique.

If small arcs occur on the surface at regular intervals, the charge stored in the internal capacitance gets dissipated regularly and thus the probability of major arcs can be minimized.

It is observed even in sustained arc (secondary) experiments that the internal capacitance plays an important role in elongation of the arc current.

Relation between charges accumulated with time on AZUR and ATJ solar panel coupon is shown figure 9. It is clear that the charging behavior is same in both the case. Maximum charge attained for 300 mm X 300 mm AZUR solar panel coupon is 38 µC while for ATJ solar panel coupon is 36 µC. Considering 36 µC as maximum charge holding capacity of a ATJ solar panel coupon of the given dimensions, RC time constant can be measured as time when coupon charge reaches Q_f/e

$$Q = Q_f/e = 36\ \mu C / 2.71 = 13.28\ \mu C$$

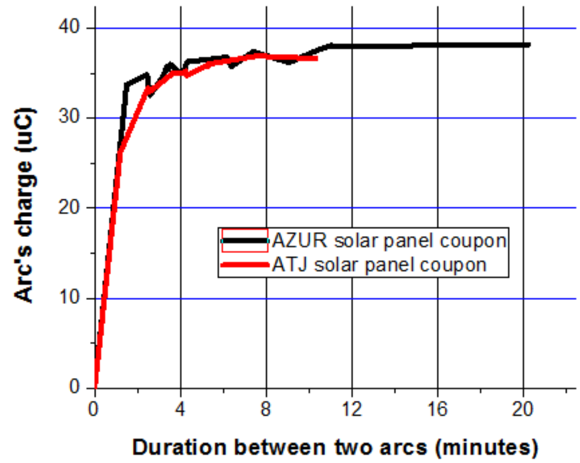

Figure 9: Graph showing relation between the charges accumulated on the solar coupon with time.

From the graph shown in figure 9, it is known that solar coupon charges upto 13.28 uC in around 60 seconds. Thus complete solar coupon gets charged in approximately 300 seconds (5 minutes). Thus, it can be concluded that if very minute arcs occur on the solar coupon's surface charge accumulation of major energy can be avoided. If an arc occurs in every 3-4 minutes, the overall charge on the solar coupon surface can be controlled; also it is experimentally proved that the minute arcs do not deteriorate the efficiency of the solar cells.

V. Future Scope and Conclusion

It is clear from the experiments that internal capacitance plays a very important role in the arc energy and charge. If efforts are made to minimize or control this capacitance, rigorousness of arc can be minimized. As this capacitance is dependent on bias voltage and the electron gun shower, and increases with time, a method for its accurate measurement with time is required.

VI. Aknowledgement

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