Progress in Spacecraft Environment Interactions II: Prediction and Control of Spacecraft Charging Hazards on the International Space Station

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The inaccuracy of the early development model of International Space Station (ISS) charging clearly indicated the need for a new, more accurate charging model suitable for prediction of ISS spacecraft charging in connection with hazard assessment and control. The ISS Environments Team has developed a first-principle physics model of ISS charging (the Plasma Interaction Model [PIM]) to be used with the International Reference Ionosphere (IRI) model of the ionospheric environment to model and predict ISS charging levels. The new model was developed and verified with Floating Potential Probe data and plasma contactor unit (PCU) emission current data during calendar years 2001 and 2002. Continued verification across ISS configuration changes during construction is provided by the Floating Potential Measurement Unit (FPMU).

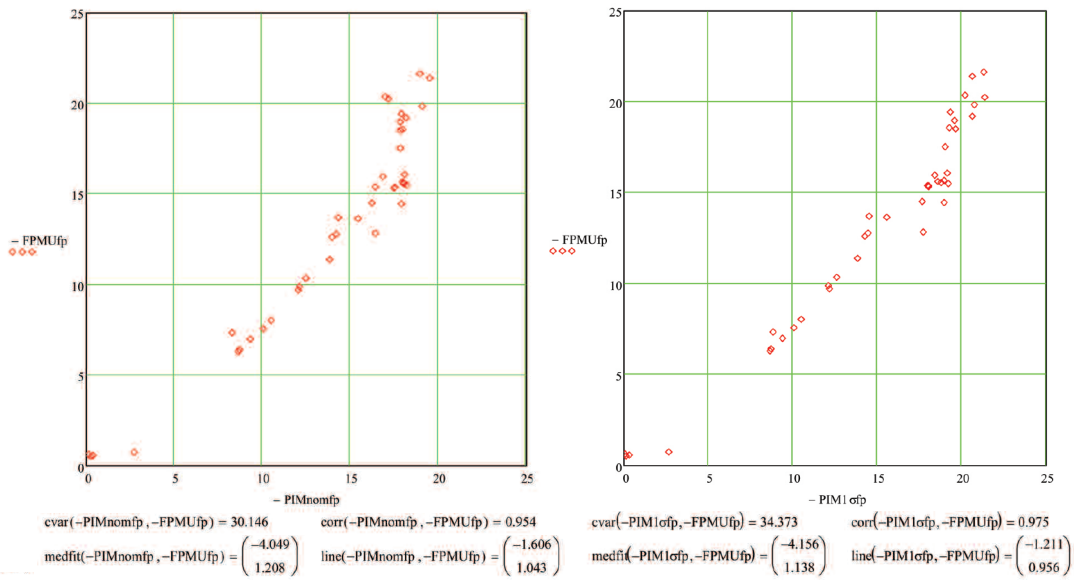

Fig. 1. *Correlations plots showing the relationship between the PIM/IRI predictions and FPMU measurements at FP.*

The FPMU was deployed on the ISS during early August 2006. A comparison of PIM/IRI predictions of ISS floating potential (FP) at the measurement point (FPMU site) with FPMU measurements of floating potential is shown in figure 1. The plot on the left side of figure 1 shows the correlation between PIM/IRI predictions and FPMU measurements using the climatologically defined mean (0σ) IRI ionosphere for the times of interest, and the resulting correlation coefficient is 0.954. The plot on the right side of figure 1 shows the correlation between PIM/IRI predications and FPMU measurements when the climatologically defined +1σ worst-case charging environment is used with the PIM/IRI model for the times of interest, and the resulting correlation coefficient is 0.975. FPMU measurements of ionospheric densities and temperatures are in better agreement with the +1σ charging environment. In either case, the PIM/IRI model proved remarkably accurate on its first comparison with measurement data, and with no need to adjust or tweak any of the input parameters.

The ability to accurately predict ISS FP for a particular set of ionospheric conditions is only one-half of the hazard assessment and control problem. Predicting how often ISS FP values may exceed some hazard threshold requires an understanding of the natural variability of the ionosphere itself. The IRI 2001 (or most recent released version thereof, IRI-2007) is used to estimate the climatologically average values of ionospheric parameters along the ISS flight path. Natural variability is determined by statistical analysis of many thousands of satellite and incoherent scatter radar data points around the corresponding IRI predictions for the range of latitudes, longitudes, and altitudes applicable to ISS operations. The result is the ISS Ionospheric Variability Specification PIM calculations using the IRI-2001/2007 ionosphere predict average or statistical mean ISS FP values, and the variability analysis allows the probability of occurrence of the one-, two- and three-sigma extreme FP values to be calculated around the climatologically defined mean for a particular ISS flight path on a particular Greenwich mean time day and time.

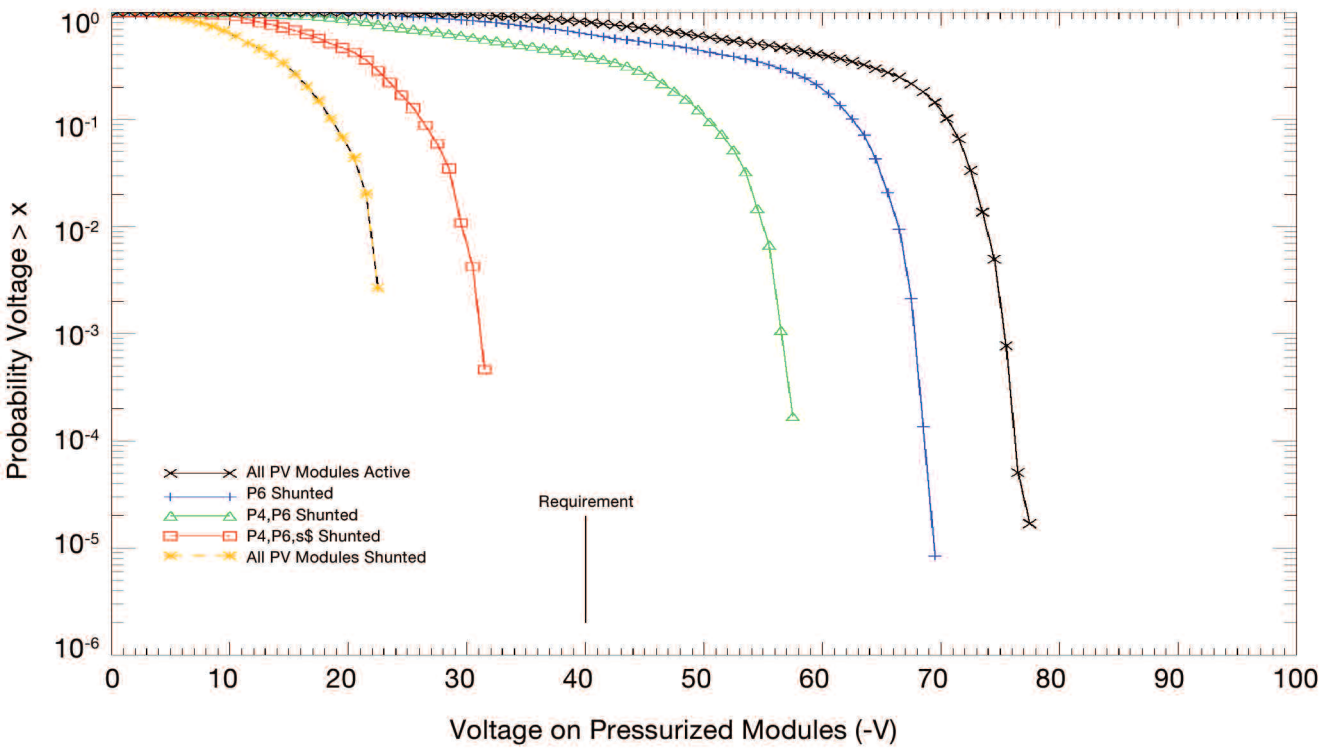

Fig. 2. The probability of occurrence of various FP values (over the life of the Program) along the ISS Flight/Stage 15A (targeted for launch in 2008).

Two hazards associated with ISS spacecraft charging processes have been identified: 1) a critical vehicle hazard (HR-ISS-EVA-305) in which surface dielectric breakdown arcing could degrade the thermal control properties of some surfaces leading to external surface touch temperature violations during extravehicular activity (EVA); and 2) a catastrophic EVA electric shock hazard (HR-ISS-EVA-312) driven to a large extent by the electrical characteristics of the U.S. spacesuit when occupied by a human being. An FP control point of -40V was established by the EVA Project Office for the EVA shock hazard. No charging/arcing threats to ISS avionics or pyrotechnics were identified. ISS requirements for electrical system grounding and bonding, as well as electromagnetic interference/electromagnetic compatibility requirements render ISS systems immune to spacecraft charging and arcing risks. ISS is equipped with two PCUs. Each PCU is able to clamp the ISS floating potential values to less negative than -40V at all locations on the ISS and for all build stages through end of program.

Using the PIM model of ISS plasma charging, the IRI model of the nominal ionosphere, and the ISS ionospheric variability specification, we can predict how often, during a period of about 10 years, we expect the ISS FP to exceed the -40V limit. Results of these calculations for the ISS vehicle configuration corresponding to the ISS Flight/Stage 15A are shown in figure 2. Figure 3 shows an ISS vehicle floating potential map for the worst-case charging environment at the Assembly Complete build stage. Note that the truss tip FP can be more negative than the centerline FP as a result of magnetic induction contributions. The verified PIM/IRI model is used to support ISS safety assessments, hazard control development, and maintenance as well as mission operations planning.

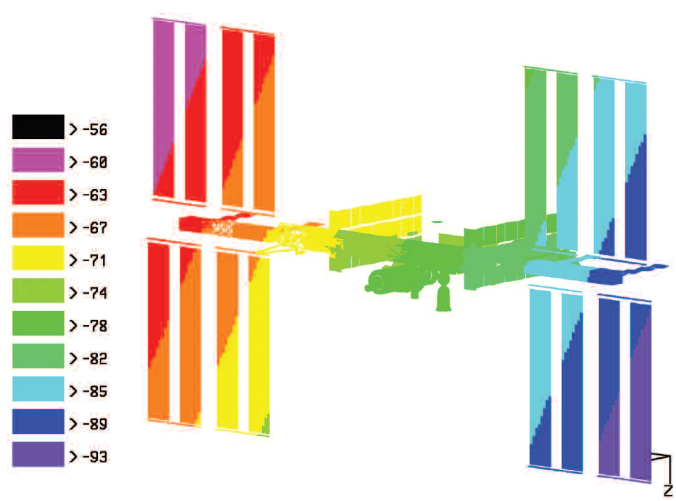

Fig. 3. An FP map of ISS for the worst-case charging environment of Figure 2. Note that FP can be more negative.