Lunar Power Systems: Operational Changes and Environmental Hazards

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Background

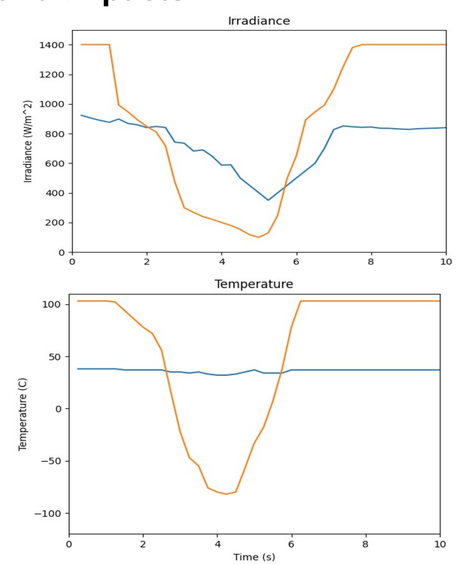
- The space industry is expected to establish a lasting human presence on the Moon in the coming decade [1].
- A reliable and resilient electric power grid is a pivotal requirement to sustain human life on the surface of the Moon and other extraterrestrial bodies [2].
- The Lunar environment introduces many novel conditions not experienced by Earth-based power systems, which will require a new approach to power system design and operation [3]-[5].
- This research investigates the impact of three likely failure modes - generation loss and two short circuit faults - on voltage stability in both the Earth and Lunar environment.

Environmental Hazards and Impacts

Lunar Hazard	Secondary Power System Impacts
Lunar Dust	• Sudden loss of generation, storage, or load • Damage to power system assets • False instrument readings

Plasma effects	• Sudden loss of generation, storage, transmission
	• Sudden fault due to:
	  • High impedance short
	  • Sensor error
	  • Switch error
	  • Short circuit
	  • Bad or stale data

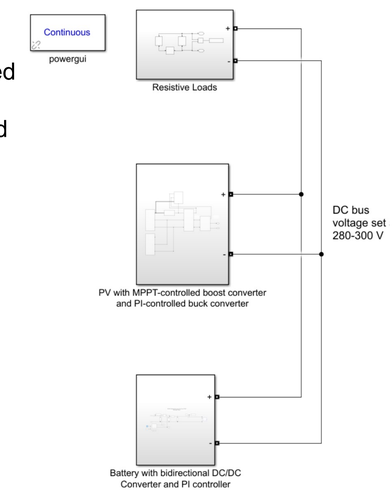
Micrometeorites	• Sudden loss of generation, storage, transmission, or load • High impedance fault
Thermal Extremes	• Sudden loss of generation, storage, or transmission • Accelerated degradation of power system assets • Electrical short • Arcing



Earth Conditions — Lunar Conditions

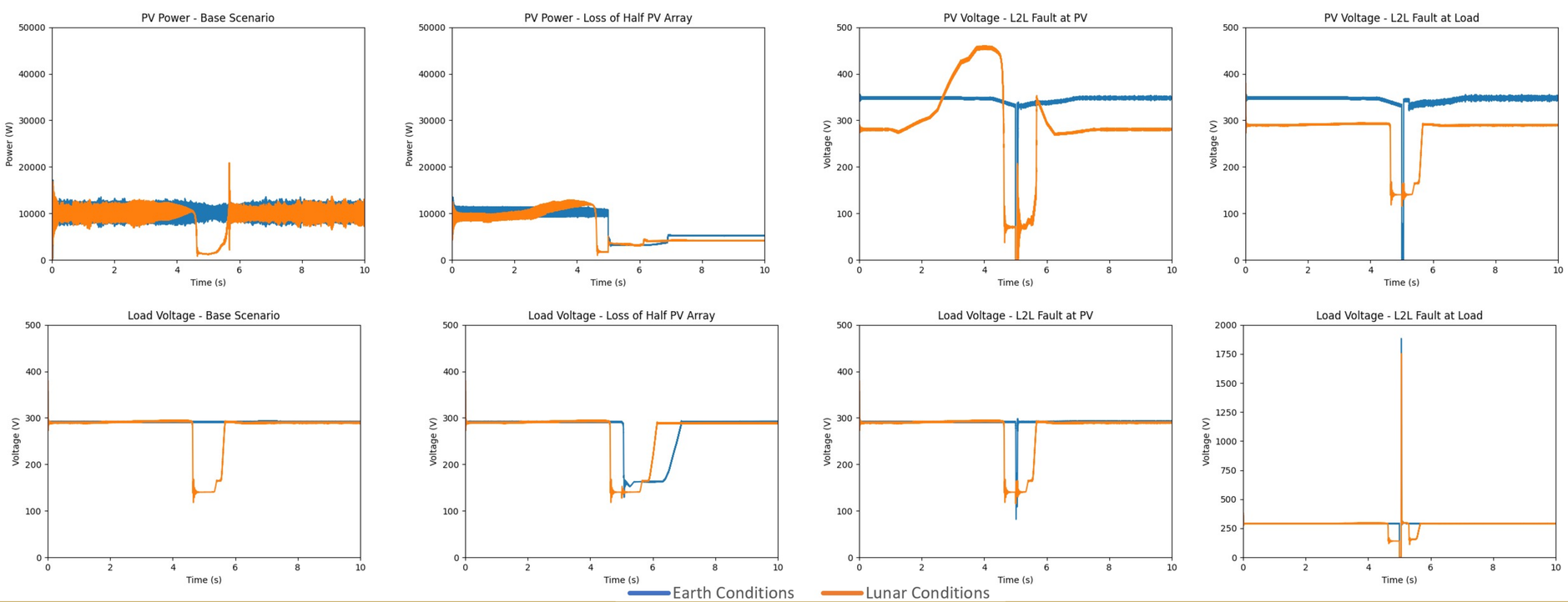
Simulation Environment

- DC microgrid consisting of
  - 50 kW solar PV,
  - boost converter controlled by MPPT,
  - buck converter controlled by PI,
  - 96 kWh battery storage with PI-controlled buck-boost converter, and
  - fluctuating loads.
- 10-second simulation scenarios include:
  - Base case (no fault)
  - Loss of half of PV array
  - Line-to-line fault at PV
  - Line-to-line fault at load
- Faults are introduced at 5 seconds for 3 cycles.



Modeled in MATLAB Simulink

Simulation Results



Earth Conditions — Lunar Conditions

Conclusions

- All scenarios created voltage instability in the system, but in some cases the naïve controls were able to recover the voltage provided to the loads and DC bus.
- The base case results show that under normal operation Lunar environmental conditions create voltage instability and resource inadequacy, both worsened by loss of generation and faults.
- Results show that conventional controls are insufficient for maintaining system stability under the potentially hazardous conditions of the Moon and present an opportunity for smart controls.

References

[1] "NASA plans to build a moon-orbiting space station: Here's what you should know," https://www.space.com/41763-nasa-lunar-orbiting-platform-gateway-basics.html, accessed: 2021-11-06. [2] H. J. Fincannon, "Lunar environment and lunar power needs," Springer Handbook Series Contribution, 2020. [3] A. D. Bintoudi, C. Timplalexis, G. Mendes, J. M. Guerrero, and C. Demoulias, "Design of space microgrid for manned lunar base: Spinning-in terrestrial technologies," in 2019 European Space Power Conference (ESPC). IEEE, 2019, pp. 1–8. [4] L. Johnson, "Orbital space solar power option for a lunar village," in 10th IAA Symposium on the future of space exploration: towards space village and beyond, 2017. [5] Z. Khan, A. Vranis, A. Zavoico, S. Freid, and B. Manners, "Power system concepts for the lunar outpost: A review of the power generation, energy storage, power management and distribution (pmad) system requirements and potential technologies for development of the lunar outpost," in AIP Conference Proceedings, vol. 813, no. 1. American Institute of Physics, 2006, pp. 1083–1092.