Feasibility of Passive MOSFET Paralleling for Photovoltaic Current-Voltage Curves

Alden Mapes, William Sekulic, Byron McDanold, Josh Parker

National Renewable Energy Laboratory, Golden, CO 80401 USA

Introduction

- Current-Voltage (IV) curves are an essential method of characterizing photovoltaic (PV) cells and modules that captures the current output of the device at a range of output voltages [1].
- The FLEA load was developed as a low-cost way to capture IV-curves and track maximum power for a wide range of PV devices, from small research cells to large modules.

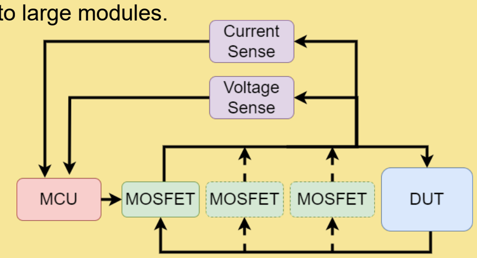

***Fig 1** A block diagram of the modified FLEA system*

- The FLEA is being developed with the goal of being fully open source and adaptable.
- MOSFETs are used an active resistor, controlling current through the module.
- For high-power modules, it becomes impractical to dissipate the power in a single MOSFET so paralleled MOSFETs are needed [2].
- When MOSFETs operate in the linear mode, they can experience positive feedback between current and temperature, which can cause a single MOSFET to monopolize current and fail [3].
- We evaluate passive circuit solutions to parallel MOSFETs for low cost IV-curve tracing and maximum power point tracking.

Methods

- We monitored temperature and current flow through each MOSFET.
- MOSFETs with an extended Forward Bias Operating Area were used to allow linear operation.
- Each MOSFET had a separate gate resistor to control for transient effects and a ballast resistor to help balance the power-sharing.
- For outdoor IV-curves, we modified a FLEA load with an external voltage divider and an amplifier to drive the higher gate voltages of these Linear MOSFETs.
- We characterized a generic 260W multi-crystalline silicon module and a 575W monocrystalline silicon bifacial module.

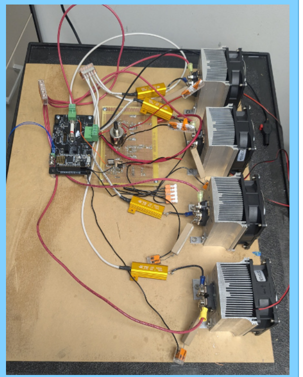

***Fig 2** The outdoor 4 MOSFET setup*

- To cool the MOSFETs, we used heat sinks mounted to fans
- A model of the behavior of the MOSFETs at a certain threshold voltages is shown compared to observed voltages in figure 5.

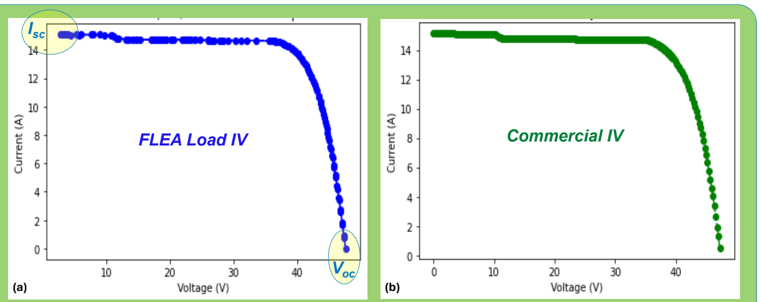

***Fig 3** showing IV curves taken on a 575 W module outdoors using 4 MOSFETs with a modified FLEA load [a] compared with an IV curve taken consecutively using a commercially available unit [b]*

Results

- We were able to characterize a 575W module outdoors
- Rapid thermal runaway was avoidable with proper circuit design and oversizing.
- The number of MOSFETs did not impact the FLEA's accuracy beyond the decreased I_{sc} due to lower $R_{DS\ on}$
- Slow unbalancing of current between devices occurred outside.
- While device characteristics affected current sharing, this did not cause breakdown.

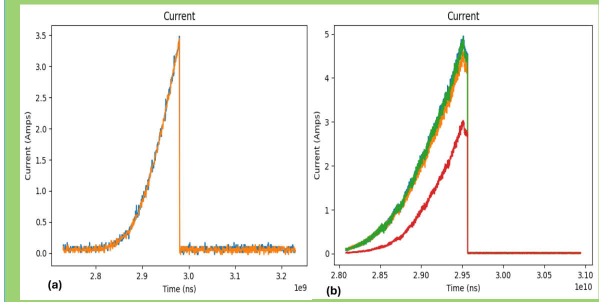

***Fig 4** current sharing between 2 well matched MOSFETs (a) compared to 4 MOSFETs with more deviation in device characteristics*

- A heatsink without a fan was unable to dissipate the heat from generated.
- FLEA loads are capable of measuring currents of 15 amps without external MOSFETs.

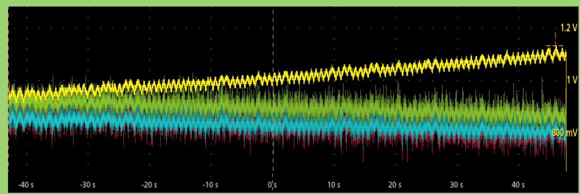

***Fig 5** current sharing after intentionally disconnecting a fan during an outdoor test*

Discussion

- While it is feasible to use passively controlled parallel MOSFETs for IV curve tracing, other operations like continuous maximum power tracking an active control scheme may provide control for higher power modules.
- An active operational amplifier control scheme is almost a requirement to adjust each MOSFET gate (V_{GS}) and reduce current imbalance.
- It is recommended to oversize MOSFETs to account for the high temperatures which they may experience during operation, as well as expected deviations in power-sharing.
- Using heat sinks analogous to those used to cool CPUs is an effective way of dissipating heat from MOSFETs.
- Binning MOSFETs by device characteristics is an effective way to ensure currents are well-matched between devices.

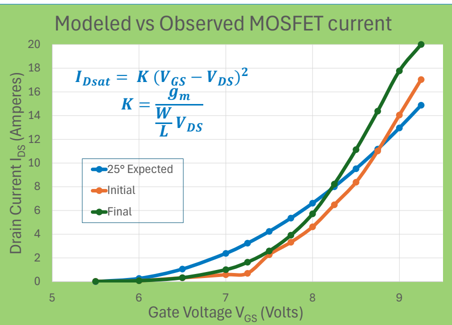

***Fig 6** Comparison between initial and final current flow and modeled current flow at a given gate voltage*

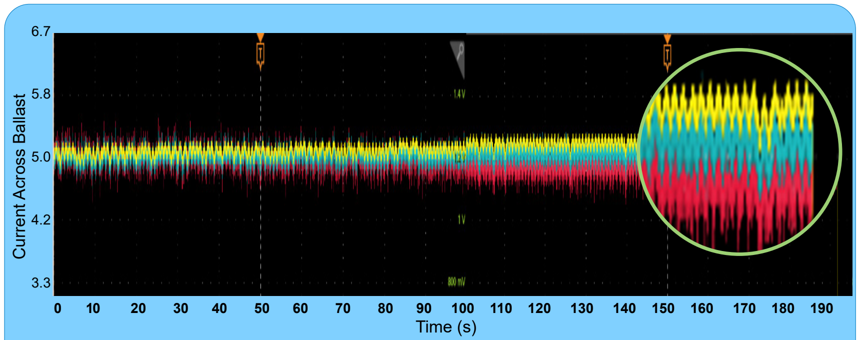

***Fig 7** A slow deviation between the currents of three devices during outdoor testing final difference ~8%*

References

[1] ASTM Standard G 1036-02. Standard Test Methods for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells. West Conshohocken. PA: ASTM International. 2019

[2] J. B. Forsythe, "Paralleling of Power MOSFETs for Higher Power Output," 1981 Annual Meeting Industry Applications Society, Philadelphia, PA, USA, 1981, pp. 777-796.

[3] AN11599 Using power MOSFETs in parallel, Nexperia, Nijmegen, Netherlands, Rev 1, 7 July 2015, Available: https://www.mouser.com/pdfDocs/AN11599.pdf.

Acknowledgments

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