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Enhancing Solar Module Testing: A Faster and Accurate Measurement Approach for High Efficiency Modules

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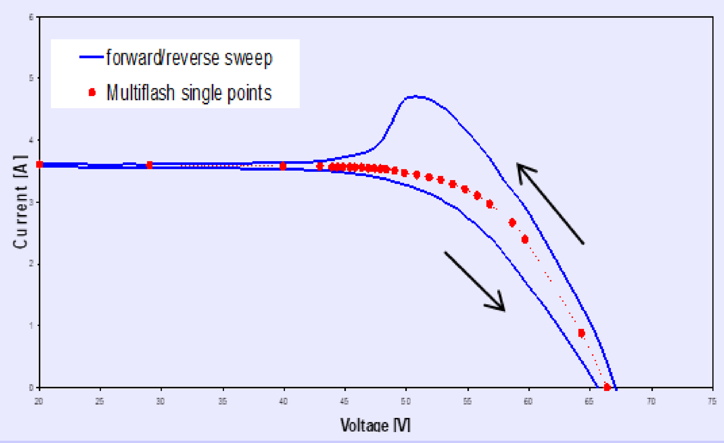
Motivation

The **ATTRACT Project** (Advanced techniques for the characterisation of photovoltaic modules) aimed to improve the **electrical characterization of high efficiency modules** affected by capacitive effects, by **reducing the time effort** needed for measurements at different irradiance and temperature levels **without affecting accuracy**.

Introduction

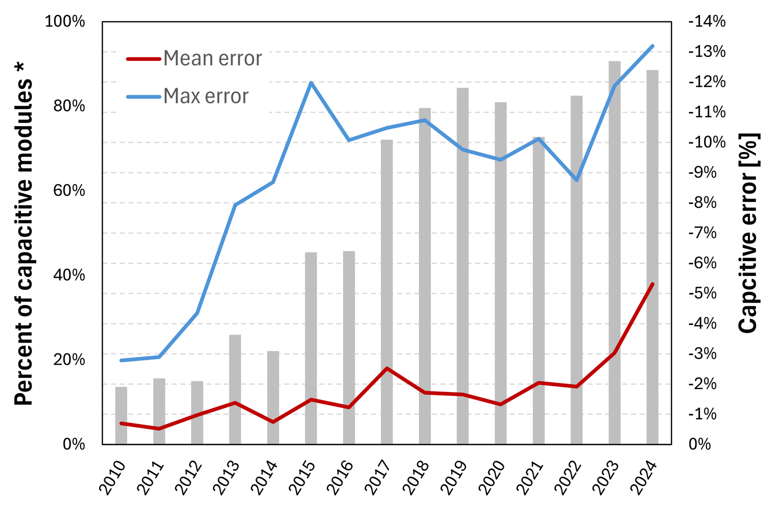
Capacitive Effect

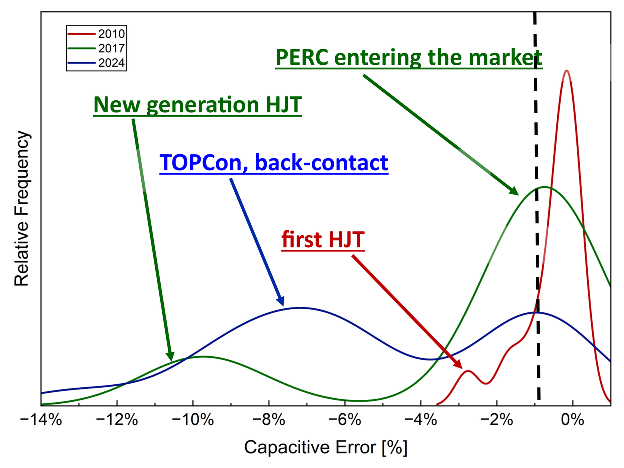
The growing prevalence of high-efficiency modules (PERC, HJT, IBC and TOPCon) with higher cell capacitances [1], has made accurate measurement with pulsed solar simulators increasingly challenging.



Example showing the capacitive effect on a 10ms pulsed solar simulator

SUPSI PVLAB Statistics





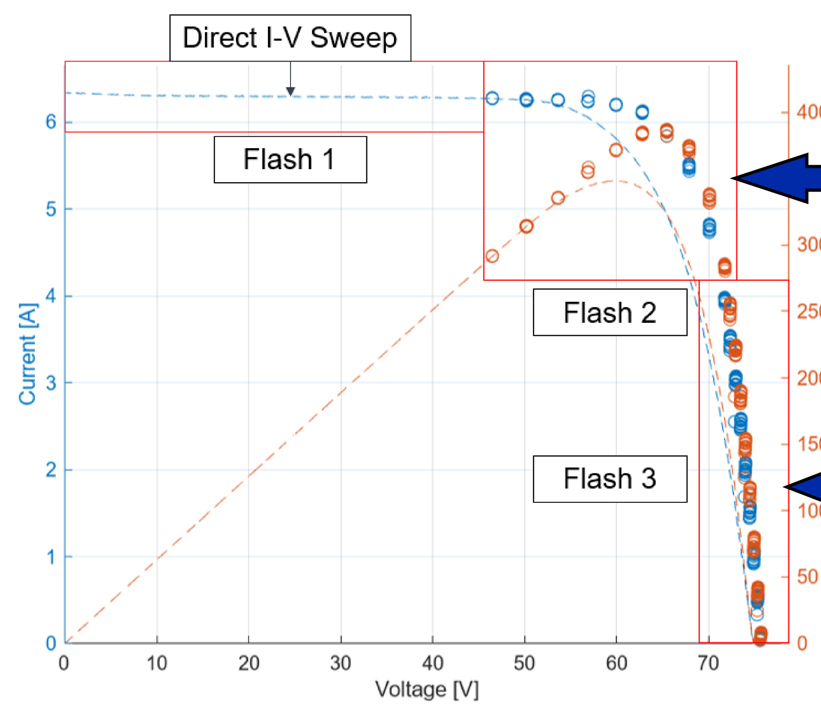
* Modules with an error >0.5% are considered to be capacitive

Advantages & Disadantages of Existing Test Methods

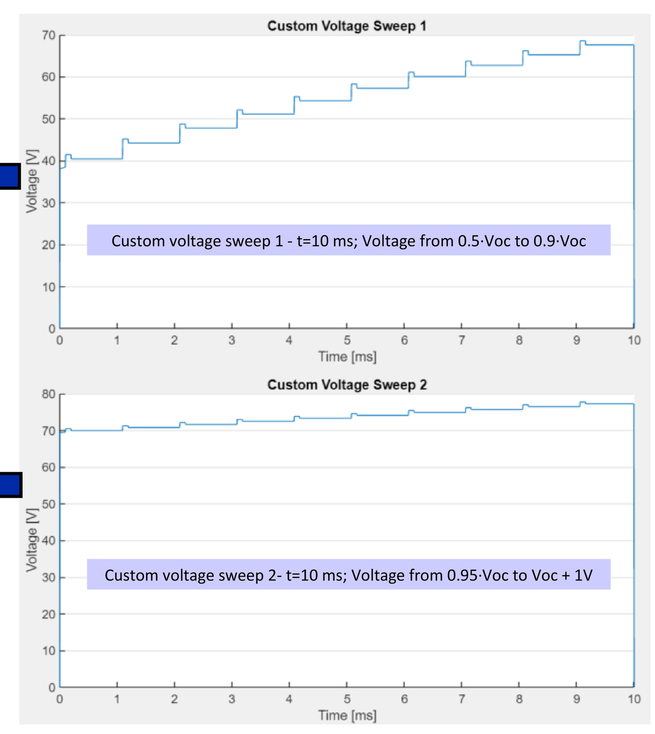
Approach	Description	Applicability	Advantages	Disadvantages
Single I-V sweep	Fast voltage sweep from Isc to Voc within single flash.	Non-capacitive modules	Standard approach available on most test equipment's. Very fast.	Underestimates the power of capacitive modules.
Multi-flash measurement	Fixed voltage within multiple flashes.	High to ultra-high capacitive modules	Very accurate.	Time consuming and high usage of lamp. Non standard modules (e.g reduced number of cells, ultra large cells, …) are more complex to be measured.
Steady state measurement	Slow voltage sweep with a steady state solar simulator.	All modules	Avoidance of capacitive measurement errors.	Requires expensive Class A+ steady state solar simulator. Difficult control of module temperature.
Multi-sectional measurement	Reduced voltage sweeps within multiple flashes.	Low-medium capacitive modules.	Fast and accurate method for low capacitive modules.	A reconstruction of the I-V curve is required.
Dragonback® measurement	Single sawtooth-like voltage ramp within single flash.	Most capacitive modules. Mainly for in-line testing in production.	Very fast and accurate.	Complex procedure for the determination of the appropriate sawtooth parameters.
Dark I-V measurement	I-V curve correction based on steady state and transient dark I-V curves.	To be validated for different technologies.	Need of reduced number of flashes.	Requires specific electronic load. Accuracy is limited by the accuracy of the series resistance Rs used for the correction.
I-V curve correction method	I-V curve correction based on theoretical models and additional measurements (e.g dark impedance)	To be validated for different technologies.	Need of reduced number of flashes.	Accuracy is limited by the methodology and accuracy of the correction parameters.

Fast & Accurate Measurement Procedure for Capacitive Modules

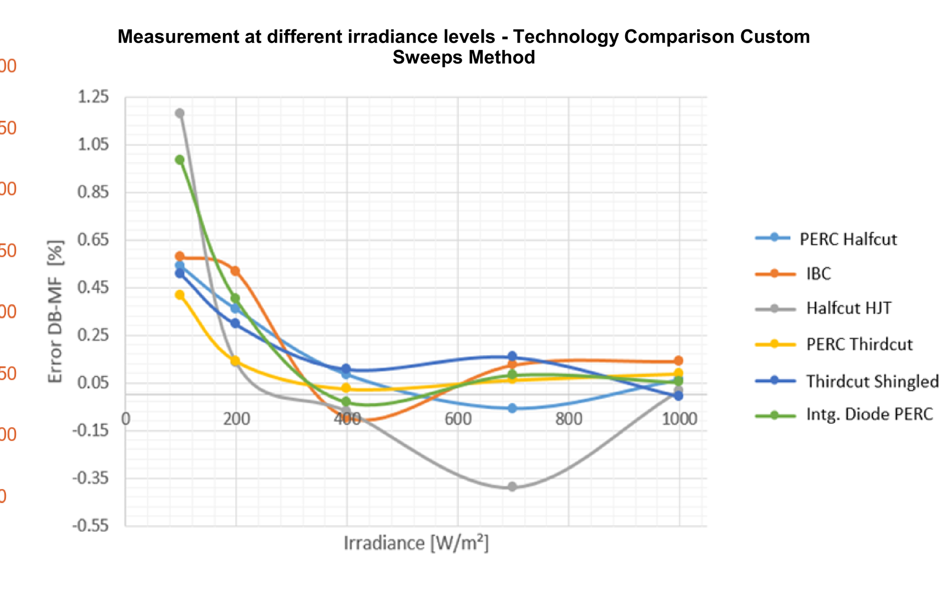
- The method consists in measuring the I-V curve of PV modules through a multi-flash approach that combines the direct sweep techniques with Dragonback® flashes [2].
- The I-V curve is obtained by combining the results of the flashes and fitting the curve.
- A direct I-V sweep is performed to obtain the initial segment of the curve (0 - 0.7·Voc), followed by 1-2 custom voltage sweeps to measure the remaining sections.



Result of a Custom Sweeps measurement with 3 flashes on a IBC module with equivalent capacitance of ΔPm=11.3%



Custom Sweeps- 3 flashes final result



Measurement at different irradiance levels, technology comparison using the custom sweeps methodology

Result

The Custom Sweeps approach was introduced and validated within an international laboratory inter-comparison, demonstrating:

⇒ a reduction in the effective measurement time for a full power matrix of **10 times less** than the best reference method (multi-flash approach)

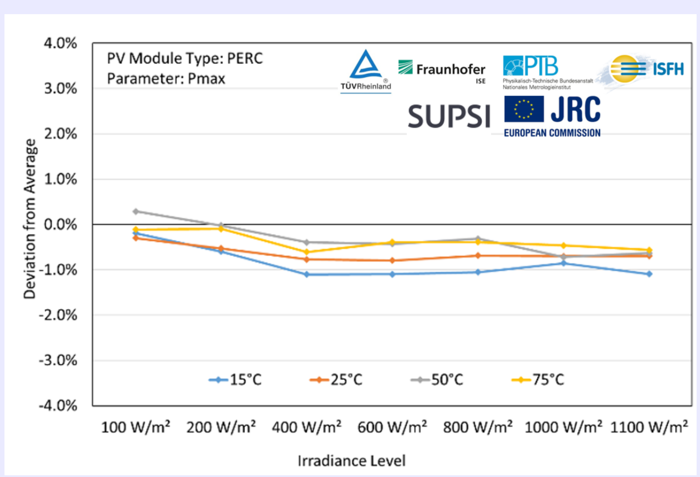
⇒ uncertainties close to the one achieved with the best reference methods (uPmax = **±1.1%** [k=2])

⇒ close to constant uncertainties over the whole range of applicability (100-1100 W/m² and 15-65°C)

Test	Multi-flash	Custom Sweeps
Maximum power at STC	900 s (15 min)	90 s (1.5 min)
Measure at different Irradiance levels (GCO)	4500 s (75 min)	450 s (7.5 min)
Power Matrix	25200 s (420 min)	2520 s (42 min)

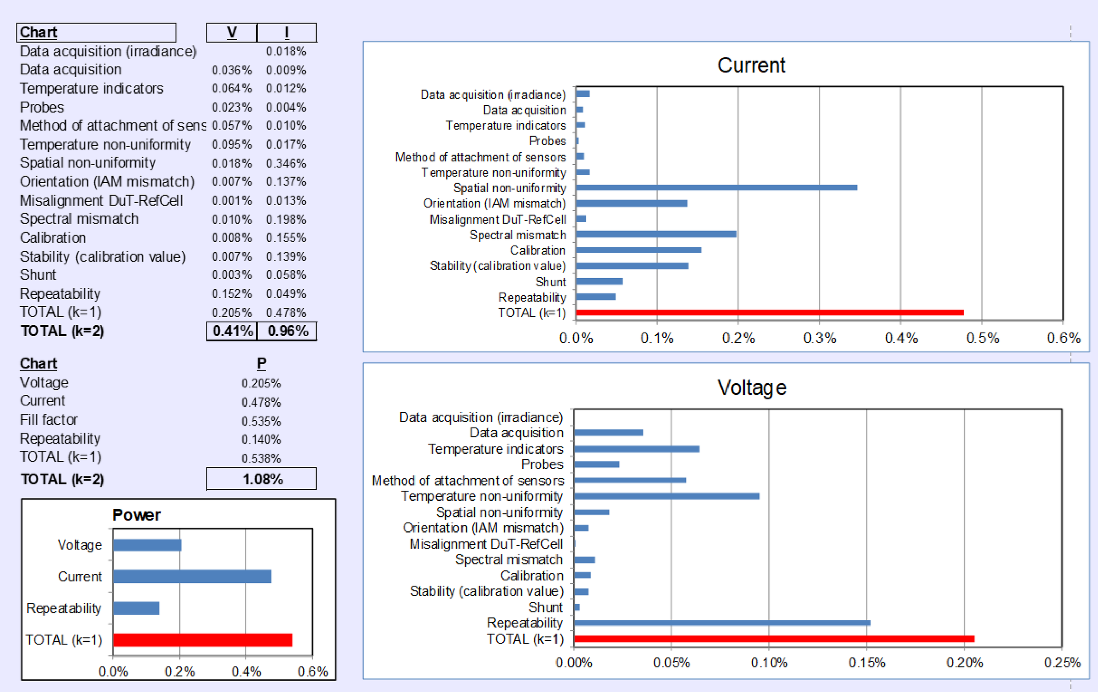
Effective measurement time for multi-flash and custom sweeps methods. Not considering temperature stabilization.

International laboratory inter-comparison partners: **TÜV Rheinland Solar, Fraunhofer ISE, SUPSI PVLab, Institute for Solar Energy Research GmbH, Physikalisch-Technische Bundesantstalt (PTB) and the European Solar Test Installation (JRC).**



International laboratory inter-comparison results. Deviation from average of the 6 laboratories for the maximum power in the power matrix test using the custom sweeps as measuring method.

Accuracy



New best P_{max} uncertainty for c-Si modules

u(k=2,>95%)= **±1.1%** *
(old value ±1.6%)

* Audited August 2024

Reference values
Not accredited laboratories ±2-3%
Mobile test laboratories ±3-4%

References:

[1] M. Pravettoni, D. Poh, J. Prakash Singh, J. Wei Ho, and K. Nakayashiki, "The effect of capacitance on high-efficiency photovoltaic modules: A review of testing methods and related uncertainties,"

[2] A. Virtuani, G. Rigamonti, P. Beljean, G. Friesen, M. Pravettoni, and D. Chianese, "A fast and accurate method for the performance testing of high-efficiency C-Si photovoltaic modules using A 10 Ms single-pulse solar simulator," in Conference Record of the IEEE Photovoltaic Specialists Conference, 2012, pp. 496–500. doi: 10.1109/PVSC.2012.6317664.