Testing and Modeling of Photovoltaic Power Systems in Nearly Zero Energy Buildings

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Research context and motivation

- Actual challenges of the building sector: increasing energy efficiency and reducing pollution → main strategies: optimization of the energy consumption and the production from Renewable Energy Sources (RES)
- Realization of nearly Zero Energy Buildings (nZEBs), in which their loads are significantly fulfilled by *local* RES (for example PhotoVoltaic, PV, generators)
- PV plants can be affected by electrical or mechanical defects and failures → underperformance → current diagnosis methods (InfraRed Thermography, IRT, and ELectroluminescence, EL): expensive and provinding non-continuous state of PV health

Addressed research questions/problems

Design of an energy community consisting of nZEBs

Energy and economic benefits of a community of nZEBs with respect to independent users.

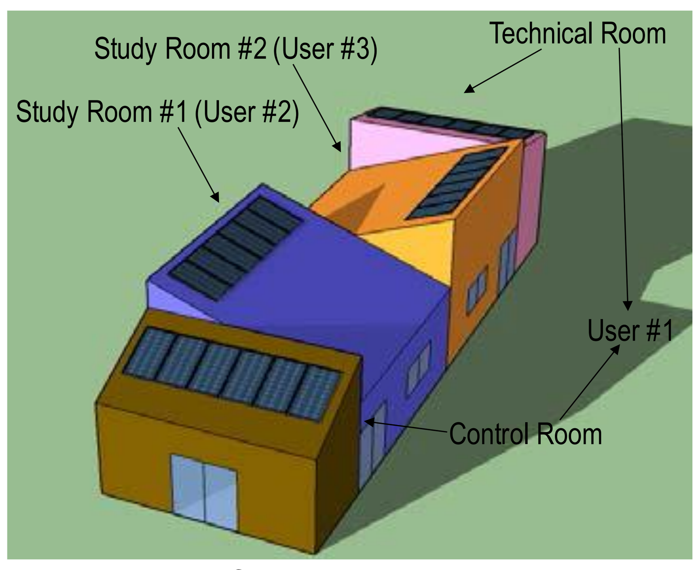
Automatic detection of defects in PV generators

Real time detection of defects by DC/AC converter instead of conventional diagnostics (IRT and EL tests).

Novel contributions

Design of an energy community consisting of nZEBs

- 3 all-electric new nZEBs while in the majority of the projects → retrofit actions on existing buildings (limited energy efficiency)
- load similar to tertiary sector buildings → good match between production (PV) and consumption



Layout of the energy community

Automatic detection of defects in PV generators

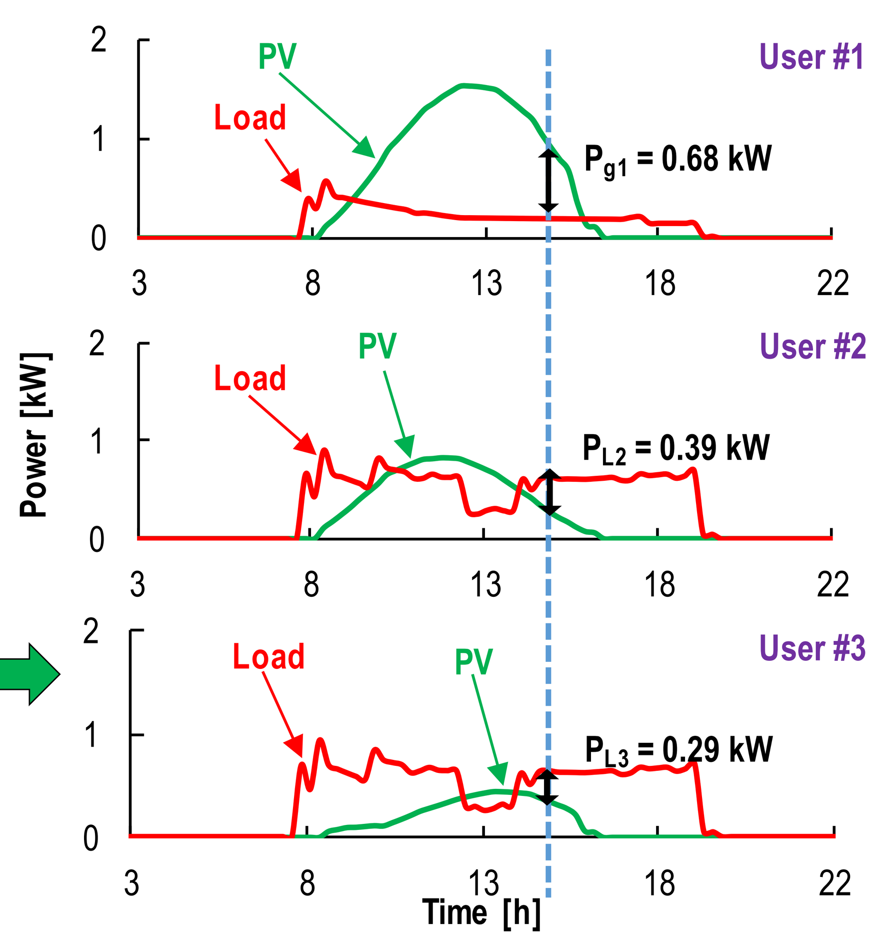
Development of an algorithm which permits the sensorless real time detection of defects in PV generators.

Adopted methodologies

Design of an energy community consisting of nZEBs

The adopted procedure is the following:

- Architectural design of nZEBs as energy community
- Definition of thermal and electrical loads
- Design of optimal collection of solar energy
- PV-storage modeling and sizing
- Power balance
- Check on the self sufficiency → in case of low performance: Reduction of thermal demand, Electrical Demand Side Management, Increased PV-storage size

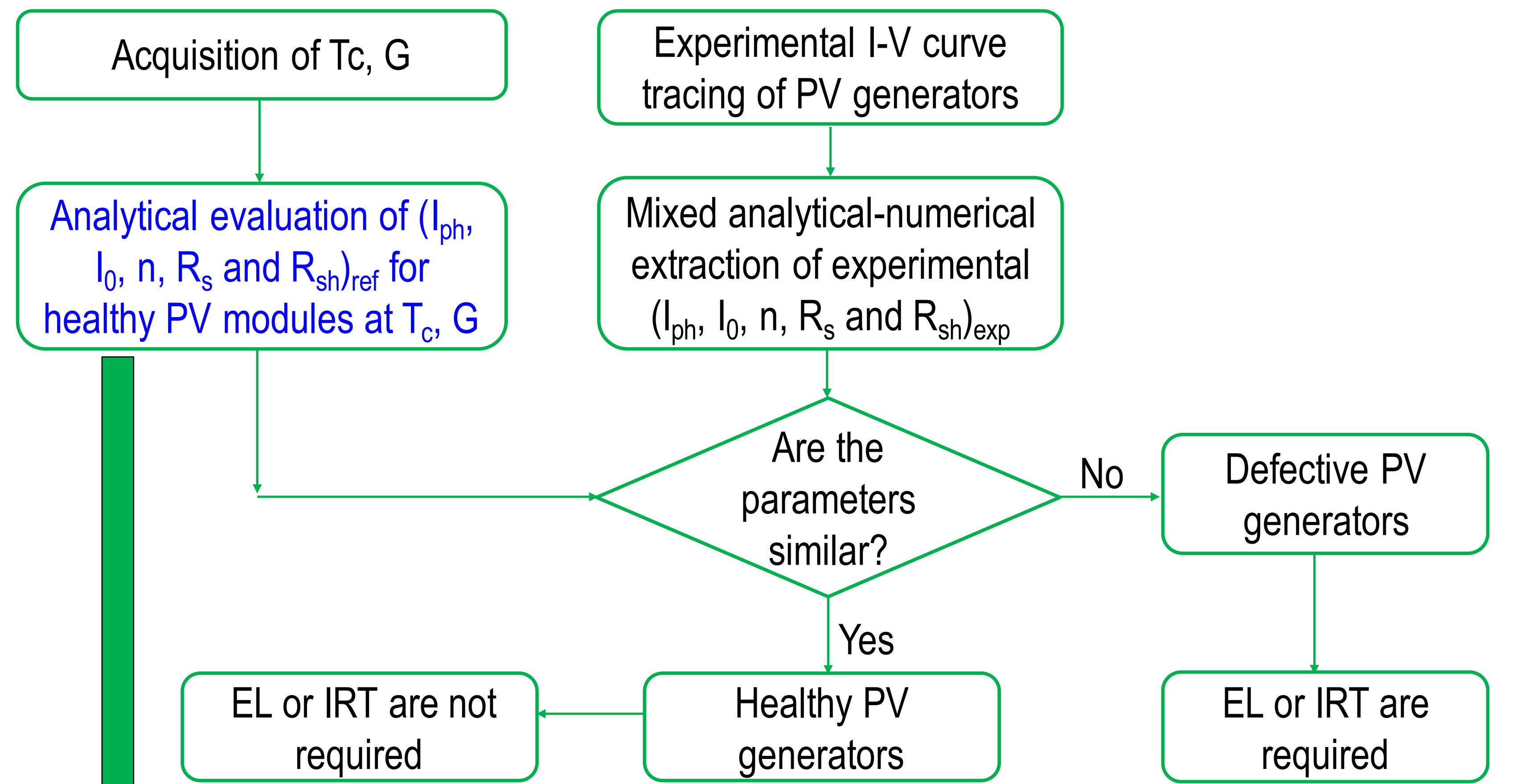


Power profiles on January 15th

Adopted methodologies

Automatic detection of defects in PV generators

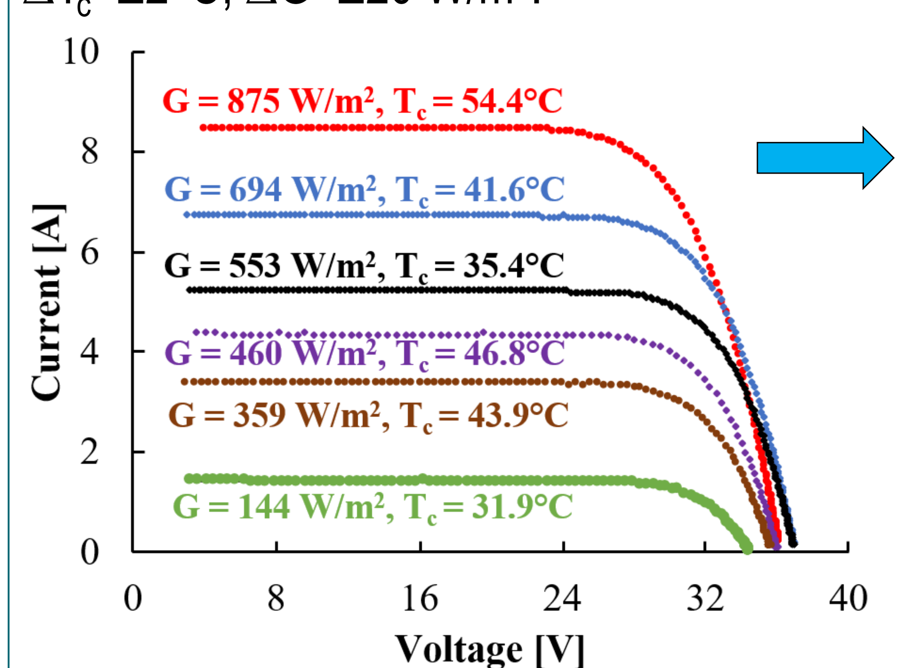
DC/AC converters acquire the I-V curve of PV generators, extract in real time the 5 parameters of the equivalent circuit from the experimental data and evaluate the state of health of the generators by comparing the current parameters (from experiments) with reference values for healthy PV modules.



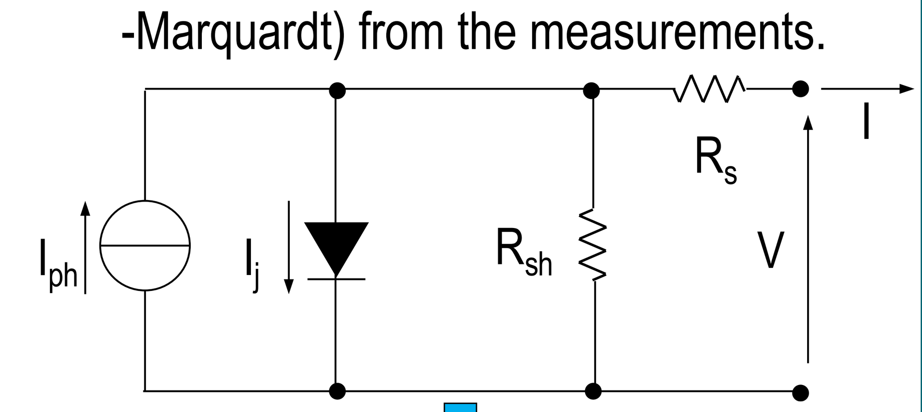
Flowchart of the procedure

Identification of semi-empirical equations for a m-Si PV module under test

I-V curves are measured in several (G, T_c) with an automatic calibrated data acquisition system: $\Delta V=\pm 0.1\%$, $\Delta I=\pm 1\%$, $\Delta P=\pm 1\%$, $\Delta T_c=\pm 2°C$, $\Delta G=\pm 20$ W/m^2.



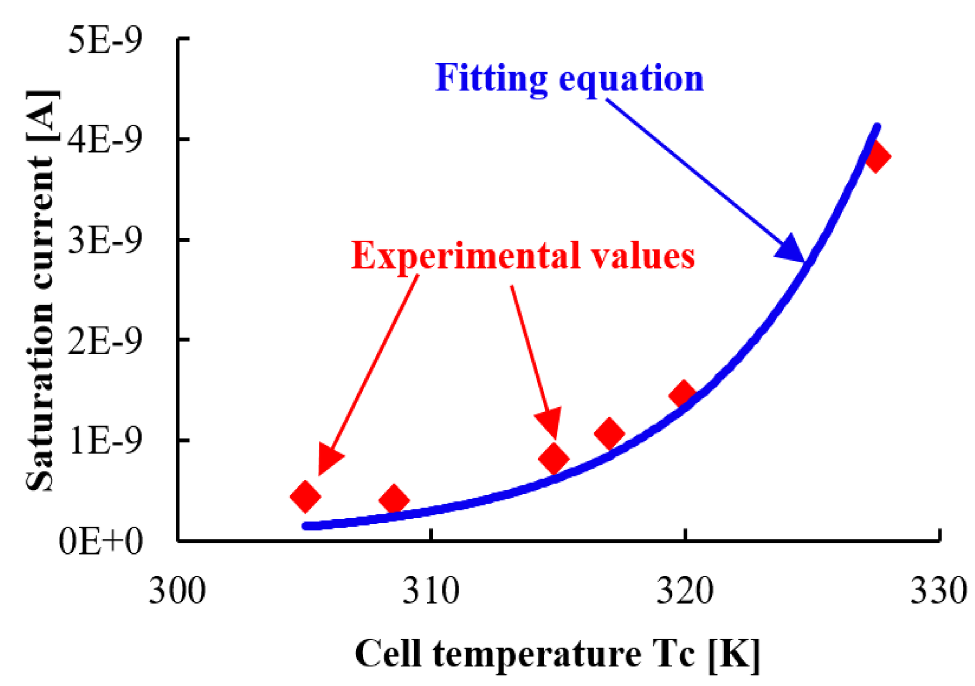
The five parameters of the equivalent circuit are extracted (Levenberg-Marquardt) from the measurements.



A nonlinear regression on experimental parameters permits to identify the semi-empirical equations for the dependence with G, T_c.

The optimal set (a, b, c, d, e, f) has to be optimized for the specific PV generator.

$$\begin{cases} I_{ph}=f(a,\ G,\ G_{STC},\ \alpha,\ T_c,\ T_{STC}) \\ I_0=f(b,\ T_c,\ T_{STC},\ E_{g,STC},\ E_g) \\ n=f(c) \\ R_s=f(d,\ e,\ G,\ G_{STC},\ T_c,\ T_{STC}) \\ R_{sh}=f(f,\ G,\ G_{STC}) \end{cases}$$



Future work

Design of an energy community consisting of nZEBs

- Energy and economic analysis to determine the selling price of electricity between the users of the microgrid → dependence on the orientation of PV modules, surplus/deficit, PV-storage size, current State Of Charge (SOC) of the batteries

Automatic detection of defects in PV generators

- Application of the procedure to a sample of PV generators for three technologies (conventional m-Si, high efficiency m-Si and p-Si)
- Determination of the range of parameters for healthy and defective PV modules → a priori identification of the type of defect and integration of the procedure in the inverter software

List of attended classes

- 01LGSRV – Characterization and planning of small-scale multigeneration systems (September 2019, 5 credits)
- 01QEZRV – Sviluppo e gestione di sistemi di acquisizione dati (June-July 2019, 5 credits)
- 02ITTRV – Generatori e impianti fotovoltaici (September 2019, 5 credits)
- European PhD School, Gaeta (May 2019, 4 credits)

Submitted and published works

1. F. Spertino, A. Ciocia, P. Di Leo, S. Fichera, G. Malgaroli, A. Ratclif; "*Towards the Complete Self-Sufficiency of a nZEBs microgrid by Photovoltaic Generators and Heat Pumps: Methods and Applications*", IEEE Transactions on Industry Applications, Special Issue, 2019
2. F. Spertino, E. Chiodo, A. Ciocia, G. Malgaroli, A. Ratclif, "Maintenance Activity, Reliability Analysis and Related Energy Losses in Five Operating Photovoltaic Plants", EEEIC, Genova, 2019, pp. 1-6
3. P. Di Leo, F. Spertino, S. Fichera, G. Malgaroli, A. Ratclif; "*Improvement of Self-Sufficiency for an Innovative Nearly Zero Energy Building by Photovoltaic Generators*", IEEE PowerTech, Milano, 2019, pp. 1-6
4. A. Ciocia, A. Carullo, P. Di Leo, G. Malgaroli, F. Spertino; "*Realization and Use of an IR Camera for Laboratory and On-field Electroluminescence Inspections of Silicon Photovoltaic Modules*", PVSC 2019, Chicago, 2019
5. A. Ciocia, G. Malgaroli, A. Spedicato, F. Spertino, H. Andrei, V. A. Boicea; "*Quality Check during Manufacturing of Custom Photovoltaic Modules with Back-Contact Cells*", UPEC, Bucharest, 2019
6. F. Bizzarri, S. Nitti, G. Malgaroli; "*The use of drones in the maintenance of photovoltaic fields*", Science and future 2, Torino, 2019
7. F. Spertino, G. Chicco, A. Ciocia, G. Malgaroli, A. Mazza, A. Russo; "*Harmonic distortion and unbalance analysis in multi-inverter photovoltaic systems*", SPEEDAM, Amalfi, 2018, pp.1031-1036

POLITECNICO DI TORINO

PhD program in
Electrical, Electronics and Communications Engineering