enel Green Power

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Caratterizzazione e massimizzazione dell'efficienza di impianti di produzione di energia elettrica da fonti rinnovabili tramite l'utilizzo di elettronica di potenza distribuita
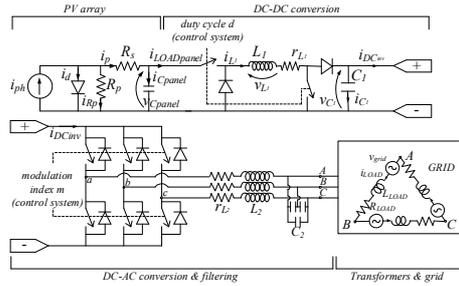
OVERVIEW

- ❏ The installation of **distributed converters** and of **distributed electrochemical storage systems** in large PV fields is a very topical subject.
- ❏ Unfortunately, the **evaluation of performance** in comparison to standard configurations (central inverters) as well as the **energy management of the battery packs** in utility-scale PV fields are **difficult tasks** for several reasons, for example:
  - ➢ Large number of partial unavailabilities
  - ➢ Monitoring systems issues leading to missing or wrong data
  - ➢ Large number of time-varying parameters depending on seasonality, degradation rates, power derating in case of high temperatures, etc.
- ❏ A **proper modeling approach** can **overcome this kind of issues** allowing the assessment of a suitable energy management strategy

MODELING APPROACH

- ❏ **For large PV plant:** development of a **novel behavioral model based on a modified state-space average method** devoted to large PV plants with multiple conversion stages DC/DC and DC/AC getting a good trade-off between accuracy and complexity

$$\dot{x} = \overline{A}x + \overline{B}u$$
$$y = \overline{C}x + \overline{D}u$$

$$x = \begin{bmatrix} v_{Cpanel} \\ i_{L1} \\ v_{C1} \\ x_1 \\ \dots \\ x_{18} \end{bmatrix} \quad u = \begin{bmatrix} i_{ph} \\ i_d \\ V_{grid} \end{bmatrix}$$

$$y = \begin{bmatrix} x_1 \\ \dots \\ x_{12} \end{bmatrix}$$

x_i = symmetrical components

$i_{ab} = 2x_1\cos\omega t - 2x_2\sin\omega t$
$i_{bc} = 2x_3\cos\omega t - 2x_4\sin\omega t$
$i_{ca} = 2x_5\cos\omega t - 2x_6\sin\omega t$
$v_{AB} = 2x_7\cos\omega t - 2x_8\sin\omega t$
$v_{BC} = 2x_9\cos\omega t - 2x_{10}\sin\omega t$
$v_{CA} = 2x_{11}\cos\omega t - 2x_{12}\sin\omega t$
$i_{LOAD,AB} = 2x_{13}\cos\omega t - 2x_{14}\sin\omega t$
$i_{LOAD,BC} = 2x_{15}\cos\omega t - 2x_{16}\sin\omega t$
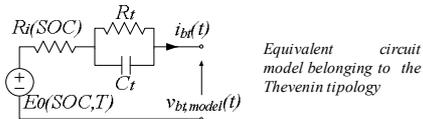$i_{LOAD,CA} = 2x_{17}\cos\omega t - 2x_{18}\sin\omega t$

Block diagram of a generic grid-connected PV system with multi-stage conversion system.
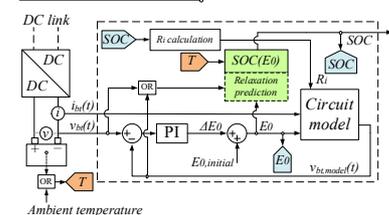State-space representation for each component. All the components are mixed into a single state-space average model.
The DC-bus current plays a key role linking the "DC side" with the "AC side".

- ❏ **For batteries:** Development of a **real-time model-based algorithm for the estimation of SOC (State of Charge), SOH (State of Health), PC (Power Capability) and EC (Energy Capability)**

*Equivalent circuit model belonging to the Thevenin tipology*

State-space averaging modeling approach

$\overline{A} = A_{ON}d + A_{OFF}(1-d)$
$\overline{B} = B_{ON}d + B_{OFF}(1-d)$
$\overline{C}$ = identity matrix
$\overline{D}$ = null

The elements of these matrices are listed in the full paper

PI-based observer to perform SOC estimation, integration of a voltage relaxation prediction function

The **PC** represents the **power that the battery pack can continuously manage** for a given **time horizon Δt** without overcoming the fixed SOC thresholds. The product between PC and Δt represents an estimation of the EC. Such parameters are crucial to properly size the battery packs being part of a distributed storage system in a large PV plant.

VALIDATION TESTS: PV PLANTS

About the **behavioral model of PV plants**, its **accuracy** can be assessed as the relative difference between the **measured power curve** (provided by **dataloggers** mounted in operating PV plants) and the power curve provided by the model. Referring to the energy produced on a daily basis, we experienced an **average relative error about 3.5 %** that is satisfactory with respect to the typical precision of meters and sensors in large PV plants. At the same time, there are **significant benefits in terms of computational time**.

VALIDATION TESTS: BATTERIES

The validation process of the battery estimation algorithm has been carried out performing some **tests on the experimental bench** shown in the picture.
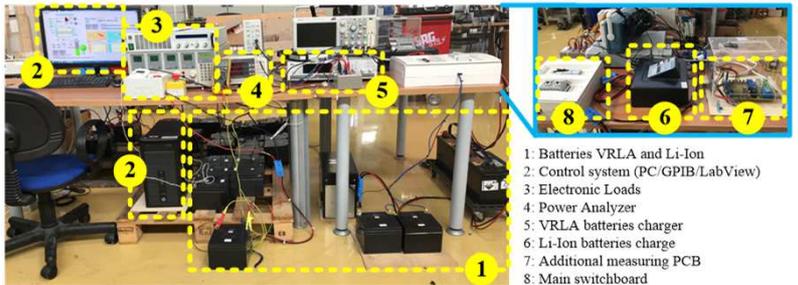

1: Batteries VRLA and Li-Ion
2: Control system (PC/GPIB/LabView)
3: Electronic Loads
4: Power Analyzer
5: VRLA batteries charger
6: Li-Ion batteries charge
7: Additional measuring PCB
8: Main switchboard
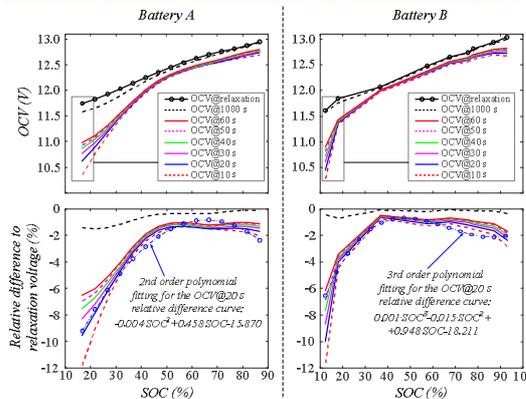
Open circuit voltage (OCV) at different time intervals after the discharge shows a typical trend with respect to the relaxation voltage and to the actual SOC. This trend can be approximated with a low order polynomial function and easily implemented in look-up tables.

2nd order polynomial fitting for the OCV@20 s relative difference curve:
$-0.004\,SOC^2 + 0.458\,SOC - 15.870$

3rd order polynomial fitting for the OCV@20 s relative difference curve:
$0.001\,SOC^3 - 0.015\,SOC^2 + 0.948\,SOC - 18.211$

A CASE STUDY: 2 MW PV PLANT IN CENTRAL ITALY

500 kW PV experimental subfield with string optimizers

Actual configuration of the experimental subfield

Hypothesis: adding a distributed storage system
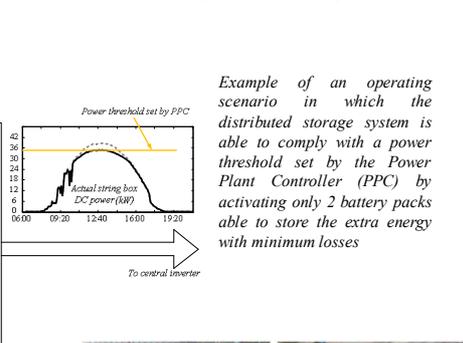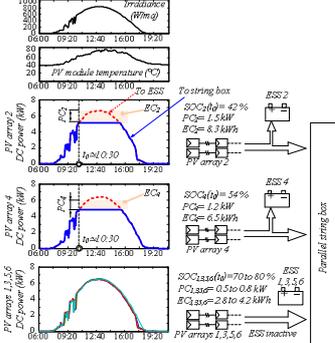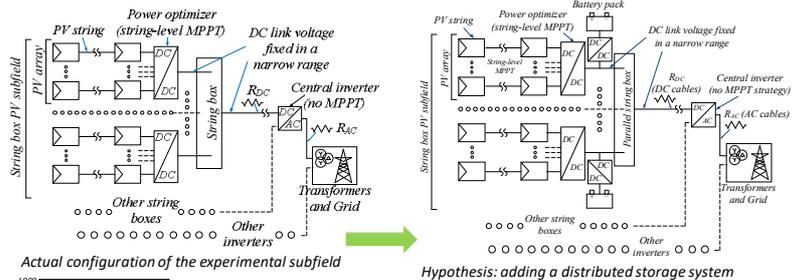
Example of an operating scenario in which the distributed storage system is able to comply with a power threshold set by the Power Plant Controller (PPC) by activating only 2 battery packs able to store the extra energy with minimum losses

Pictures of the PV plant and of the optimizers

PAPERS / CONFERENCES

- G. Nobile, M. Cacciato, G. Scarcella, G. Scelba, "Losses Minimization Control for an Integrated Multi-Drives Topology devoted to Hybrid Electric Vehicles", published in IEEE Transactions on Industrial Electronics
- G. Nobile, M. Cacciato, G. Scarcella, G. Scelba, A. G. F. Di Stefano, G. Leotta, P. M. Pugliatti, F. Bizzarri "Performance assessment of utility-scale PV plants exploiting a novel integrated state-space average modelling approach", submitted for publication in Taylor & Francis EPE Journal
- G. Nobile, M. Cacciato, G. Scarcella, G. Scelba, E. Vasta, A. G. F. Di Stefano, G. Leotta, P. M. Pugliatti, F. Bizzarri "Distributed converters in large PV plants: performance analysis supported by behavioral models", in proceedings of the IEEE ELECTRIMACS 2019 Conference, Salerno (Italy), 21-23 May 2019
- G. Nobile, M. Cacciato, G. Scarcella, G. Scelba, E. Vasta, L. Tornello, A. G. F. Di Stefano, G. Leotta, P. M. Pugliatti, F. Bizzarri "A novel model-based approach for the energy management of distributed storage systems in utility-scale PV fields", in proceedings of the IEEE EPE 2019 Conference, Genova (Italy), 3-5 Sep 2019