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A power and energy procedure in operating photovoltaic systems to quantify the losses according to the causes

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Abstract

Recently, after high feed-in tariffs in Italy, retroactive cuts in the energy payments have generated economic concern about several grid-connected photovoltaic (PV) systems with poor performance. In this paper the proposed procedure suggests some rules for determining the sources of losses and thus minimizing poor performance in the energy production. The on-site field inspection, the identification of the irradiance sensors, as close as possible the PV system, and the assessment of energy production are three preliminary steps which do not require experimental tests. The fourth step is to test the arrays of PV modules on-site. The fifth step is to test only the PV strings or single modules belonging to arrays with poor performance (e.g. mismatch of current–voltage curves). The sixth step is to use the thermo-graphic camera and the electroluminescence at the PV-module level. The seventh step is to monitor the DC racks of each inverter or the individual inverter, if equipped with only one Maximum Power Point Tracker (MPPT). Experimental results on real PV systems show the effectiveness of this procedure.

Keywords: Solar cell *I–V* mismatch; PV testing; Electroluminescence; Grid-connected PV system

1. Introduction

Today, after years of generous feed-in tariff with the consequent deployment of grid-connected photovoltaic (PV) systems, a new phase occurs in Italy, where a retroactive cut is in force for the amount paid on energy production (Italian Law). PV systems, characterized by sufficient energy production in the previous framework, are no more adequate to produce profits for the investors within the new regulations. Hence, it is important to evaluate the losses in the energy production according to the different causes. The Building Integrated PhotoVoltaic (BIPV) systems are affected by a number of worsening phenomena (Chicco et al., 2014) such as: shading effects generated by near obstacles; thermal gradients from lower parts to upper parts of the roofs; impact of dirt for pollution; and non-optimal exposition to the Sun. But the most of photovoltaic capacity is composed of large PV systems mounted at ground level. These plants are characterized by: partial shading on the PV modules, if the mutual distances among the mounting structures were reduced to increase the land utilization; placement of PV modules too close to the

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Nomenclature

Acronyms

ADAS	Automatic Data Acquisition System
BIPV	Building Integrated PhotoVoltaic
GMPV	Ground Mounted PhotoVoltaic
EL	ElectroLuminescence
IR	InfraRed
MPPT	Maximum Power Point Tracker
m-Si	mono-crystalline Silicon
p-Si	poly-crystalline Silicon
PCU	Power Conditioning Unit
PID	Potential Induced Degradation
PV	PhotoVoltaic
RMS	Root Mean Square
STC	Standard Test Conditions

Symbol Description

I–V	current–voltage
E_{AC_p}	predicted daily energy delivered to the AC grid (kW h)
E_{AC_m}	monitored daily energy delivered to the AC grid (kW h)
ε_{p-m}	relative deviation between E_{AC_p} and E_{AC_m}
$P_{p,k}$	k-th peak power of PV array (kWp)
$Y_{r,k}$	k-th reference yield on the plane of array (h/year)
η_{therm}	thermal efficiency of the array
γ	maximum power temperature coefficient of PV modules (pu/°C)
T_c	cell temperature (°C)
ΔT	deviation of cell temperature from the STC value (°C)
η_{array}	efficiency due to non-thermal losses of the PV array
η_{shade}	efficiency due to shading effect on the PV array
η_{PCU}	efficiency of PCU
$P_{M,k}$	maximum power of the k-th module in stand-alone operation (kW)
$P_{M,array}$	maximum power at STC after array connection (kW)
$\ell_{mis}^{(array)}$	relative power losses due to I–V mismatch in a PV array
G	solar irradiance (W/m^2)
T_a	ambient temperature (°C)
I_{sc}	short circuit current (A)
V_{oc}	open circuit voltage of PV generator (V)
P_M	maximum power of PV generator (kW)
FF	fill factor
P_{mpp}	maximum power after irradiance and temperature corrections at STC (kW or W)
I_{mpp}	current at maximum power after irradiance and temperature corrections at STC (A)
V_{mpp}	voltage at maximum power after irradiance and temperature corrections at STC (V)
ΔI_{mpp}	current deviation at MPP with respect to datasheet
ΔV_{mpp}	voltage deviation at MPP with respect to datasheet
I_{ph}	photovoltaic current of solar-cell equivalent circuit (A)
m	junction quality factor of solar-cell equivalent circuit
I_0	dark saturation current of solar-cell equivalent circuit (μA)
R_s	series resistance of solar-cell equivalent circuit (Ω)
R_{sh}	shunt resistance of solar-cell equivalent circuit (Ω)

ground with the inherent effect of dampness and dirt accumulation on the frame. As previously written, in Italy a simultaneous condition of high feed-in tariff and low price of PV modules triggered the installation of ≈11 GWp in 2011. The supply of the components, PV modules and Power Conditioning Units (PCUs), was difficult with many delays. The need for speedy design and installation sometimes caused drawbacks summarized in the following bullet points:

- The mismatch between an optimal design and the installation has provoked the possibility of:
  1. Current–voltage (I–V) mismatch in the case of slightly different peak power in series connected modules of the strings connected in parallel inside a PV array.
  2. Partial shading on the PV modules.
  3. A non-optimal match between the peak power of the PV array and the rated power of the power conditioning unit (many times named “inverter”).
  4. Cracks in silicon solar cells due to improper handling during transportation and installation.
- The use of components, such as PV modules and PCUs, which are not of the best manufacturing quality and may exhibit underperformance (i.e. mismatch in the electrical parameters of the PV modules) during the outdoor operation, but are readily available on the market at the moment of the installation.

Most of the underperformance observed in the field is due to PV modules rather than to the other components.