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A detailed analysis of gains and losses of a fully-integrated flat roof amorphous silicon photovoltaic plant

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Abstract

In 2003 a fully-integrated photovoltaic (PV) plant composed by amorphous silicon PV modules was installed on top of a flat roof in Lugano (Southern Switzerland) – a site representative for most of continental Europe – and continuously monitored since. This work follows a previous study which analyzed the first 2 years of operation of the plant, ascribing most of the noticeable winter losses to reflection losses due the lower position of the sun in the sky. Other loss mechanisms were discussed only from a qualitative point of view. The energy production of this particular PV installation is in fact influenced by several combined phenomena such as Staebler–Wronski, spectral variations, temperature and optical losses effects.

The present work aims to widen the analysis by discerning between these partly competitive effects and attempts to give a quantitative description of the influence which each single phenomenon has on the energy performance of the PV plant. For this purpose, single PV modules similar to those of the plant (triple-junction a-Si) were subjected to several indoor and outdoor tests.

By means of indoor characterization we found that reflection losses become significant for angles of incidence larger than 50°. Repeated indoor and outdoor degradation–recovery cycles underlined the influence of annealing time and temperature on the recovery of the PV modules. In particular outdoor degradation tests showed that at our latitudes (46°N) the influence of the Staebler–Wronski effect on the output power of these devices is around 10% (±5% around an annual average value).

The influence of the spectral effects on the current of amorphous silicon modules was assessed by means of outdoor IV characterization: the short circuit current decreases linearly with AM value at a slope between 4% and 8% per AM-unit depending on the technology under investigation.

Combining these three effects with the effect of temperature the authors are able to perform a simulation of gains and losses of the a-Si modules which well approximates the energy performance of the CPT-Solar plant over a whole year.

Keywords: Amorphous silicon; Photovoltaic plant; Performance ratio; Building Integrated PhotoVoltaics; BIPV; Flat roof

1. Introduction

Flat roofs of large industrial buildings represent a huge surface which is generally not exploited. Some studies attempted to quantify the amount of this surface: an IEA Report estimates the useful roof surface available for Building Integrated PhotoVoltaics (BIPV) in more than 5000 km^2 in Europe and around 10,000 km^2 in the USA (International Energy Agency, 2002). Another study estimates that alone in Germany a surface of 100 km^2 of newly built flat roofs is available every year (Remmels, 2010). Due to the huge availability of such surfaces, the idea of covering flat-roofs with PV-plants is very appealing by an economical and environmental point of view.

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However, the main issue regarding the installation of a PV plant on top of roofs is that often the existing structure is not able to bear additional loads. In fact because of the availability of large surfaces, generally the conversion efficiency of the PV modules is not necessarily the most significant parameter for selecting the optimal PV technology; rather the ratio power per weight (W_p/kg) acquires relevance. For amorphous silicon (a-Si) flexible modules this ratio is around 16 W_p/kg, which corresponds actually to that of crystalline silicon (c-Si) framed modules: 12–17 W_p/kg (Ransome, 2009). The benefit of flexible PV laminates is that they do not require any further ballast, but can easily be integrated e.g. into waterproof membranes or other building components, becoming a constituting part of the roof itself.

An issue related to BIPV is generally a reduced ventilation of the panels which increases their average working temperatures (Sample and Virtuani, 2009), inducing a loss of power and generally affecting the energy yield of the PV plant. The power temperature coefficient for amorphous silicon (∼−0.25%/°C) is already significantly lower than for conventional c-Si (∼−0.5%/°C), however, the real advantage of a-Si is the positive effect that thermal insulation produces on the recovery of the light-induced defects (Staebler–Wronski effect) as clearly shown by several authors (Hof et al., 1996; Cereghetti et al., 2000; Lechner et al., 2009).

At SUPSI the combined effects of these phenomena were thoroughly monitored when a triple junction amorphous silicon photovoltaic plant composed of Uni-Solar modules was installed on top of a flat roof of a high-school (2003) in Lugano. The PV plant is fully integrated into the roof of the building and installed on top of a thermal insulating layer which reduces the thermal losses of the building and the ventilation of the PV modules. Plant details and monitoring of the first years of operation are given in Pola et al. (2007).

The analysis of Pola, Chianese and Bernasconi showed the pronounced beneficial effect of the thermal insulation on the performance of the a-Si modules with annual energy yield +5% higher compared to the energy yield of an open-rack mounted reference module of the same technology with same orientation and tilt angle.

The previous study considered the energy losses of the system and in particular the noticeable winter losses were attributed mainly to reflection losses due the lower position of the sun in the sky. Other loss mechanisms were discussed only from a qualitative point of view.

Four phenomena in fact mainly influence the behaviour of this quasi horizontal fully-integrated a-Si PV plant:

(1) optical losses due to the quasi horizontal tilt;
(2) degradation and regeneration cycles due to the typical a-Si Staebler–Wronski effect;
(3) spectral effects due to the narrow spectral response of a-Si;
(4) intrinsic loss of power due to higher working temperature (negative temperature coefficients), particularly pronounced in this case due to the full integration of the PV system.

Table 1
List of the most relevant units, and acronyms used in the paper.

Units	
Photovoltaic module/system	*Irradiance*
P_m = maximum power [W]	G = irradiance [W/m^2]
P_N = nominal power [W]	G_{STC} = irradiance value at STC, 1000 W/m^2
W_p = Watt peak [W]	G_{gh} = global horizontal irradiance
I_{SC} = short circuit current	X_{gh} = extraterrestrial horizontal irradiance
γ = temperature coefficient of P_m [%/°C]	AM = air mass
FY = final yield [kW h/kWp]	K_T = clearness index
Y_R = reference yield [h]	IAM = Incidence Angle Modifier [°]
PR = performance ratio [%]	AOI, Θ = angle of incidence [°]
T_{bom} = back of module temperature [°C]	*Other*
λ = power losses	t = time [s]
ε = performance factor	T = temperature [°C]
Acronyms	
Technical	*General*
a-Si = amorphous silicon	ASHRAE = American Society of Heating, Refrigerating and Air-Conditioning Engineers
c-Si = cristalline silicon	BIPV = Building Integrated Photovoltaic
DC = direct current	CPT = Centro Professionale Trevano
HQI lamp = hydrargyrum quartz Iodide lamp	IEA = International Energy Agency
IV-curve = current–tension characteristic	IEC = International Electrotechnical Commission
MMF = mismatch factor	PV = photovoltaic
MPPT = Maximum Power Point Tracker	
Pt100 = platinum (Pt) thermo-resistor	
SK = Sjerps-Koomen model (Sjerps-Koomen and Alsema, 1995)	
SIT = standard irradiance and temperature conditions	
STC = Standard Test Conditions	