Renewable Energy 66 (2014) 612–624

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Temperature and wind speed impact on the efficiency of PV installations. Experience obtained from outdoor measurements in Greece

John K. Kaldellis*,[1], Marina Kapsali, Kosmas A. Kavadias

Lab of Soft Energy Applications & Environmental Protection, TEI of Piraeus, P.O. Box 41046, Athens 12201, Greece

ARTICLE INFO

Article history:
Received 6 August 2013
Accepted 24 December 2013
Available online 5 February 2014

Keywords:
Thermal losses
Temperature coefficient
Thermal loss factor
Power output
Polycrystalline silicon solar cells

ABSTRACT

Although efficiency of photovoltaic (PV) modules is usually specified under standard test conditions (STC), their operation under real field conditions is of great importance for obtaining accurate prediction of their efficiency and power output. The PV conversion process, on top of the instantaneous solar radiation, depends also on the modules' temperature. Module temperature is in turn influenced by climate conditions as well as by the technical characteristics of the PV panels. Taking into consideration the extended theoretical background in the field so far, the current study is focused on the investigation of the temperature variation effect on the operation of commercial PV applications based on in-situ measurements at varying weather conditions. Particularly, one year outdoor data for two existing commercial (m-Si) PV systems operated in South Greece, i.e. an unventilated building-integrated (81 kW_p) one and an open rack mounted (150 kW_p) one, were collected and evaluated. The examined PV systems were equipped with back surface temperature sensors in order to determine module and ambient temperatures, while real wind speed measurements were also obtained for assessing the dominant effect of local wind speed on the PVs' thermal loss mechanisms. According to the results obtained, the efficiency (or power) temperature coefficient has been found negative, taking absolute values between 0.30%/°C and 0.45%/°C, with the lower values corresponding to the ventilated free-standing frames.

1. Introduction

Considerable progress has been encountered during the recent years in the development of photovoltaic (PV) modules, with new concepts of improved performance characteristics, remarkable reliability and long service period released in the market every so often [1,2]. At the same time, technological innovation along with policy support, economies of scale, improved manufacturing processes and rapid PV market growth have led to significant reduction of manufacturing costs, reflected by a well-documented downward trend in module prices over the years (see Fig. 1) [3–5]. In fact, it is since the 70s that global module prices present a reduction of 20% on average for every doubling of cumulative installed capacity (learning factor), resulting in a price reduction from about $60/$W_p$ to about $2.2/$W_p$ (or from 46 €/W_p to 1.7 €/W_p, based on present day currency conversion prices, that is, $1 = €0.77) between 1976 and 2010. In this context, the average price of a PV module in Europe reached approximately 1.2 €/W_p in 2011 [4], although quite lower module prices have been reported since, i.e. in the order of 0.5–0.6 €/W_p (see for example [6,7]).

Together with this global trend of continuous decline in PV prices, sustaining and vigorous R&D efforts in the PV manufacturing industry [8,9] have resulted in consistent improvements with regards to solar cell energy conversion efficiencies for commercially available PV modules (see for example Fig. 1). To this end, present solar cell energy conversion efficiencies for commercially available PVs are around 14–25% (sufficiently maintained for a 25–30 year module lifetime), although several new generation concepts that have recently emerged demonstrate efficiencies that even reach 40% [10,11].

To this end, the impressive progress made to date in PV technology in combination with the positive public attitude towards Renewable Energy Sources (RES) [12] and the environmentally friendly character of PV plants, have led to an exponential increase in the worldwide installed PV capacity, Fig. 2. At present, the PV market is growing rapidly with the worldwide capacity exceeding 100 GW in 2012 (Fig. 2), at an average annual increase rate of about

* Corresponding author. Tel.: +30 210 5381237; fax: +30 210 5381348.
E-mail address: jkald@teipir.gr (J.K. Kaldellis).
[1] http://www.sealab.gr.

0960-1481/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.renene.2013.12.041

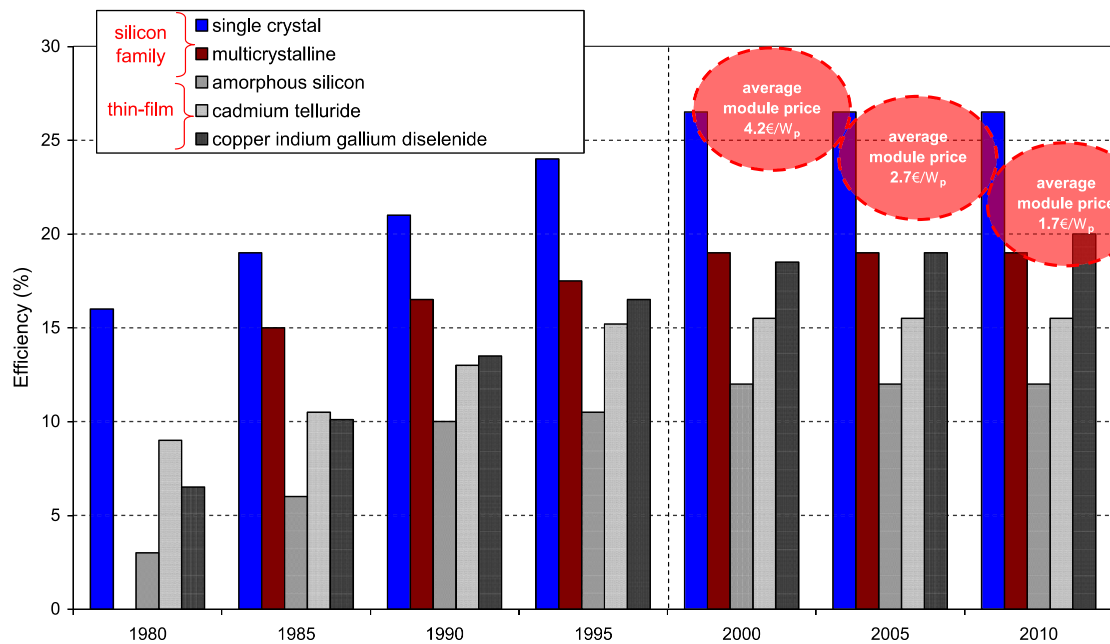

Fig. 1. Efficiency development of several PV module technologies and average PV module price in Europe. Based on data found at [4,5].

40–45% that makes the PV industry one of the fastest growing industries worldwide. As a result, PV installations are no longer considered as supporting a niche market. Contrariwise, PV technology is nowadays increasingly competitive to conventional sources of electricity generation and can thus be qualified as a vital component of future energy supply for our planet.

Despite the notable technological improvement in PV technology, investigation of external factors which may influence the energy performance of PVs', such as weather conditions [13] or natural occurring phenomena [14], is still of considerable interest. In this regard, one of the critical factors negatively affecting PV energy performance is the increase of the corresponding cell temperature. For this purpose, remarkable effort has been made during recent years to estimate the PV panels' temperature and its effect on the former performance, mainly on the basis of detailed theoretical analyses [15–17]. Taking into consideration the

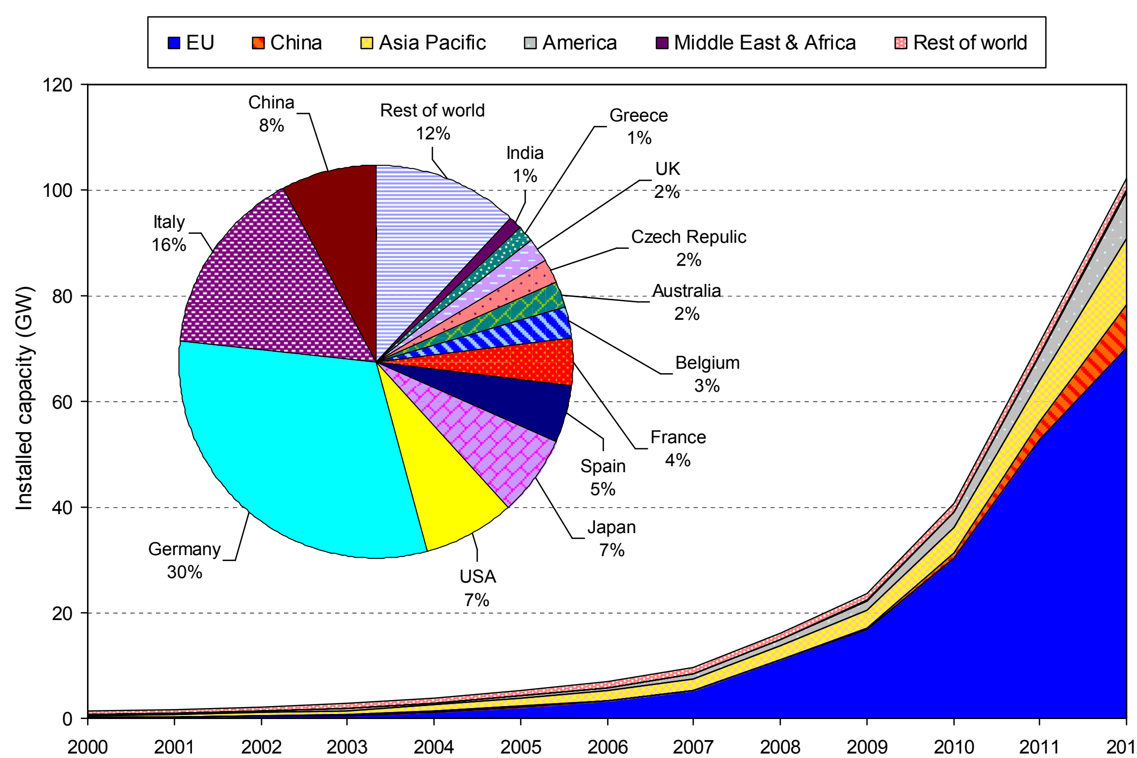

Fig. 2. Growth of the global PV market.