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Performance of solar photovoltaic modules under arid climatic conditions: A review

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ABSTRACT

Arid and semi-arid climates are blessed with abundant sunshine, and photovoltaic (PV) modules are now widely used under these climatic conditions. The aim of this paper is to put into perspective the recent uses of solar PV installations under arid climates with the evolution of PV technologies. The novelty of this review is to present up-to-date experimental results under such climates, and to plot results of experiments running for about one year or more. The effect of environmental parameters such as weather or dust are analyzed depending on different locations and technologies. These parameters have a tremendous impact on PV modules performance and degradation, and it is critically important to consider them carefully when implementing a PV installation under such conditions. From this review, general conclusions and guidelines are presented.

1. Introduction

Photovoltaic panels and concentrated solar thermal power are the most well-established technologies used to convert solar energy into electricity. Using photovoltaic (PV) cells to convert light into electricity is a clean and sustainable way of energy production. Nowadays the dominant solar technology uses crystalline silicon (multicrystalline and monocrystalline) as semiconductor material. However, solar technologies using advanced materials such as amorphous silicon (a-Si), copper indium gallium selenide (CIGS), or cadmium telluride (CdTe) are becoming more and more attractive due to higher efficiency in different climatic conditions and lower production costs (Brun et al., 2016).

Adjustment of operational characteristics (such as reliability, availability, maintainability, safety, efficiency and ability to forecast energy production) is the main challenge for maintaining and controlling energy from variable energy sources. In this context, operating conditions (for example, operating temperature) of PV installations are critical in the overall system performance. The electricity production of PV cells is highly dependent on climatic conditions. Moreover, arid conditions, especially at high temperatures, are not optimal for the use of solar PV. However, there is room for development as arid climates are linked with widely available sunshine.

Several environmental parameters can have a huge impact on solar PV performance. In Brazil, meteorological (temperature, humidity, radiation) or mechanical (shocks) parameters prove to affect the PV modules performance and damage the system on a 16 years basis (Afonso and Carvalho, 2015).

The solar PV modules are sensitive to temperature: the efficiency decreases with increasing temperature. The theoretical magnitude of the impact depend on the technology used and can vary for each PV module (Dupré et al., 2016). Skoplaki and Palyvos (2009) insist on the strong correlation between temperature and performance. However, there are many different formulas, and the relevant one should be chosen carefully.

To limit the temperature of the modules, Schiro et al. (2017) tested a water-cooling system for PV panels. They concluded that the system can be a worthy one if the original temperature of the module is high enough and the water sink easily accessible. Du et al. (2016) place emphasis on the influence of the wind to cool down solar PV panels. A regular wind can decrease the temperature of a module and thus increase its efficiency. Thus, including wind in PV modules prevision models can help to increase their accuracy.

Many arid locations are dusty or sandy. This raises the issue of soiling: dust or sand deposition can affect the performance of PV panels: the particles deposited on the surface of the panel obscure the rays of the sun and thus decreases performance. Also, both panel and dust types have an influence on dust deposition (Zaihidee et al., 2016). By preventing soiling, performance of solar PV can be significantly improved: mechanical cleaning, water-based or water-free solutions has been considered; the latest one (electrostatic or electrodynamic) looks

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promising due to its efficiency and low maintenance needs. Deb and Brakmbhatt (2018). Also, wind can help to remove dust and limit the impact of soiling, especially for large particles (Jiang et al., 2018).

Assessment of solar irradiance is complex. The atmosphere contains different substances such as water vapor, clouds, aerosols, or greenhouse gases that differ both temporally and geographically. The atmosphere usually decreases the value of solar irradiance from 35% (clear sky) to 90% (sky with thick clouds) (IPPC, 2011). In hot arid climates, irradiance is important but dust in suspension in the atmosphere can absorb the impending rays and affect the efficiency of solar PV modules (Deb and Brakmbhatt, 2018). Therefore, atmospheric conditions have a significant impact on efficiency even in absence of thick cloud cover in dry areas with little rainfall.

Developing countries with arid environments could benefit from the use of solar PV technologies. Their needs in energy are increasing, and these technologies have tremendous qualities under these climates, but some drawbacks as well. The objective of this paper is to review the variation of performance of PV cells depending on technologies and environmental factors. The novelty is to present up-to-date results under arid climatic conditions, and compare the results of the available experiments running for about one year or more. Technologies, average precipitation and average daily temperature are considered to outline preliminary conclusions from graphical representations. The paper progresses as follows: in Section 2, an overview of the PV technology is given. A review of PV system parameters is described in Section 3. In Section 4, a literature review of PV systems performances in arid and semi-arid locations is presented. Discussion and results of the main performance parameters of several PV power systems with full-scale performance data in different locations are presented in Section 5.

2. Solar PV technology

2.1. Overview

Current solar technologies are the result of decades of performance and cost improvements. Each type of solar energy technology is based on different materials and architecture and has its own merits. Analysis and comparison between different technologies can help to adopt the most efficient and advantageous system respecting certain conditions. Due to various PV applications, different technologies are easily available in the market, with a wide range of efficiencies and costs. A system with a lower efficiency is generally cheaper, but requires a large area for a given energy output, thus increasing costs of land and maintenance (Martín-Chivelet, 2016).

By connecting solar panels in parallel or series, it is possible to get high voltages and currents (reaching up to 1 kV) (Abdelkader and Sharaf, 2010). The conversion of light to energy is due to an electron-hole pair generated from the absorption of light; then, the electron goes to the negative terminal and the hole goes to the positive terminal. This action generates electrical power.

PV technologies involve solar panels made of solar cells, and each cell contains a photovoltaic material. The PV effect is due to the semiconductor material band structure characteristics which emits electrons by absorbing energy from electromagnetic radiation (Nelson, 2003). The main focus of solar technology engineers is to improve efficiency of solar cells to convert as much light as possible into electrical energy. The conversion efficiency is the ratio of energy that a PV cell converts into electricity by the amount of solar energy striking the PV cell (Nelson, 2003).

2.2. Photovoltaic solar panel technologies

There are three generations of PV technologies (Du et al., 2016):

- First generation: Gallium arsenide (GaAs), and crystalline silicon (c-Si) such as multicrystalline (multi-Si) silicon and monocrystalline (mono-Si) silicon;
- Second generation (thin films): amorpheous silicon (a-Si), CdTe, or copper indium gallium (di) selenide (CIS/CIGS);
- Third generation: dye-sensitized, organic and multi-junction.

The first and second generation technologies are already used for very large scale PV power plants (Komoto, 2015):

- In China: c-Si technology for Longyangxia dam (520 $MW_{DC/AC}$ and Germud (500 $MW_{DC/AC}$)
- In USA: CdTe in Agua Caliente (290 MW_{AC}) and in San Luis Obispo (550 MW_{AC})
- In Japan: CIS in Osaka (12 MW)
- In Thailand: thin film in Lobpuri (84 MW_{DC})

The energy pay-back time has been estimated for different technologies in the Gobi desert in China. CIS and multi-Si technologies have the lowest pay-back (below 2.3 years), it is 2.4 years for a-Si technology; the pay-back of thin films is measured at 2.4 and 2.6 years; and 2.4 and 2.8 years for mono-Si (Komoto, 2015).

2.2.1. Crystalline silicon (first generation)

Most PV systems (in 2015, 93% of the production) are based on Si-wafer PV (ISE, 2017). To-date, the best efficiency obtained with mono-Si is 26.6% (Green et al., 2017); for multi-Si, the best efficiency reaches about 21%. Multi-Si panels are less expensive than mono-Si panels, but the disordered atomic structure results in lower efficiency. Monocrystalline and multicrystalline silicon modules have almost the same low power degradation (0.5% yearly for both technologies) (Jordan and Kurtz, 2012). Production of multicrystalline silicon is typically done through a screen printing process. In contrast, production of monocrystalline silicon may be achieved in a variety of ways. The commercial manufacturing typically includes a buried contact process.

Mono-Si cells have a higher conversion efficiency, but a higher production cost, while multi-Si cells are slightly less efficient but cheaper (Nogueira et al., 2015). The main parameters affecting the performance of these technologies are cell temperature and solar radiation intensity, as shown in Fig. 1a and b.

Crystalline silicon PV modules should remain the dominant PV technology for the foreseeable future due to their reliable and proven technology, abundant primary resources, and long lifetime. The major problem of crystalline silicon technologies is that they require efficiency improvements together with an increase in resource consumption efficiency. These requirements can be achieved through an enhanced approach, manufacturing automation, and reduction of raw-material consumption (IPPC, 2011).

2.2.2. Thin films (second generation)

Thin films have several advantages: (1) low consumption of raw materials, (2) attractive appearance, easy integration into buildings, and (3) high automation and production efficiency (Raugei et al., 2007). Moreover, high efficiency at relatively high temperatures coupled with low sensitivity to overheating creates competitive advantages for this technology, in particular in regions with hot arid climatic conditions.

Cadmium telluride (CdTe) panels hold a market-leading position in thin film technologies (Helbig et al., 2016). However, materials used in their manufacturing processes are less abundant than silicon, and are of a toxic source. At the same time, manufacturing process of CIGS cells is less demanding as it is cost-effective compared to CdTe cells (Raugei et al., 2007). Therefore, all these factors make it difficult to determine which of the thin-film technologies will obtain the highest market share in the long-run (Helbig et al., 2016). Also, it should be emphasized that experimental measurements indicate that CdTe offers the best temperature coefficient which makes this material a good candidate for climatic regions experiencing high temperatures (Dash and Gupta,