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Energy performance of different silicon photovoltaic technologies under hot and harsh climate

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ABSTRACT

This paper presents a performance comparison study performed on four photovoltaic modules. Three silicon technologies are concerned: one monocrystalline module, two polycrystalline modules and one module of tandem structure (amorphous/microcrystalline) also known as micromorph module. The modules I–V data and meteorological data have been measured during one year using an outdoor monitoring test facility named "IV bench". This set up is installed at Ouagadougou (Latitude 12.45° North, Longitude 1.56° West) in Sudano Sahelian climate. The actual maximum power, the average performance ratios, the series resistances and the maximum power temperature coefficient of tested modules are determined from the outdoor measurements and used for comparison study. The power of all the modules has been stabilized in outdoor conditions before the performance analysis. The results show that the micromorph module presents the best performance on the selected site, with an average performance ratio of 92%. The monocrystalline and polycrystalline modules from the same manufacturer, have both an average performance ratio of 84%. The second polycrystalline module from another manufacturer, strangely presents the lowest average performance ratio (80%) due to both its large series resistance and the high maximum power temperature coefficient in operating conditions.

1. Introduction

In sub-Saharan Africa, most countries are facing energy crisis which is characterized by several hours of electrical load shedding, especially during the dry season where yearly peak loads are usually reached. In 2000, the governments of West African countries have adopted through the ECOWAS/WAMU (Economic Community of West Africa States/West African Monetary Union), a white paper that should guide the West African region energy policy until 2015. According to this white paper [1], at least 20% of new investments in electricity generation in rural and peri-urban areas should concern renewable energies. Even if it will be hard to reach that goal, the energy policy of many West African countries, has been greatly changed. Moreover, due to the constant decrease in the price of PV (photovoltaic) modules, the interest of African developing countries for PV energy has increased during these last decades. For example, in Cape Verde several PV plants are been installed; the largest one has a power of 5 MW. In Burkina Faso, a project is underway for four PV fields (17; 5.5; 17 and 11 MW). Individual kits and hybrid (PV/Diesel) small systems are mostly developed for sub Saharan African rural populations as the rural electrification rate is very low, about 16% in 2012 according to the International Energy Agency [2].

On the other hand, there are several technologies of photovoltaic modules on the market. But, the lack of guide and forecasting tools suited to African climates and dusty environment, makes the technological choices very critical. The bad choice of a PV technology is known to be one of the failure causes for many PV energy projects. In fact, photovoltaic modules manufacturers provide characteristic measured in STC (standard test conditions) conditions which cannot be reached in real operating conditions.

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Furthermore, PV modules performances and ageing strongly depend on the climate and the environment of the installation site. Indeed, the performances of a PV module under real conditions depend on the weather [3–5], the solar spectrum, the spectral response of each technology [6], and the module/cell design [7]. For example, a high level of irradiation would be beneficial to crystalline technologies whereas amorphous silicon and chalcopyrite based modules present current and voltage mismatch due to material metastable phenomenon [6]. Several studies have focused on the knowledge, for a given natural environment, of the photovoltaic technology that provides the best trade-off between the cost and the performances of the module.

- C. Cañete et al. [6] performed a comparative study under the meteorological conditions of Southern Spain, on four different photovoltaic module technologies: amorphous silicon (a-Si), tandem structure of amorphous silicon and microcrystalline silicon (a-Si/μc-Si), cadmium telluride (CdTe) and polycrystalline silicon module (pc-Si). The results of their study show that the performance of thin film modules is better than that of pc-Si modules for this location.
- Akhmad et al. [8] compared the performance of pc-Si and a-Si at Kobe, Japan, and recommend the use of a-Si modules for this region.
- Sharma et al. [9] studied the performances of a-Si, p-Si and HIT technologies, under Indian climatic conditions. They show that HIT and a-Si have better performance than p-Si at this location.
- Y. Poissant [10] have evaluated four different novel PV module technologies (back-contact crystalline Silicon, laser-grooved buried junction crystalline Silicon, amorphous Silicon triple-junction, and heterojunction Silicon). His study showed an equivalent performance for these technologies under different irradiance levels and confirmed that the multijunction amorphous silicon and heterojunction silicon technologies are not more affected by temperature than other novel crystalline silicon technologies.
- Eric Maluta [11] analysed the performances of crystalline and amorphous modules under South Africa climate conditions. He showed that both technologies give close and satisfactory performance for the climate of this region.
- M. Shaltout et al. [12] compared monocrystalline, polycrystalline and amorphous silicon solar cells under desert climate. They advise the use of polycrystalline silicon cells in PV applications in such climate.
- K. Nishioka et al. [13] compared heterojunction silicon, c-Si and p-Si module at NAIST (Nara Institute of Science and Technology) under Japan climate and found that the HIT technology is better suited for this region due to his low temperature dependency.
- T. Minemoto et al. [14] analysed the effect of spectral irradiance distribution on the outdoor performance of amorphous Si/thin-film crystalline Si stacked photovoltaic modules installed at Kusatsu-city (Japan). This study revealed that the a-Si/μc-Si stacked PV module was highly spectrally sensitive compared to poly-Si PV modules installed in the same conditions.
- A. Carr et al. [15] compared five different types of photovoltaic modules in the temperate climate of Perth, Western Australia. The types of modules examined in this study are: crystalline silicon (c-Si), LGBC (laser grooved buried contact) c-Si, polycrystalline silicon (p-Si), triple junction amorphous silicon (3j a-Si) and CIS (copper indium diselenide). This analysis shows that the LGBC c-Si module (BP585) is better suited with this region.
- Aste et al. [16] made an comparative analysis of crystalline silicon cells (c-Si), micromorphous cells (a-Si/μc-Si) and heterojunction under temperate climates of Italy. The analysis shows roughly that in warmer months micromorphous a-Si/μc-Si silicon cells, achieve a performance higher than the other technologies tested, due to his low temperature coefficient and thermal annealing.

All these above-mentioned studies clearly show the difficulty when it comes to choose the appropriate PV technology for a given site.

The aim of the present study is to compare under sudano-sahelian climate (Ouagadougou/Burkina Faso) three silicon PV technologies namely monocrystalline (c-Si), polycrystalline (p-Si) and amorphous silicon tandem structure (a-Si/μc-Si) and to see which one is more suitable for this environment.

This paper is organized in four sections including this one. Section 2 provides a description of the experimental PV test facility. The measurement analysis methodology is explained in Section 3. Finally, results and discussions are presented in Section 4.

2. Experimental PV test facility and testing procedure

The current study is performed on four silicon photovoltaic modules of three different technologies:

- one monocrystalline (sc-Si) module of 50 W named VIC003
- two polycrystalline (pc-Si) modules of 50 W (VIC006, SUN011) from two different manufacturers
- one tandem structure of amorphous/microcrystalline (aSi:H/μc-Si:H) module of 128 W (SHA017). This technology is also known as micromorph.

According to information provided by manufacturers, it can be noticed that all "wafer" modules (VIC003, VIC006, SUN011) were encapsulated in the same way. Once the cells are interconnected, the assembly is coated with EVA (ethyl vinyl acetate) film. The back side of the cells is covered with a white tedlar while a glass is placed at the front. The modules frame is made with anodised aluminium. For the thin film module (SHA017), the process is quite different. The layers constituting the solar cells are successively deposited on the front glass. Then, the last layer (the back contact) is covered with an encapsulant and a glass called the rear glass. The module STC performances as given by the manufacturers, are presented in Table 1.

As shown in Table 1, the modules belonging to the three technologies, have different areas, efficiencies and temperature coefficients. These differences relating to their cell intrinsic structure, lead up to different behaviour of each module depending on the on-site weather conditions. At the beginning of the study, all the modules are in their first year of outdoor exposure under natural sunlight. However, prior to starting the measurements, the modules were exposed to the sun during a sufficient time to offset the initial degradation that may occur in the photovoltaic modules especially for the thin film technology as depicted in IEC 61646 standard [17].

The modules were then characterized with a test facility named "I–V bench" (Fig. 1) from August 1st 2014 to July 31st 2015 (during one year). The I–V bench, is installed on the experimental platform of the Laboratory of Solar Energy and Energy Savings (12.45° North, 1.5625° West) nearby Ouagadougou (Burkina Faso) and entirely dedicated to the outdoor characterization and the monitoring of the PV modules' performances.

Fig. 2 shows (a) the schematic diagram of the I–V curve measurement and, (b) the outdoor installed modules and meteorological measurement equipment. The module were oriented southwards and tilted at angle of 14°, close to the latitude (12.45° North) of the site. The angle is chosen slightly superior to the latitude to favour the self-cleaning of the dust and the streaming of