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Experimental Study and Modeling of Three Grid-Connected Photovoltaic Technologies of Meknes City

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ABSTRACT

Photovoltaic (PV) systems are the most promising renewable energy source in Morocco due to its abundant solar irradiation. The Moroccan government has launched various renewable energy programs to encourage the use of PV systems. In this work we present a comparative study in terms of energy produced and the efficiency of a grid connected photovoltaic (PV) system installed on the roof of the building occupied by the "Ecole Supérieure de Technologie de Meknes" (ESTM). The on-grid connected photovoltaic system has a total power of 5860 Watts (Wp). This system provides an average daily reduction of 30 kWh in the consumption of electrical energy at ESTM facilities; this will allow us to save fossil fuels and reduce emissions of greenhouse gas. The average annual production of electric power is estimated at 10.5 MWh, equivalent to burning 0.9 tons of oil, which will prevent the emission of about 2 tons / year of CO2 in the atmosphere. Three different commercial solar modules, manufactured with different materials and technologies in monocrystalline silicon, polycrystalline silicon and amorphous silicon were tested.

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1. INTRODUCTION

Global annual solar power production is estimated to reach 500GW by 2020, from 40.134 GW in 2014, making this market one of the fastest growing ones. Solar Photovoltaic market is a billion dollar sector with China leading the market of producing Photovoltaic cells. Germany is one of the leading countries for installing Photovoltaic across the country and has an installed capacity of 37 GW. It leads the pack with China, United States of America, Japan, and Italy closely on its heels. According to EPIA (European Photovoltaic Industry Association), PV electricity will represent 14% of the global power consumption in 2030. At that time, PV technology will provide electricity to more than 4.5 billion people, including 3.2 billion people in developing countries where PV is an economical way of generating electricity, especially in remote areas.

Reliable energy supply is vitally important to meet the growing electricity demand and hence to sustain the socio-economic progress of Morocco. With the kingdom's electricity consumption projected to double by 2025 and to increase more than five times by 2050, substantial investments in additional power generation capacities are required. Faced by the dual challenge of importing 96% of its energy supplies as fossil fuels from abroad [1,2], and being highly vulnerable to the effects of climate change, Morocco has, therefore, explicitly set low-carbon and climate change resilient development as its strategic development priority.

As a consequence, a myriad of national strategies plans and programs have been initiated to achieve poverty-reducing sustainable development whilst taking steps to preserve the environment. Additionally, the kingdom put in place a new National Energy Strategy aiming to reach a share of 52% of installed power capacities from renewable energy by 2030 [3].

Two units of 2 kW for monocristalline and polycrystalline technologies and 1.86 kW for amorphous technology grid-connected PV systems have been installed at Ecole Supérieure de Technologie de Meknes (ESTM) in Morocco. The monitoring system has been constructed for measuring and analyzing the performance of PV systems to observe the overall effect of meteorological conditions on their operation characteristics by field test. The performance of PV systems has been evaluated and analyzed. On the basis of these investigation results, the performance of PV systems has been simulated and compared with the measured performance of PV systems [4].

2. PHOTOVOLTAIC PARK

The pilot PV Park is located in Meknes, with an installed capacity of 5.86 kWc. The Park is comprised of 8 SW 255 polycrystalline silicon PV modules, SW 255 monocrystalline silicon PV modules and 12 NT-155 AF amorphous silicon PV modules. The specifications of PV module installed at the ESTM are summarized in Tables 1, and Figure 1 shows the PV Park. The PV modules are arranged in series in each, and connected to 3 Sunny Boy 2000HF inverters installed on the supporting structure, plus connection boxes, irradiance and temperature measurement instrumentation and data logging system, the measured data are recorded averaged every 5 min and stored on a disk for analyzing and evaluating. A schematic of the whole system is shown in Figure 2. The PV system is mounted on a stainless steel support structure facing south and tilted at 30°. Such a tilt angle was chosen to maximize yearly energy production [5].

Figure 1. PV Systems Installed in the ESTM

Table 1. PV Module Specifications (Under Standard Test Conditions)

Cell type	Mono	Poly	Amorph
Nominal power	255	255	155
Short-circuit current (A)	8.66	8.88	2.56
Open-circuit voltage (V)	37,8	38	85.5
Maximum power point current (A)	8.15	8.32	2.38
Maximum power point voltage(V)	31.4	30.9	65.2

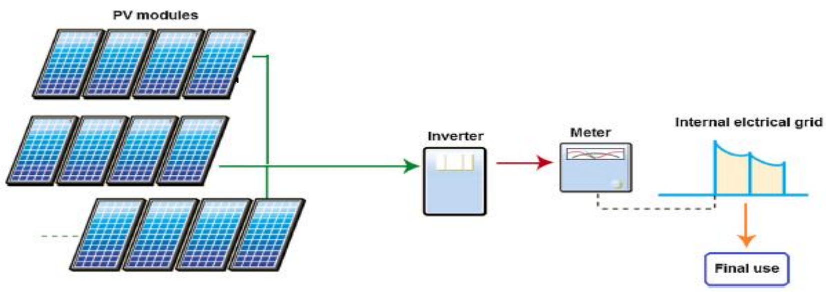

Figure 2. Structure of the Considered Grid-Connected PV System

3. MATHEMATICAL MODEL OF PV PANELS

A mathematical model of single diode PV cell is developed based on current-voltage relationship of a solar cell. An ideal PV cell is represented by a current source and an anti-parallel diode connected to it. A practical PV cell is an addition of equivalent series and a shunt resistance parameter to an ideal PV cell. Figure 3. shows the ideal and practical PV cell of single diode model [6].

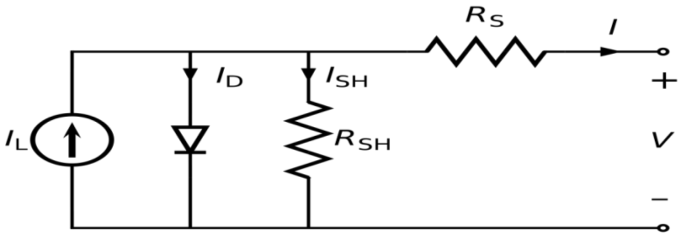

Figure 3. Equivalent circuit of the solar cell

Photovoltaic current I_{ph} is directly proportional to the intensity of solar radiation G(W/m^2):

$$I_{ph} = \frac{G}{G_{ref}}\left(I_{sc} + \mu_{sc}.\left(T - T_{ref}\right)\right) \tag{1}$$

Where, I_{sc}: short circuit current *(A)* ; μ_{sc}: Manufacturer-supplied temperature coefficient of short circuit current in amps per degree.; *T:* operating temperature *(K)*; G: solar irradiation (W/m^2); $G_{ref;}$ T_{ref} : reference solar irradiation and temperature.

The current through diode I_d and the reverse saturation current I_0 can be expressed as follows

$$I_d = I_0\left(e^{\frac{q.(V+I.R_S)}{n.A.N_S.T.K}} - 1\right) \tag{2}$$

$$I_0 = I_{0,ref}.\left(\frac{T}{T_{ref}}\right)^{\frac{3}{n}}.e^{\frac{E_g.q.\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)}{A.K}} \tag{3}$$

Where q is an electron charge value, V is output voltage, K is the Boltzman constant, A is ideality factor, $I_{0,ref}$ is reverse saturation current at reference temperature, E_g is size of gap between the conductivity and the valence bands.
The current in the resistance R_p is given by:

$$I_{R_P} = \frac{V + I.R_S}{R_p} \tag{4}$$

Where: I is the PV module current, V is the module output voltage, R_s is module series resistance and R_{sh} is module parallel resistance.
The following relation applies to output current:

$$I = (\Delta T.\mu + I_{cc}).\frac{G}{Gref} - I_0\left(\exp^{\left(\frac{I.Rs+V}{Ns.A.n.T.K}\right)^q} - 1\right) - \frac{V + I.Rs}{Rp} \tag{5}$$

4. PERFORMANCE RESULTS OF PV SYSTEMS

The incident global irradiance in the array plane and the ambient temperature were measured every 5 min and stored in the logger system. The hourly variation of solar radiation intensity and ambient temperature from 06:00 to 18:00 on a typical day of October in Meknes is shown in Figure 4. During this time period, the radiation intensity initially rises to a maximum value of approximately 900 W/ m^2 at 12:00, then decreases. The ambient temperature rises to a peak value at 13:00 and then decreases.

The PV module daily operating temperature for polycrystalline and amorphous panel and the ambient temperature measured during daylight hours over the monitored period are shown in Figure 5. The daily temperatures of cells increase from 16 ° C at sunrise for both technologies, reaching the maximum value of 42 °C for polycrystalline cells and 44°C for amorphous cells at midi, the ambient temperature follows the same logic evolution than the peaks; this is seen quite clearly on the daily temperature profile of these cells.

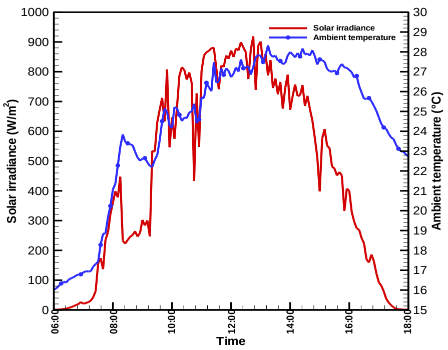

Figure 4. Solar Irradiance and Ambient Temperature for a Typical Day of October

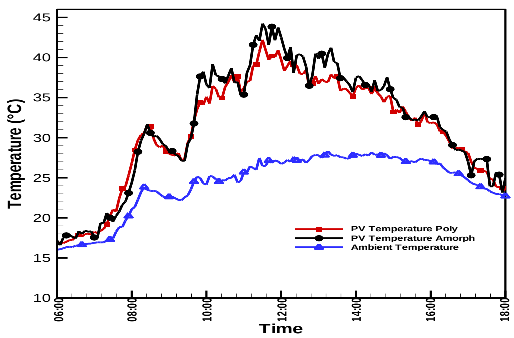

Figure 5. Hourly Ambient Air and PV Module Temperature Measured During a Typical Day of October

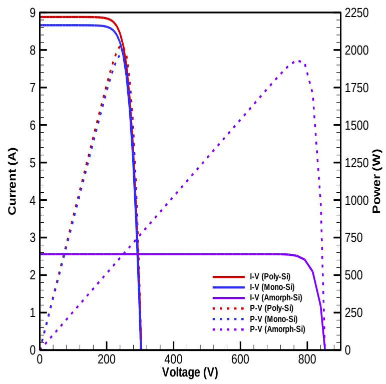

Figure 6. Comparison between Poly-Si, Mono-Si and Amorph-Si Characteristic Curves.

Figure 6 shows the characteristic curves I-V and P-V for the Poly-Si, Mono-Si and Amorph-Si modules at STC. It is clear that the characteristic curves I-V and P-V modeled under Matlab simulink for the three technologies are very similar to those given by the constructor. Figure 7 shows the graph of the total monthly energy produced by the three PV systems during the year 2016. This energy was calculated as the sum of the total daily energy produced by each system. It is possible to appreciate that the months with greater energy production are those of spring and summer with Monthly average energies of 280 to 354 *kWh*. On the other hand, this average diminishes to 203-242 *kWh* during rainy months with a smaller solar incidence.

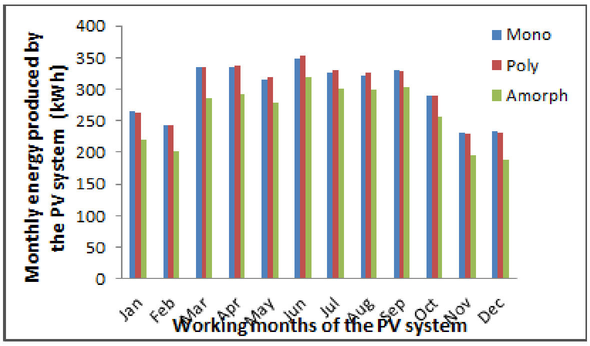

Figure 7. Monthly Energy Produced by the PV

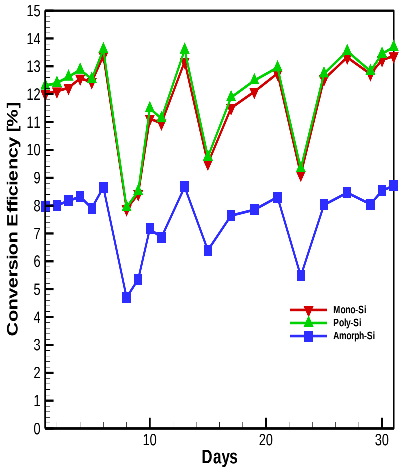

Figure 8. Efficiency of Three Types of Solar Panels at Midday for October

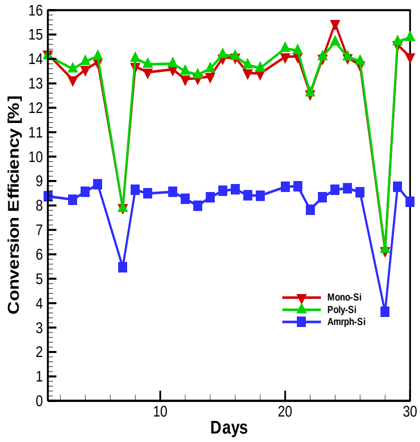

Figure 9. Efficiency of Three Types of Solar Panels at Midday for November

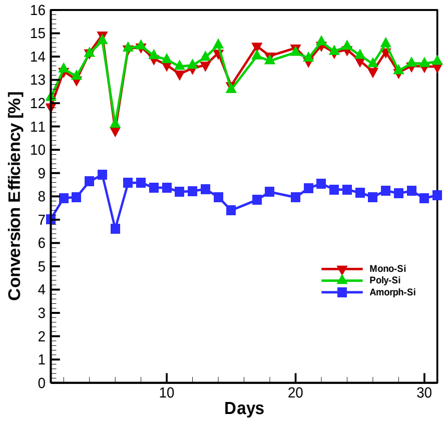

Figure 10. Efficiency of Three Types of Solar Panels at Midday for December

Figure 8, 9 and 10 illustrates a comparison between the results of the performance of the three types of solar panels showing the values of efficiencies of each type at same conditions in term of ambient temperature and solar irradiance.

It is noticeable from the previous figures that the three types of solar systems depend on the nature of the materials of its cells. The monocrystalline and polycrystalline solar cells come first and then the amorphous [7],[11]. The conversion efficiency of PV array does not strongly depend on irradiance but rather on module surface temperature [12,13]. Therefore, there is a necessity for carrying out a detailed temperature correction of the PV module efficiency and for investigating this dependence on DC output power versus meteorological characteristics such as irradiance and PV module surface temperature.

5. CONCLUSION

Monitoring system and three technologies with total power 5.86 kWp grid-connected PV systems installed on the roof of an administrative building at the High School of Technology of Meknes (Morocco). Meteorological data of the site were derived from the monitoring system and simulations were carried out using MATLAB SIMULINK software. The performance of 5.86 kWp grid connected PV systems for three installed technologies (Mono-Si, Poly-Si and Amorph-Si) were compared and analyzed during the three month of autumn of monitoring period. The main results of the simulation are:

- Average of energy conversion efficiency of amorphous technology (8%) is much lower than the mono-crystalline (12.86%) and poly-crystalline (13%) modules during the autumn periods.
- The Poly-Si technology has slightly better performance than the Mono-Si system.
- The annual net energy output (EAC) of Poly-Si based technology (3592 kWh) is 0.37% higher than that of Mono-Si based technology (3579 kWh)
- Results given by PVSYST are in good agreement with the values measured on the site.

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