Performances of PV Systems in Tunisia: Establishment of New Database

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Received: 22.01.2017 Accepted: 11.03.2017

Abstract- An experimental study is performed on two different PV systems with amorphous and polycrystalline technologies. Two platforms of the same equipment considered for this study are installed in the South West and the North of Tunisia. New experimental data base is established during a period of two years; for which Hourly, daily and monthly solar radiation variations are established. The annual solar radiation obtained in the South West is 18 % higher than that measured in the North. Experimental results are compared to the available databases; Satellite Application Facility on Climate Monitoring (CM-SAF) and National Aeronautics and Space Administration (NASA) during a whole year (2015). For the PV systems installed in the South West of Tunisia, the annual final yield and performance ratio are determined. A comparison between the data obtained with the amorphous and polycrystalline technologies is conducted.

Keywords: Photovoltaic, Solar radiation, experimental study, final yield, Performance Ratio, Amorphous, polycrystalline.

1. Introduction

Measurement of solar radiation is considered as the most important parameter for design and development of any solar energy system. Most researchers usually use the statistical approach to study and to predict the solar radiation trend and the methods that have been previously used and discussed in several works [1-4]. Monthly average daily solar radiation data on the earth's surface is a fundamental input and an important parameter for many aspects of climatology, hydrology, architecture, crop yield prediction, and design of solar energy-based projects [5]. Daily solar radiation data are often required in agro meteorological calculations. Also monthly mean daily data are needed for the estimation of long-term solar system performances, but these were measured at very few weather stations. The solar radiation data is essential to the work of the potential assessment, design, planning and performance monitoring of solar energy systems. The choice of the sites for the installation of photovoltaic systems and the analysis of their performances require the knowledge of the solar irradiation data [6]. Several research works have been made to estimate solar radiation in some regions in Tunisia using different methods. Baklouti et al. [7] Developed model that can be used to estimate the hourly global, diffuse and direct solar radiations for horizontal surfaces and the total daily solar radiation on an inclined and vertical surfaces in the region of Sfax, Tunisia. In the same location, for the estimation of the hourly and daily solar radiations the Liu and Jordon model is used. In addition, the values of monthly of average daily solar radiation on a horizontal surface are taken from NASA data base and local meteorology station. The obtained results are compared with the PVGIS (Photovoltaic Geographical Information System) data. Other researchers have been conducted regarding solar energy forecasting using the Artificial Neural Network techniques (ANN). Numerous meteorological and geographical variables such as maximum temperature, relative humidity, sunshine duration, cloud cover, latitude, longitude, and altitude have been used to develop the ANN models for solar prediction [7]. El Ouderni et al. [8] concentrated on the gulf of Tunis, in Tunisia and proposed a model to estimate the hourly solar radiation. Meher Chelbi et al. [9] assessed a comparison between many Angström [10] type regression models, such as the linear, quadratic, cubic, logarithmic and exponential models, and estimation of the global solar radiation on horizontal surfaces over a territory. In Tunisia, as a case of study for the Angström methodology, meteorological stations, that provide global solar radiation and sunshine duration data, are used as references to validate studied models. The statistical analysis demonstrated a good precision of the models used to estimate the solar potential. The monthly average daily global solar radiation is about 6.9 MJ/m^2/day in the North of Tunisia during January, While 28 MJ/m^2/day are obtained in the South East of Tunisia in June (the surroundings of the Gulf). Considering the map of Tunisia, the monthly average daily solar radiation increases from 15.7 in the North to19.4 MJ/m^2/day in the South. In Africa, Mecibah et al. [11] conducted an evaluation of eleven empirical models based on sunshine duration and air temperature for six Algerian cities. According to a comparison between their results, the authors found that the sunshine-based models, particularly the quadratic and the cubic models, lead to better results than the air temperature-based models. Besides, Ghouari et al [12] aimed in their work, to analyse the performance of a 1.6 kWp grid connected PV system installed at Batna University, Algeria. The average daily solar energy received was 5.21 kWh/m^2.d. According to this study, the grid connected PV system can be a good electricity generator, in this region. The performance ratio of the PV plant was ranged between 51 and 61%. Furthermore, during the period of 2015. The annual final yield was 1065.6 kWh/kWp. Besides, an analysis of the energy losses in the system was established, in order to determine the effect of the capture and losses on the total energy balance of the system. For PV technologies performance estimation, in India, Ramana et al. [13] tried to model different technologies of PV modules using single diode model. The proposed method utilized independently, the characteristics of diode ideality factor, shunt resistance and serie resistances in order to develop accurate solar PV model. Besides, the experimental values obtained from the solar array simulator were used to implement the proposed approach. This work focused on developing an appropriate method for thin film solar modules using simplified approach. The model is simulated in MATLAB and is validated with available theoretical simulation and experimental values gathered from solar array simulator. Whereas, In Iran, Hosseini et al. [14] studied the effect of different local and environmental conditions on the performance of an on grid 20 kW pilot PV power plant. For this purpose, they analysed instantaneous effects of environmental parameters, such as solar irradiance, ambient temperature, module temperature, partial shading, and wind speed. It is revealed that the instantaneous generated current is linearly proportional with solar irradiance. According to cumulative data, the pilot installation has produced a total of 105 MWh/year and an average of 2.75 MWh/month of electrical energy in 2015. Among the analyzed parameters, the shadow had a significant effect on PV system performances. In the same context, several researchers, such as M. R. Rashel et al. [15] studied the effect of shadow on PV cell production. According to them, there are diverse detected aspects of shadow effects, for which the PV cell output is minimized or reduced to zero. Indeed, the shadow effects are depending on the type of PV cell connections (in parallel or in series). In case when PV cells are in series and one cell is out of order due to shadow, the whole related PV series will not be operational. However, in parallel connection case, if one cell is shadowed, the others still working independently. Using SIMULINK software, the authors had analyzed the shadowing effect for the two indicated cases. Other theoretical studies have been developed to estimate panel temperatures based on irradiance, ambient temperature and other parameters such as wind speed and configuration design. In fact the module temperature models have been extensively verified for northern hemisphere locations [16-22]. Moreover, Many simulations of PV performance models were presented in the references [22-25]. For standalone photovoltaic applications, battery modeling constituted the interest of many researchers. Blaifi et al. [26], developed models in the purpose to evaluate the battery's voltage output under real PV system conditions. In order to establish a dynamic and static simulation, the comparison between theoretical results and actual measurements was performed to prove the good accuracy. In other works, with the purpose of drawing the behavior of next-generation PV systems, G. Acciari et al. [27] compared the performances of PV windows, which could be interested by architects. In more details, a study of a dye sensitized solar cell (DSSC) and blue and grey thin film silicon panels have been established. The systems can be sited behind a window or behind a wall of glass blocks. The comparison of the three generation systems are basically referred on two terms; both efficiency and Fill Factor. In the last years, the cost of photovoltaic systems had significantly declined. Also the cost of this kind of electrical energy is the same in many countries in Europe. G.O. Francia study [28] was interested in the impact of technological improvement of PV module in comparison with the available silicon technology on the Levelized Cost of Photovoltaic Energy (LCOE). For the future investigations and in order to make PV plants widely used in Europe, research and development approach was essentially interested in decreasing installation costs. Besides, F. Pauliet al. investigations [29] were interested in Italian domestic photovoltaic market. They conducted precious analysis of LCOE related to PV plant investment. In Africa, many regions suffer from lack of electric energy [30]. Several millions of population live in desert regions. Some works [30] are interested in the strategy of decentralized renewable energy systems (DRES) taking into consideration the increase of the local domestic electricity needs.

Therefore, photovoltaic energy is in full expansion in the North of Africa particularly in Tunisia. Several theoretical solar radiation databases are available but they are quite different. Reliable solar radiation databases are required in order to determine photovoltaic system performances with good accuracy. As a case of study, in Tunisia national programs are established to improve the use of solar energy as a key factor to balance the energy expenditure. In fact the PV systems industry is in full expansion. Consequently real data base on PV energy potential is substantially required to optimize the performances of PV systems used in several fields such as industry, agriculture, Air Conditioning and refrigeration. In this context, establishment of experimental database of PV system is considered as the most important parameter for the design and the development of any solar energy system. In fact several investors are interested in PV system investigation in Tunisia. Experimental data on real operating conditions constitutes helpful tools to choose the suitable region in order to optimize their performance investments. This work deals with an experimental study conducted on two PV system technologies located in different regions in Tunisia.

2. Experimental Device

The PV systems used for this study are constituted by two platforms. The first one is constituted by two PV systems located in Tozeur (South west of Tunisia) as presented in Fig. 1.a, for which two PV technologies are used. An amorphous technology of 1.24 kWp of power is invested. While the other technology is polycrystalline of about 1.47 kWp of power. The second platform is an amorphous technology solar installation of 0. 930 kWp of power installed at the Tunis city, (North of Tunisia), as indicated in Fig. 1.b. The mean PV systems specifications are indicated in Table 1.

Fig. 1.a. Tozeur City. **Fig. 1.b.** Tunis City.

Fig. 1. The PV platforms

Fig. 2.a. Data acquisition system **Fig. 2.b.** Solar sensor box

Fig. 2: Data acquisition equipment

Each platform is equipped with the same data acquisition system used to record and convert the sensor outputs related to solar radiation, cell and ambient temperatures, and PV production of two installations. Furthermore a solar sensor box [31] is installed with the same orientation and inclination as well as the panels (Fig.2). The solar radiation measurements are performed each 5 min. The technical specifications of the different sensors are indicated in Table 2. The stations are oriented in full south with an inclination of 30° and taken away from any shading. Meteorological Data correspond at the location of Tunis such is (latitude: 36°49′08″ N, longitude: 10°09′56″ E, elevation: 11 m above the sea level,). While, Meteorological Data correspond at the location of Tozeur such is (latitude: 33°50’ N, longitude: 8°08′00″ E, elevation: 61m above the sea level,). These results have been collected from NASA, Surface meteorology and Solar Energy. Measurement of solar radiation is considered as the most important parameter for the design and development of any solar energy systems. Two temperature sensors of 0.1 °C of accuracy are used to measure the panel and ambient temperatures. All precautions are taken to make good connections with minimum losses and perturbations.

Table 1. Mean PV systems specifications.

Module technology	Polycrystalline	Amorphous
Power (Wp)	245	155
Number of module	6	8
Module technology	Axitec	Nexpower
Module Power tolerance	± 3%	-0/+3%
Inverters	SMA SB1700	SMA SB1700
Inverter DC measurement tolerance	±4%	±4%

Table 2. SMA sunny sensor box characteristics

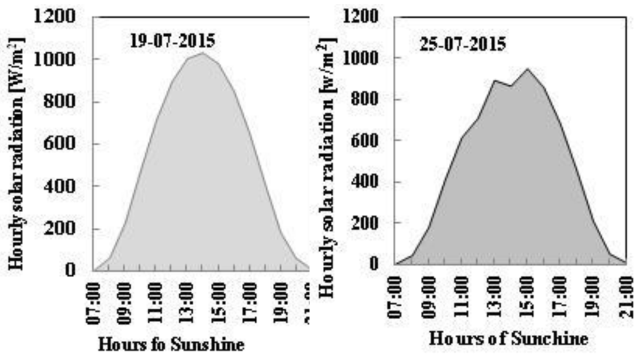
	Solar radiation sensor	Temperature sensors
Measurement accuracy	±8%	Platinum sensor (Pt100)
Measurement range	0W/m²…1500 W/m²	-20°C…+110°C
Measurement Sensor	PV cell amorphous silicon (a-Si)	±0.5%
Resolution	1%	0.1°C

3. Results and Interpretations

3.1. Evolution of Solar radiation in Tunisia.

In this study, the solar radiation is measured each 5 minutes. Obtained data are presented as hourly, daily, monthly and annual solar radiation. As earlier indicated in tables 1 and 2, the measurement errors are estimated of about 8 % for solar radiation and less than 1 % for temperature. The obtained results will be presented taking into consideration the indicated accuracies.

Figures 3 and 4 depict the hourly solar radiation variations for good and bad sunny days in the two regions Tozeur and Tunis. The maximum value reached in Tozeur region is about 1100 W/m^2 for summer season (see Fig.3). That constitutes a specific advantage since the value of power density of the earth's atmosphere is 1353 W/m^2 [32]. Furthermore obtained experimental results show that it is possible to produce PV energy even during the cloudy days as shown in Fig.4. In fact for such cloudy days, the mean value is about 300 W/m^2 for a period over than 5 hours, in the South West. While in the North it is only about 150 W/m^2.



3.a TozeurCity (South) **3.b.** Tunis City (Nortrh)

Fig. 3. Hourly solar radiation of a good sunny day, in Tozeur and Tunis.

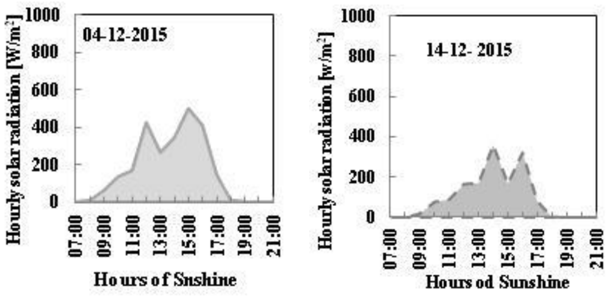


Fig. 4.b. Tozeur City **Fig .4.a.** Tunis City

Fig. 4. Hourly solar radiation of a bad sunny day, in Tozeur and Tunis.

The evolutions of average daily solar radiation, for the different seasons, are presented in Figures 5 and 6 for South and North region respectively.

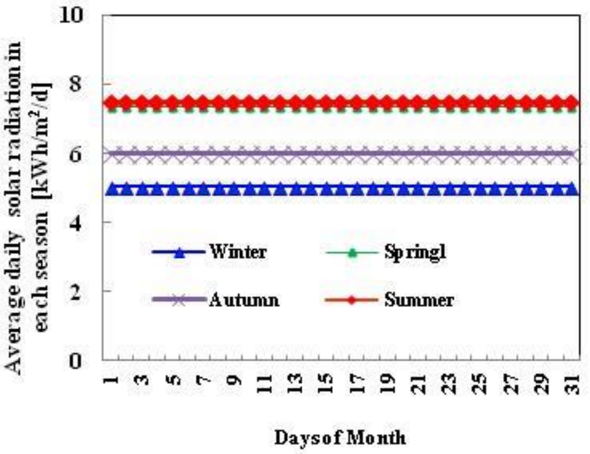


Fig. 5. Average of daily solar radiation for the different seasons in South West of Tunisia

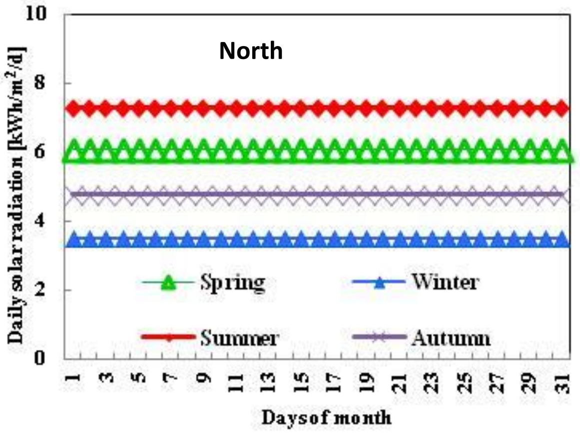


Fig. 6. Average of daily solar radiation for the different seasons in North of Tunisia

According to above figures, the mean value of solar radiation for Winter season is about 5.04 and 3.325 kWh/m^2/day in the South West and the North of Tunisia respectively. For the Spring month, the average daily solar radiation value is about 7.35 kWh/m^2/day in Tozeur and 6.082 kWh/m^2 in Tunis. As expected the maximum average daily solar radiation value is obtained in Summer of about 7.49 kWh/m^2/day, in Tozeur and 7.3 kWh/m^2/day in Tunis. The relative differences between solar radiation values obtained in the two sites for the different seasons are presented Fig.7. One can see that the important difference is shown in Winter and Autumn, this can be explained by the fact, in the South West of Tunisia, although the sunshine duration is less than that obtained in Summer, the ambient temperature is near 25°C which could be significant to the panel efficiency.

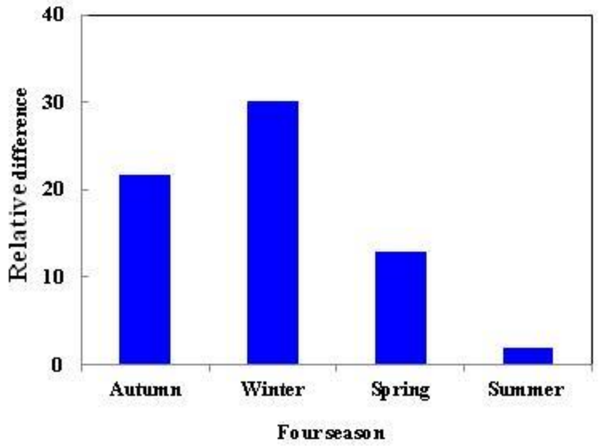


Fig. 7. Relative difference between the solar radiation values measured in South West and in the North of Tunisia**.**

Figures 8 and 9 present the average values of hourly solar radiation, during over the year 2015, which is between 200 and 350 W/m^2 in the South West of Tunisia (Fig. 8) and between 100 and 300 W/m^2 in the North of Tunisia (Fig. 9). The annual average of hourly solar radiation is about 272 W/m^2 in Tozeur while in Tunis is about 222 W/m^2. The relative difference regarding the two region's values is about 18%.

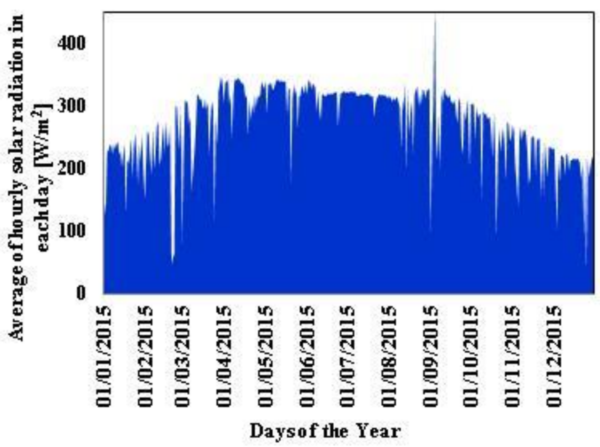


Fig. 8. Average of hourly solar radiation in the whole year(2015), in the South West of Tunisia

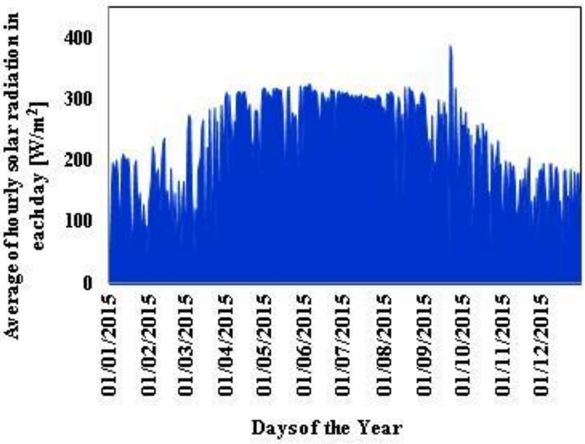


Fig. 9. Average of hourly solar radiation in the whole year (2015), in the North of Tunisia

Monthly solar radiation is required to constitute a reliable data for solar radiation useful for further investigations in solar energy industry. It is obvious that the South West of Tunisia provides a monthly solar radiation much more important than the North. The relative difference between the monthly solar radiation values, obtained in the two indicated sites, is presented in Fig.10. One can see that, from October to March, the relative difference remains higher than 20 %. In addition much more areas are available in the South West region than in the North. That constitutes a motivating factor for the investors in the PV fields.

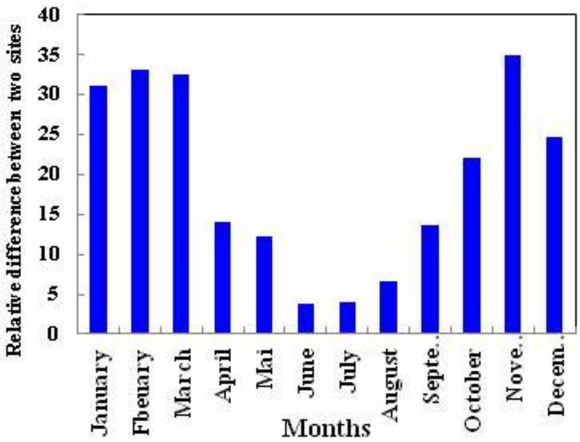


Fig.10. Relative difference between two sites

The annual solar radiation is about 2374.45 kWh /m^2/year in the South West. While in the North it is around 1951,927 kWh/m^2/year. Noting that for the Tozeur city, the least solar radiation is about 146.5 kWh/m^2, obtained in December. While, the most important monthly solar radiation is about 235.474kWh/m^2, obtained in July.

A comparison between the experimental results (TunCom) and the available databases like CM-SAF and NASA is performed during a whole year (2015), in the South West of Tunisia as depicted in Fig.11. During Winter season (from December to March) the solar radiation obtained in the actual study (TunCom) is slightly lower than that obtained from CM-SAF data base (used in Pvgis software) as shown in Fig.11. A maximum difference of about 17 % is obtained in February. While, from April to September, Tun-Com generates higher values. A maximum relative gap of about 9.6 % is obtained on May. During the whole year, the NASA data base (used in Pvsyst software) gives the lowest values of solar radiation. Considering the annual solar radiation values, the experimental TunCom data are closely near to the CM-SAF ones with relative difference around 1 %. While, this difference is more than17 % regarding NASA data base.

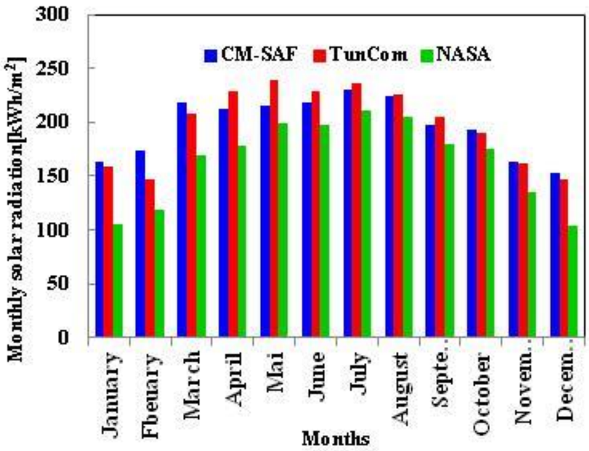


Fig. 11. Monthly solar radiation in inclined surface according to three databases in the South West of Tunisia

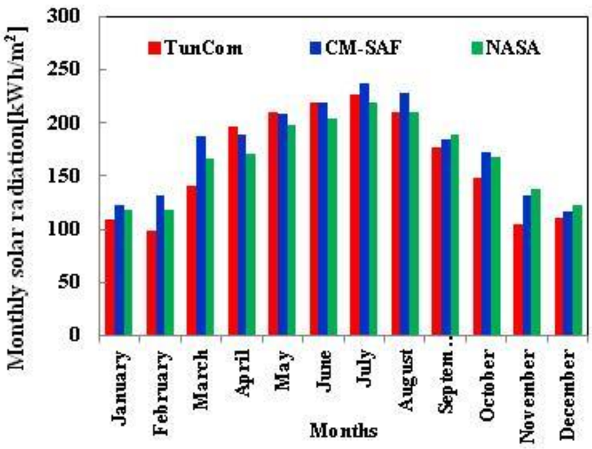


Fig. 12. Monthly solar radiation in inclined surface according to three databases in the North of Tunisia

Figure 12 shows the monthly solar radiation data obtained from the three indicated database, in the North of Tunisia. The relative difference between TunCom and NASA data is about 20 %. While the CM-SAF data base gives solar radiation values 4 % higher than TunCom ones.

3.2. Ambient and panel temperature evolutions.

Seeing the arid climate of the South West of Tunisia, the ambient temperature is generally more than 18°C. Indeed, during the sunshine period, a net difference between the daily ambient and panel temperatures may exceed 20°C in Tozeur and Tunis cities as shown in Fig. 13. That may affect significantly the panel efficiency.

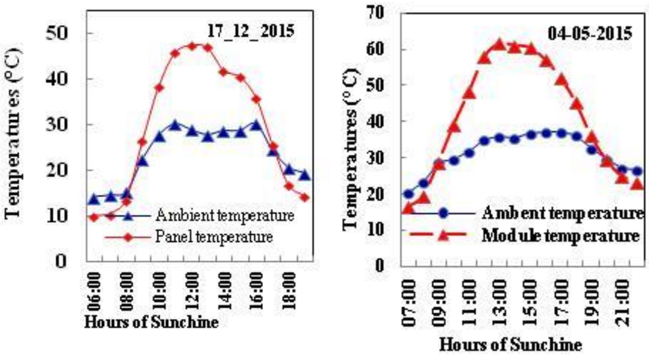


Fig. 13.a. Tozeur City **Fig. 13.b.** Tunis City

Fig.13. Daily evolution of cell temperature and ambient temperatures.

In the purpose to evaluate the difference between the cell and ambient temperatures during the whole year, an average is determined as follows:

For each day i and for every 5 minutes during the sunshine period, the cell and ambient temperatures ($T_{cel,i}$ and $T_{amb,i}$) are simultaneously measured with an incertitude of 0.1°C. The instant difference $\Delta T_{inst,i}$ is given by:

$$\Delta T_{inst,i} = T_{cel,i} - T_{amb,i} \quad (1)$$

The monthly average of the temperature difference, $\Delta T_{mont,j}$, is calculated by:

$$\Delta T_{mont,j} = \sum_{1}^{n} \Delta T_{inst,i} / n \quad (2)$$

Where n is the number of days for each month.

The seasonally average, $\Delta T_{sea,j}$, is deduced from previous equation:

$$\Delta T_{sea,j} = \sum_{1}^{3} \Delta T_{mont,i} / 3 \quad (3)$$

Figures 14 and 15 show the seasonally average difference between the cell and ambient temperatures, $\Delta T_{sea,j}$, measured during sunshine periods in the North and South West of Tunisia.

In Autumn, the most important difference between cell and ambient temperature is about 16 °C obtained from 12:00 to 15:00 PM in the North and in the South West. During Spring season the most important difference is about 19 °C, obtained from 11:00 AM to 14:00 PM, in Tozeur. Whereas, in Tunis, the maximum difference value is about 15°C. For summer season a maximum difference value of 20 °C is obtained in Tozeur from 13:00 PM to 14:30 PM. While , in Tunis, this difference is near 17 °C. In Winter season the maximum difference value for the two sites is lower than 10 °C. The average value of $\Delta T_{sea,j}$ during the four seasons is around 16 °C, measured from 12:00 AM to 15:00 PM, in Tozeur, While, in Tunis, this value is around 14°C.

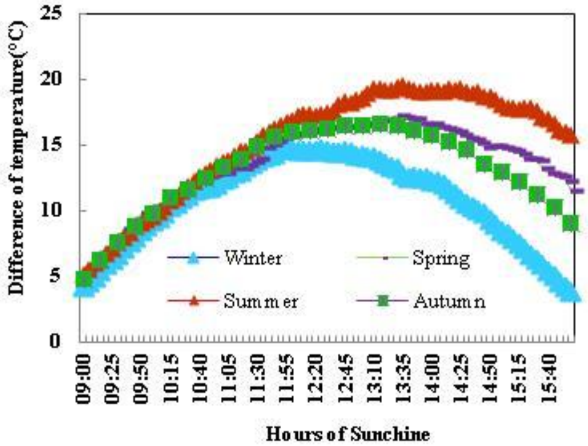


Fig.14. Difference between cell and ambient temperatures in different seasons for the South West of Tunisia**.**

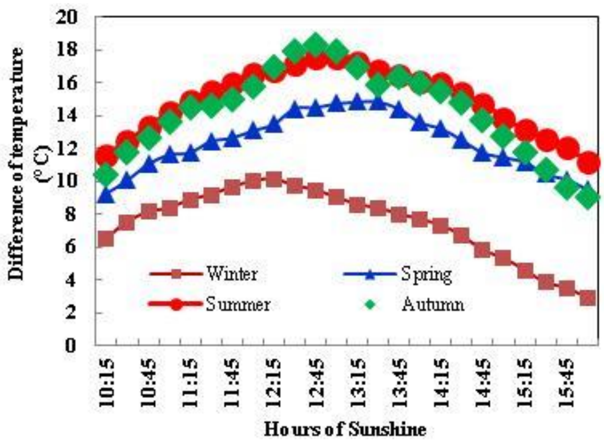


Fig.15. Difference between cell and ambient temperatures in different seasons for the North of Tunisia.

From the obtained results related to the difference between the cell and ambient temperature, and in order to improve the panel efficiency the integration of a refrigeration system is required.

Taking into consideration the important value of this difference, an energy recovery system may be integrated for two purposes; improving the PV panel efficiency and valorizing the recuperated energy. Indeed, for a $\Delta T_{sea,j}$ of 16 °C and using water as refrigerant the recovered energy is determined according to NTU method as follows:

$$\dot{Q}_{recov} = \varepsilon \dot{Q}_{max} \quad (4)$$

$$\dot{Q}_{max} = C_w (T_{cell} - T_{w,in}) \quad (5)$$

$$C_w = \dot{m}_w Cp_w \quad (6)$$

Where:

ε is the heat recovery system effectiveness taken equal to 95 % [33].

$\dot{Q}_{max}$ is the maximum recovered heat capacity

C_w is the water flux capacity

$T_{w,in}$ is the inlet water temperature

For a water mass flow rate of 0.3 kg/s (18 l/min) the recovered energy capacity is about 21 kW. That leads to a recovered energy for each 5 minutes close to 6300 kJ.

3.3 Performance analysis of two grid connected PV technologies.

To characterize the production performance of PV systems a factor called final yield Y_F (kWh/kWp) is commonly defined to evaluate the actual PV production to theoretical power accomplished in standard test conditions (STC-rated power). The parameter Y_F can be expressed as:

$$Y_F = E_{PV} / P_{STC} \quad (7)$$

Where E_{PV} : is the obtained energy of the considered PV system in kWh

P_{STC} *:* is the system power measured under STC in kW

Furthermore, another factor called reference yield Y_R is used to define the ratio of solar radiation (plane-of-array irradiance) H (kWh/m^2) to the reference irradiance G_{STC} = 1 kW/m^2. This factor is expressed as:

$$Y_R = H / G_{STC} \quad (8)$$

Taking into consideration the two previous factors a performance ratio (PR) is defined as:

$$PR = Y_F / Y_R \quad (9)$$

Experimental results show that the evolutions of the indicated parameters from April to July are limited by the results obtained in March and August. Hence only the curves related to these two months are presented in the figures. Measurements are performed with an accuracy of about ± 3%.

As earlier indicated, the PV system installed in Tozeur (South West) is constituted by two different PV technologies (Amorphous and polycrystalline). In the purpose to determine the annual PV performance of the indicated technologies, the monthly final yield, Y_F, is presented in Fig. 16 during the whole year (2015). The maximum values of Y_F are obtained in July. These values are about 193.843 kWh/kWp and 186.865 kWh/kWp for amorphous and polycrystalline technologies respectively.

The maximum difference between the two technologies is about 4 %, obtained on March. While on May and June, the two technologies give practically the same final yield of about 189 kWh/kWp. From July to October the amorphous technology generates power higher than the multi-crystalline one. The maximum difference is about 6 %, obtained on August, September and October. The annual difference between these two technologies is less than 2%.

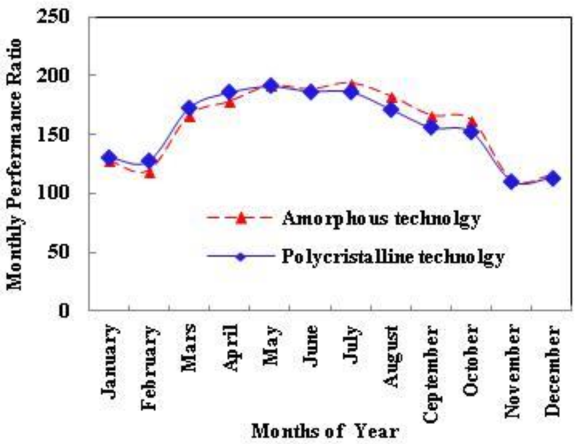


Fig.16. Monthly final yield of amorphous and multi-crystalline technologies in Tozeur**.**

Figure 17 depicts the variation of the performance ratio, PR, as defined by equation (6). From January to March the PR of polycrystalline module is slightly higher than the amorphous one. For polycrystalline system, the maximum value of PR is about 83 % obtained on February. In addition, as expected, the polycrystalline technology value of PR, in cold season, is higher than that generated in hot season [34]. In fact the lower value of PR, for this system, is about 76.2 % obtained on August. From June to November the amorphous technology generates a performance ratio higher than the polycrystalline system. The maximum value of PR is about 85.3 % obtained on October.

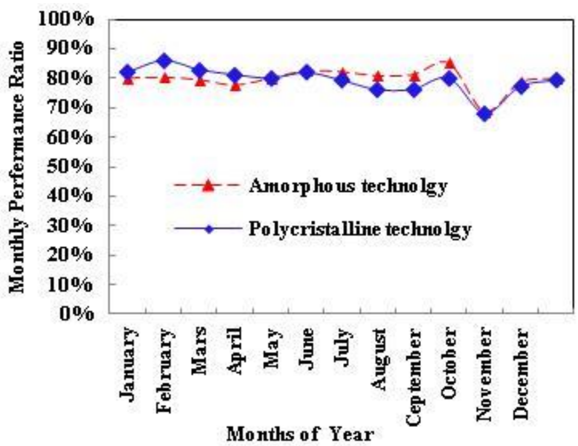


Fig.17. Monthly Performance Ratio of amorphous and polycrystalline technologies.

4. Conclusion

An experimental study is conducted on PV systems with different technologies and installed two different sites in Tunisia (the South West and the North).

New experimental data base is established during a period of two years; for which Hourly, daily and monthly solar radiation variations are recorded. A comparison between results obtained in the two sites is performed. The annual solar radiation is about 2374.45 kWh /m^2/year in the South West. While, in the North, it is around 1951,927 kWh/m^2/year. The relative difference, between these two values, is about 18 %. Experimental results (TunCom) are also compared to the available databases CM-SAF and NASA during a whole year (2015). A difference between TunCom annual solar radiation and CM-SAF data is about 1 %. However, this difference is more than17 % regarding NASA data base, in the South West of Tunisia. While, in the North, The relative difference between TunCom and NASA data is about 20 %. And the CM-SAF data base gives solar radiation values 4 % higher than TunCom ones.

In the South west, the annual final yield is 1887,09kWh /kWp/year about for polycrystalline technology. While for the amorphous module is about 1902,99 kWh /kWp/year. These results constitute an attractive factor for the investor in PV industry especially in the South West of Tunisia.

Acknowledgements

The equipment is offered by Solarenr Company [35] in partnership with TunCom Company [36]. Authors would like to kindly thank the managers for their support, help and fruitful collaboration.

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