J. Mater. Environ. Sci. 7 (11) (2016) 4064-4072 *Boughamrane et al.*
ISSN : 2028-2508
CODEN: JMESCN

Comparative Analysis of Measured and Simulated Performance of the Moroccan First MV Grid Connected Photovoltaic Power Plant of Assa, Southern Morocco

L. Boughamrane*, M. Boulaid, A. Tihane, A. Sdaq, K. Bouabid and A. Ihlal

Materials and Renewable Energies Laboratory, Department of Physics, Faculty of science, Ibn Zohr University 80000 Agadir, Morocco

**For correspondence:Email: boughamrane@hotmail.com (L. Boughamrane); Phone: + 212661199409; Faculty of science, Ibn Zohr University 80000 Agadir, Morocco,*

Received 25 Mars 2016, Revised 25 Aug 2016, Accepted 29 Aug 2016
Email : mohamed.boulaid@edu.uiz.ac.ma

Abstract

This paper presents preliminary results of actual measured and simulated performances of a first year 806.52 kWp grid connected photovoltaic power plant located at Assa, southern Morocco (28.63°N - 9.47°W). The PV system consists of 8 AICHI on-grid PV inverters, 100 kVA each and 3432 SHARP Brand 235 kWp modules. The plant is divided into two groups of 4 inverters, each inverter is supplied by a PV field consisting of 33 strings of 13 series-connected modules facing south at a fixed tilt of 20°.The data presented in this study were monitored during the first year of operation of the plant. The performances of the system were simulated using PVsyst software then compared with real measured data. By December 31st 2015, the plant supplied 1331.29 MWh to the local utility grid. The mean actual measured specific yield, final yield, reference yield, system efficiency, performance ratio and total energy losses are 1650.66 kWh/kWp, 4.57 kWh/kWp/day, 6.763h/day, 9.97%, 70.14% and 2.053 kWh/kWp/day respectively. The predicted values of those parameters are in close agreement with the measured results. They were found to be 1384.01 MWh, 1716.024 kWh/kWp, 4.68 kWh/kWp/day, 6.022 h/day, 10.36%, 77.9% and 1.331 kWh/kWp/day respectively. The detailed comparative study in this paper serves as a reference for continuous performance analysis of the PV plant. Besides, the comparison of actual measurements collected on site with simulated estimates given by PVsyst can help to track closely the power generation, and to establish an adequate maintenance plan.

Keywords: Photovoltaic, Grid connected, Simulation, Performance

1. Introduction

The international community has finally contracted a historic agreement at COP 21 held in Paris in 2015. The agreement targets to keep the rise in temperature below 2°C and attempts to limit the temperature increase to 1.5°C. This ambitious goal could be achieved by gradually diminishing fossil fuels consumption and encouraging the use of green energy resources Morocco, who is hosting the COP 22 in 2016, has announced an ambitious energy policy aiming at raising the share of green electricity from 42 % in 2020 to 52% by 2030.

PV technologies play a significant part in this green energy plan. The energy yield performance of a PV system in a given location is important for designing a suitable system to a particular application. A number of softwares are commercially available for predicting PV systems performances at a location of interest. These software packages use meteorological databases, PV module and inverter characteristics to predict the energy yield of PV systems [1]. However, the long-term reliability of photovoltaic plants depends strongly on direct measurements on site as numerous uncertainties in some data provided (irradiance values, soiling rate...) could lead to significant power losses and then influence the estimated cost of PV kWh. Indeed, LCOE (Levelized Cost Of Energy) calculation depends on the quality of meteorological data [2]. Direct measurements are then of great interest. In the present study, the performance analysis and prediction of 806.52 kWp grid-connected PV plant is carefully carried out in order to study the effectiveness of solar photovoltaic power generation. Actual data collected during a period of one year (2015) are analyzed and used to calculate the performance parameters of the plant. A comparison between these data and the simulated parameters using PVsyst software is evaluated [3]. The performed simulations were achieved using meteorological long-term data generated by NASA.

2. **System description and Performance analysis methodology**

2.1. *Description of the Assa PV power plant*

2.1.1 Project context description

The commissioning of the 806.52 kWp solar photovoltaic plant located 3Km from the town of Assa, over an area of 5 hectares, was held in December 2014. This power plant is part of the national energy policy to secure the country's supply of electricity, the promotion of renewable energies and environmental protection and it is the first of its kind in Morocco to be connected to the MV network allowing stakeholders to gain expertise in connecting solar power plants to the grid. In fact, in environmental terms, this photovoltaic solar plant, will have an average energy production of 1.38 GWh per year, thus avoiding emissions of nearly 847 tons of CO_2 per year. In addition, this plant will strengthen the distribution network in the region of Assa and ultimately contribute to improve the quality of service offered to customers. This project was made possible through a grant provided by the Government of Morocco with his Japanese counterpart, worth about 60 million MDH (Moroccan Dirham 9 MDH = 1 US$) for the implementation of clean energy promotion project using solar photovoltaic.

Figure 1: View of the 806.52 kWp grid-connected PV system installed at the Assa Town, southern Morocco.

2.1.2. PV array and inverters

Table 1.PV modules specifications:

Nominal parameters	**Specifications**
Maximum power [Wp]	235
Open circuit voltage [V]	37.9
Short circuit current [A]	8.49
Voltage at max power [V]	30.3
Current at max power [A]	7.76
Dimensions	L=1652mm ; l=994mm ; H=46mm

Table 2. Inverters specifications:

Nominal parameters	**Specifications**
Rated power	100 kW
Input voltage range	[290 V ; 540 V]
Operating voltage range	AC 380V ± 38V
Power factor	0.95
Efficiency of power conversion	93%

2.1.3. Monitoring and data acquisition

The PV system is installed on a rack structure mounted on the ground, 3Km from the town of Assa (28.6°N 9.5°W) over an area of 5 hectares. The power plant consists of 8 AICHI power conditioner On-grid PV inverters, and 3432 SHARP NU-235E1H modules; as can be seen in the schematic diagram below. Each inverter is supplied by a PV field consisting of 33 strings of 13 series-connected modules facing south at a fixed tilt of 20°. The data acquisition system collects data from different measurements tools as pyranometer, Temperature sensor and inverters through RS 485 bus. Data logger records and averages within an interval of 1 minute the power output of each single inverter, global solar irradiation, and ambient temperature as well as DC/AC voltage and current outputs.

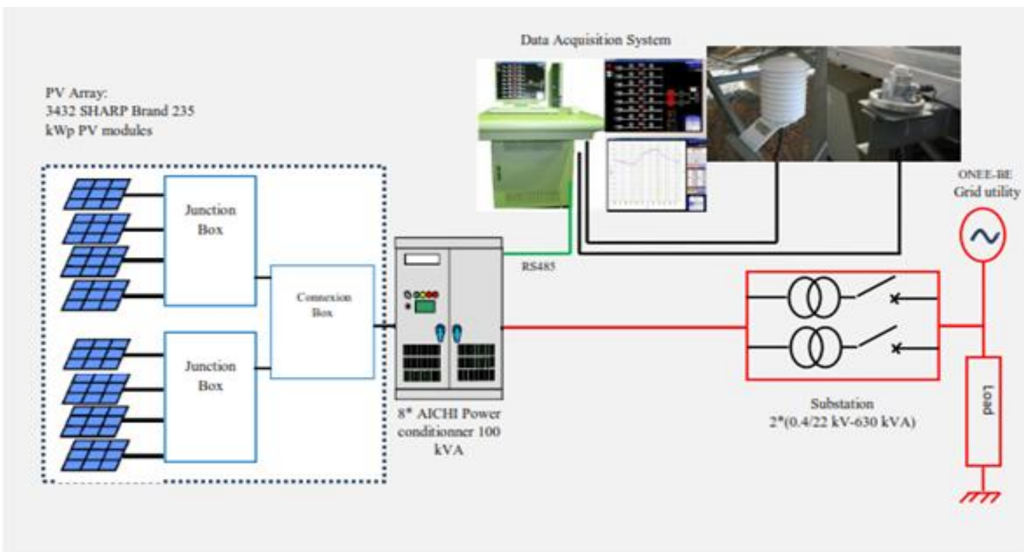

Figure 2: Schematic diagram of Assa photovoltaic power plant.

In order to strengthen the distribution network in the region, the AC energy produced is fed directly to 22 kV grid utility of Assa via two 04/22 kV Transformers of 630 kVA.

2.2 Performance analysis methodology

2.2.1. Performance parameters

To analyse the performance of a grid connected system, a number of performance parameters are being developed by International electro- technical commission [4] under reference IEC 61724. These parameters include final yield, reference yield, performance ratio, system efficiency, and capacity factor.

The Final yield refers to the total energy generated by the system for a defined period of time (day, month, and year). The annual final yield is given by the expression [1-5]:

$$Y_F = \frac{E_{AC}}{P_{PV;rated}} \qquad (1)$$

Where, (E_{AC}) is the total AC energy output (kWh) and $(P_{PV;rated})$ is the nominal power of the installed PV array at standard test conditions (STC).

The Reference yield [6-7] is defined as the ratio of total in-plane solar insolation$H_t [KWh/m^2]$ to the reference irradianceG_0 $[kW/m^2]$. This parameter represents equal number of hours at the reference irradiance and is given by:

$$Y_R = \frac{H_t}{G_0} \qquad (2)$$

Concerning the performance ratio (PR), it represents the ratio of energy fed to the grid (final yield) to the energy that the system could have produced had it operated at its rated conditions (STC) of $1KW/m^2$ (reference yield). PR represents the fraction of energy actually available after deducting energy losses [8]. PR is given by:

$$PR = \ {}^{Y_F}\!/_{Y_R} \times 100\% \qquad (3)$$

The monthly system efficiency is calculated as [7]:

$$\eta_{sys,m} = \frac{E_{AC,d}}{H_{t,m} \times A_a} \times 100\% \qquad (4)$$

Where $(A_a)$is the PV array area (m^2).

Another key parameter for evaluating PV plants is the capacity factor (CF). CF is the ratio of actual generated energy over a period, to its potential output, if it operates at full capacity. Monthly CF is calculated as [9]:

$$\mathrm{CF} = \frac{{}^{E_{AC,m}}\!/_{P_{PV;rated}}}{24 * monthdays} \times 100\% \qquad (5)$$

2.2.2. PVsyst Simulations

A number of simulation software are developed to predict the performance of a solar power plant and easily to assist designers and installers [10]. In this study, PVsyst software is used to predict the performance parameters and energy output of 806.52 kWp MV grid-connected power plant in Assa. PVsyst was design for studying, sizing and data analysising of photovoltaic grid-connected, stand-alone and water pumping systems. The PVsyst simulations inputs involve meteorological data, modules and inverters specifications. In the present paper, simulations were performed using long-term data generated by NASA databases.

3. **Results analysis and discussion**

3.1. *Weather data*

The weather data used as inputs for PVsyst software are presented and compared in this section. Figure 3 shows the comparison between measured (year of 2015) and long term average values derived from NASA-SSE for the monthly average daily total solar radiation.

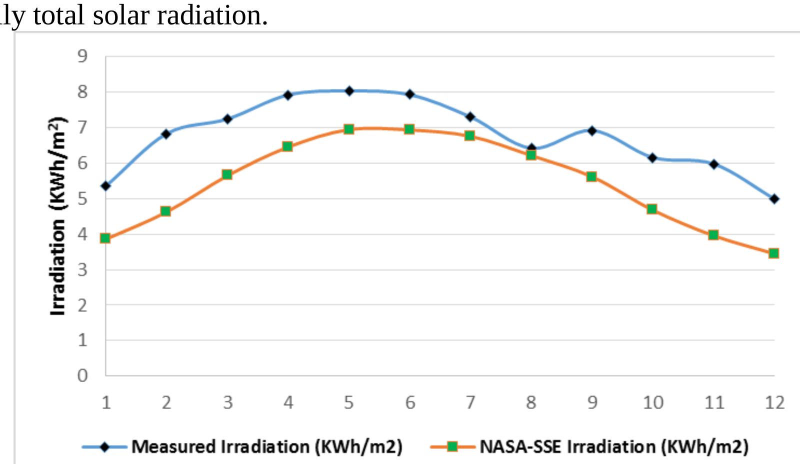

Figure 3: Comparison between measured and long-term monthly average daily total in-plane solar irradiation.

The measured and NASA derived monthly average daily solar radiation shows a deviation which varies between 13% and 34% during the most months except July and August where it stands to only 7% and 3% ,respectively.
The monthly variations in the measured and NASA derived long-term average values for ambient temperature are shown in Figure 4.
The figure shows some differences in the first semester, which varies between 6% and 21%. However, this deviation decreased significantly beginning from July and reaching 1% on August.

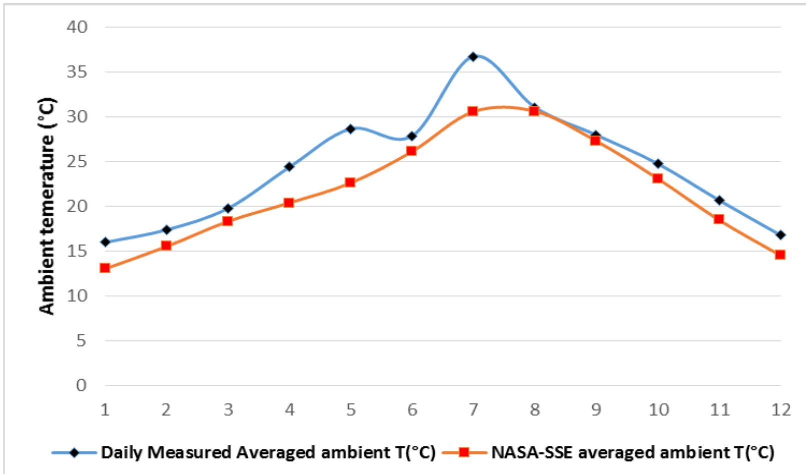

Figure 4: Monthly comparison between measured and long-term average daily ambient temperature

3.2. Performance parameters
3.2.1. Total energy

As shown in Figure 5, the monthly total energy fed to the grid has grown from 84.809 MWh in January to a maximum of 136.076 MWh recorded in April.

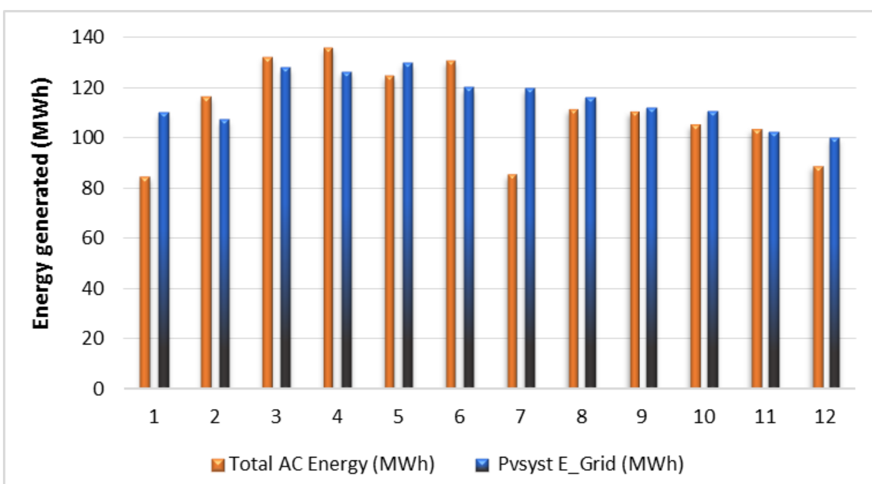

Figure 5: Comparison between measured and simulated total energy fed to the grid

This measured energy profile is linked directly to the irradiation profile as it is shown in Figure 3. The same conclusion could be drawn from the estimated energy using PVSyst. Moreover, it is found that the energy production is affected by change in temperature. Therefore; the correlation between energy profiles and irradiations are not always true. Low value of 84.8 MWh was recorded in January resulting of process and inverters testing at the beginning of that month.

The difference between the measured energy value and the energy estimated by PVsyst varies from 40 % in July, as the maximum value, and 1% in September and November, as a minimum. The measured total energy generated by the PV system in 2015 is 1331.29 MWh as measured by the inverters, while the predicted value is 1384.01 MWh.

3.2.2. Monthly averaged daily final yield

Figure 6 shows the comparison between measured and simulated monthly averaged daily final yield. The measured maximum value was recorded in April, about 5.815 kWh/kWp/day. Simulation results show also a peak of 5.2 kWh/kWp/day at the same period.

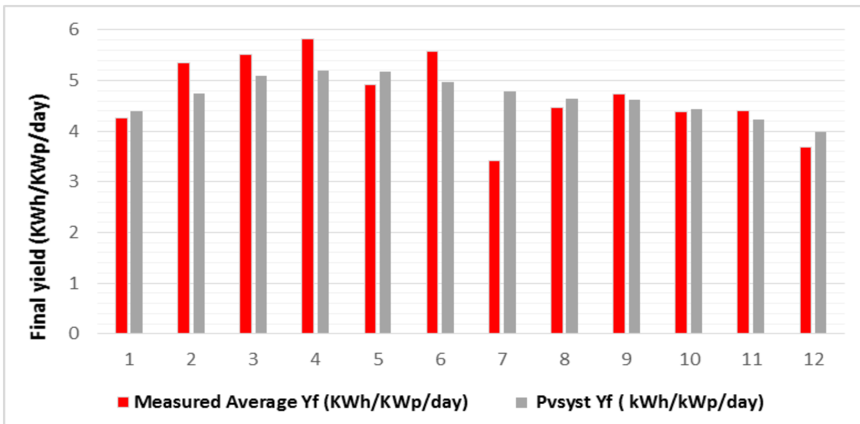

Figure 6: Comparison between measured and simulated monthly average daily final Yield

In addition, the measured specific yield is 1650.66 kWh/kWp/1year while the simulated value was found to be 1716.024 kWh/kWp/1year.

3.2.3. Monthly averaged daily reference yield

Figure 7 displays a comparison between the measured and simulated monthly averaged daily reference yield. The maximum measured value occurred in May was about 8.040 h/day. Prediction shows as well a peak of 6.74 h/day in May also.

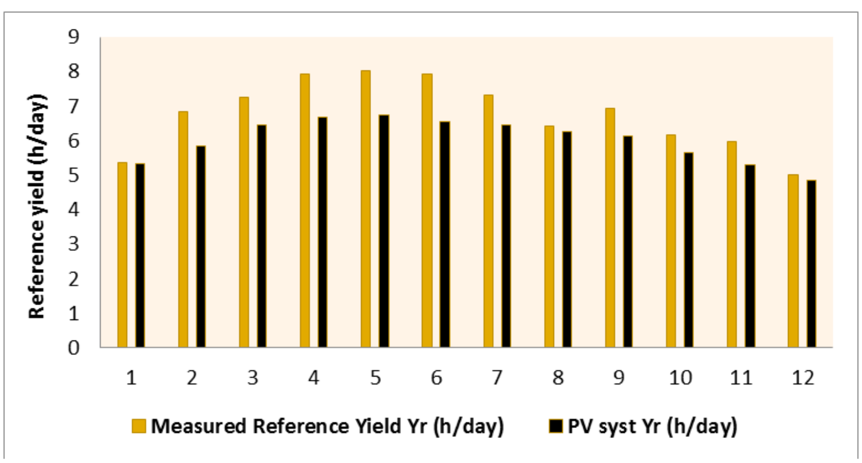

Figure 7: Comparison between measured and simulated monthly averaged daily reference Yield

3.2.4. Monthly Performance ratio

The comparison between the measured and predicted monthly performance ratio is illustrated in Figure 8.

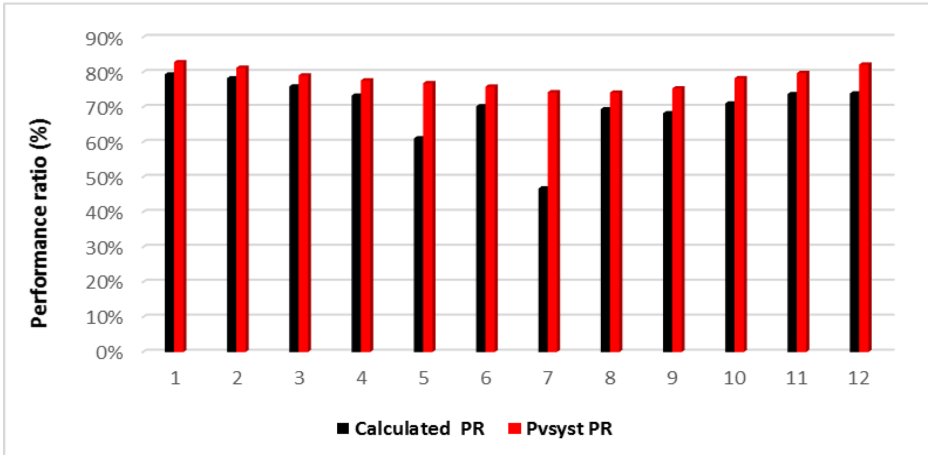

Figure 8: Comparison between measured and simulated Monthly Performance ratio

The performance ratio obtained using measured data is relatively lower than the one obtained using PVsyst derived parameters. This is particularly observed during the months of May, July. Similarly, this occurs when the ambient temperature of the region increases and causes energy losses in the PV modules.

3.2.5. Capacity factor

Capacity factor is an indicator that represents the fraction during a year when, the PV system is operating at it rated power. In this section, simulated and measured CF's are graphically represented in Figure 9. Minimum values (13%) were recorded in July and August due to the system failure during this period as mentioned before. The average annual CF is 18% compared with 19% given by PVsyst software.

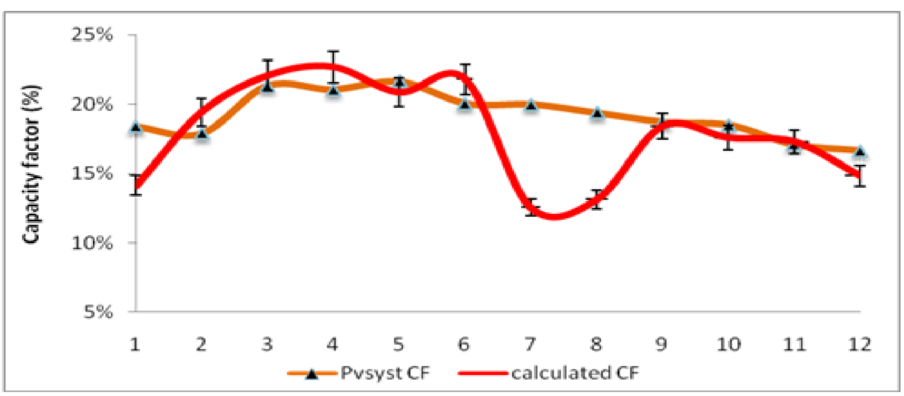

Figure 9: Monthly capacity factor comparison.

According to [8], the capacity factors of reported PV plants are found to be 13-15% in Massachusetts, in Arizona 19%, in UK 8.6% and in Egypt is 18.12%. These examples show how efficient this power plant is.

3.2.6. Efficiency

Figure 10 illustrates the comparison between real measured and predicted efficiency of Assa power plant. The average measured efficiency was found to be less with 3% than the simulated value (13%), and this is obviously due to the power generation drop recorded in January, July and August.

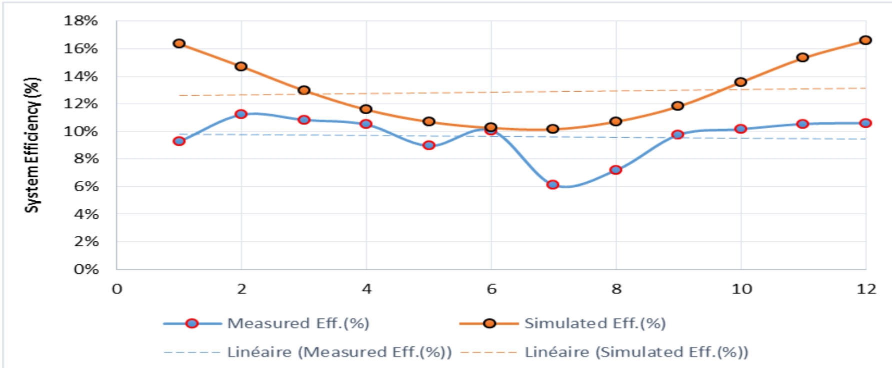

Figure 10: Monthly measured and simulated efficiency comparison

3.3. Comparison of PV system performances with other installations elsewhere

The normalized energy average yield (kWh/kWp/day) enables the comparison between different PV installations regardless of size and location. Table.3 shows some performance parameters for different grid connected PV systems recorded in others countries.

Table 3. Comparison of the performance of different ground mounted, grid-connected PV systems around the world:

Location of PV technology	Technology	Installed Capacity (kWp)	Monitoring duration	Annual average final yield (kWh/kWp/day)	performance Ratio	Refs
Khatkar-Kalan, India	p-Si	190	2011	2.33	74	[7]
Dublin, Ireland	m-Si	1.72	Nov. 2008–Oct. 2009	2.4	81.5	[5]
Eastern Cape, South Africa	p-Si	3.22	2013	4.9	84	[1]
Crete, Greece	p-Si	171.36	2007	3.66	67.4	[11]
Karnataka State, India	m-Si	3056	2011	3.75	70	[12]
Malaga, Spain	p-Si	2	1997	3.67	64.5	[13]
Trieste, Italy	m-Si/HIT	2.99 11.7	14th Oct. 2011 to 15th Oct. 2012	3.83 3.49	89.1 82.7	[14]
Nouakchot, Maurtania	a-Si	954.72	1st Sept.2014 to 31th Aug.2015	4.27	67.96	[15]
Assa, Morocco	p-Si	806.52	2015	4.71	70,14	Present study

The Comparison between the results from this study with other international studies revealed that, the PV system's annual energy yield of 4.71 kWh/kWp/day is one of the highest annual yields. It is important to mention that, our modules have never been cleaned unless when some natural cleaning (rainfall or wind) events occur. A study reported by Cheikh El BananyElhadjSidi and al. [15] has shown close agreement compared with our results, knowing that Noukchout and Assa are characterized by similar arid and desert climate conditions.

Since this study was conducted in a relatively higher temperature region of southern Morocco and taking into account an unexpected inverters failure occurred in May and July, the difference between the highest and our annual average yield could be justified. Hence, we can conclude that southern Morocco is generally a good region for deployment of PV systems.

Conclusions

The 806.52 kWp grid-connected PV power plant of Assa, southern Morocco was monitored during the year of 2015and its monthly and annual performance parameters were evaluated and compared with simulated parameters. The simulation results gave a good approximation to measured energy output and irradiation; however, the simulation is less accurate when it comes to the ambient air temperature particularly in April, May and July when temperature increases in the region. This is evident because NASA data are adopted only to estimate the PV systems performance. Furthermore, the simulation accuracy can be improved by using on-site solar resource measurements. The measured performance ratio of 70.14% indicates the big interest of solar potential in this region of Morocco, which is suitable for solar power generation. The comparison of the annual final yield of this system with other systems installed at different locations worldwide shows that Assa PV plant presents a good final yield during the monitoring period with an average of 4.71 kWh/kWp/day. This value is very promising since the modules have never been cleaned. In order to improve the performance, two recommendations has been taken to be applied in the following years, the first one is to provide an adequate maintenance plan based on the performance recorded in 2015 and the second is to equip the solar plant with anenhanced remote monitoring system.

Acknowledgments-Authors are pleased to acknowledge the Japanese cooperation for the PV plant foundation and also all installation team for their efforts and support that gave birth to a first grid connected power plant of this scale in Morocco.

References

1. Okello D., van Dyk E.E, Voster FJ., *Energy Conversion and Management.* 100 (2015)10-25.
2. Branker K, Pathak M.J.M, Pearce J.M., *Renewable and Sustainable Energy Reviews* 15 (2011) 4470-82.
3. Pvsyst. Photovoltaic design and simulation software, version demo http://www.pvsyst.com/en/, (accessed 11/01/2016).
4. IEC standard 61724. Photovoltaic system performance monitoring-guidelines for measurement, data exchange and analysis.Technical report, IEC Geneva, Switzerland; 1998.
5. Ayompe LM, Duffy A, McCormack SJ, Colon M., *Energy Conversion and Management*.52 (2011) 816.
6. Tihane A, Boulaid M, Boughamrane L, Nya M, Bouabid K, and Ihlal A., *Materials Today Proceedings.* 3 (2015) 2549-2586.
7. Sharma V, Chandel SS., *Energy. Energy*. 55 (2013) 476–85.
8. Ghouari A, Hamouda Ch., Chaghi A, Chahdi M., *International Journal of Renewable Energy Reshearch*. 6 (2016) 1.
9. Hamzeh A, Hamed S, Al-Omari Z, Sandouk A, Aldahim G. *International Journal of Renewable Energy Research*. 5 (2015) 4.
10. Merrouni A.A, Ait lahousine O.H, Moussaoui M.A, Mezrhab A., *International Journal of Renewable Energy Research*. 6 (2016) 1.
11. Kymakis E, Kalykakis S, Papazoglou T.M., *Energy Conversionand Management.* 50 (2009) 433–8.
12. Padmavathi K, Daniel S.A., *Energy for Sustainable Development.*17 (2013) 615–25.
13. Sidrach de Cardona M, Li Mara L., *RenewableEnergy*, 15. (1997) 527–30.
14. Micheli D, Alessandrini S, Robert R, Casula I., *Energy Conversion and Management*, 80 (2014) 436–45.
15. Sidi C.B.E, Ndiaye M.L, El Bah M, Mbodji A, Ndiaye A, Ndiaye P.A., *Energy Conversion and Manage.* 119 (2016) 411-421.

(2016) ; http://www.jmaterenvironsci.com/