Performance Analysis of PV System on Real Time Sun Tracking Structure for Grid Connection in Southern Algeria

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Abstract: In this study, we analyze the experimental annual energetic performance of a photovoltaic system mounted on a solar tracking structure. This equipment had been acquired by the Renewable Energy Applied Research Unit (REARU) of Ghardaia. The pv field is constituted by a monocrystalline module (specification in appendix) with a peak power of 2.25 kW, and an inverter Fronius IG15 power of 1.3 kW. The annual energy produced by the system is 3.61 MWh and injected in the internal power grid of REARU, whereas its energy calculated for the same period is 3.79 MWh, the annual produced energy of a same system with a fixed angle is 2.13MWh. The performance ratio (PR) of the system is at its minimum in January with 0.44 and its maximum in April with 0.88. Implantation site characteristics are : Latitude 32.4°, Longitude 3.80° and Altitude 468.4 m, located in the desert at 600 km south of Algiers. We begin by the presentation of each part of the system, and after that, the modeling of each sub-system. Performance indexes of the photovoltaic system connected to the power grid (PVSGC), especially the PR are measured, and also the impact of losses on energy production. All results obtained during the analyze period are presented and discussed, followed by conclusions and specific recommendations for this system type and its environment.

1 INTRODUCTION

Nowadays, renewable energy became more and more attractive and environment protection became a recurrent theme.

Algeria is a country with a large number of sunny days. The Algerian land is mainly is arid and semi-arid, where the huge demand of electricity in the warm season. To meet this demand, it is recommended to inject renewable energy production in the power grid.

In Algeria, most of electrical energy production comes from fossil energy – petrol and natural gas. The rest comes from renewable energy, mainly made up of hydraulic and photovoltaic energy.

Thanks to its geographical position, Algeria is one of the largest potential solar sites in the world. Solar irradiation on the main part of the territory exceeds 2000 h per year and 3900 h on the Highlands and Sahara.

Daily energy received on a 1m2 horizontal area is 5 kWh on the main part of the national territory, comprised of 1700 kWh/m2/year in the North and 2263 kWh/m2/year in the South. "Renewable Energy Portal"

The aim of the renewable energy development national program (2015-2030) is to reach 27% of national energy production from renewable one and 37% of installed capacity in 2030. The volume of natural gas saved by renewable energy production of

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22000 MW is approximately 300 Billion m3, equivalent to 8 times consumption volumes of 2014 year. "Renewable Energy Portal"

(FİLİK et al., 2017) have analyzed the comparison of the solar tracking photovoltaic (PV) system and the same solar fixed photovoltaic system in Eskisehir region (Central Anatolia), for the period between July to October 2016. The result is the tracking system provides nearly 33% higher electricity generation than the fixed one.

(KIVRAK et al. , 2012), they evaluate the performance between the system PV with reel time sun tracker and another one with fixed tilted in Denizli, Turkey. For the two months May and June the energy generated by the subtracting is nearly 64% when it is compared with fixed PV system. When a tracker is used a system that is set up in the area of 1000m² needs only 600m².

(Roshan et al ., 2015), report the performance of two identical PV systems, one at a fixed latitude tilt and the other on a two axis tracker. From August 2012 to March 2013 the tracker panel generates 21.2% more electricity than the fixed one, in India.

(De Simon Martin et al.,2014), have analyzed the performance of three reel PV systems, fixed, horizontal axis tracking and dual axis mount tracking located in the same geographical area in Spain.

(Bazyari et al., 2014), they study the effect of the single axis and the two axes to the fixed one in Qeshm Island of Iran in the summer of 2011. The results of analyses show that the energy received by the single axis system is 35% greater than energy received by the fixed system, while the dual axis received 4% more energy compared to the one axis system. They conclude that the single axis tracker is benefit to the Qeshm Island of Iran. Sharma et al. [6], they analyze the performance of a 190kW PV system in Khatkar-Kalan India, The performance ratio of the PV system is 74% which is higher than those in Greece, Poland and Germany but lower than that in Ireland.

(Russin et al., 2013), they study performance of PV systems from April 2012 to March 2013, in Malaysia; the performance ratio for mono crystalline was 77% while for polycrystalline was found to be 80%.

Performance study of a photovoltaic system depends directly on the installation site, weather conditions and environment. The region of Ghardaïa has a very high solar energy potential which led us to consider the production of electrical energy by photovoltaic means. On the other hand the geography of the site (rocky) imposes temperature picks between day and night during the winters and summer, as well as the peaks of wind speed in autumn and spring (sand wind), which affects the production of the systems.

To the best of our knowledge we have not found a study of the performance of photovoltaic systems with real time solar tracking, injecting the production in the Sonelgaz grid, in our region.

In this column, the performance study of the first 2.25kWp PV system connected to the grid, mounted on the real time solar tracking, located in the Saharan climate. The system is installed in the site named Noumirat Ghardaïa located 600km south of Algiers.

2 PRESENTATION AND MODELING OF THE SYSTEM

The solar panel is mounted on a real solar tracker (figure 1), the Degger tracker 3000NT (the characteristics of the 3000NT are in the appendix), equipped with two circuits based on photo diode, one fixed at the highest point of the panel for horizontal scanning and the other fixed on the lateral side for vertical scanning in order to track the focal point of the power of the sun and positioning the photovoltaic field always perpendicular to the solar ray. The photovoltaic field has a power of 2.25kWp, and is composed of 15 black mono-crystalline modules (the module’s characteristics are quoted in appendix), are connected in a single branch. The IG15 Fronius inverter connected to the grid, has a power of 1.3kW (the characteristics are in appendix).

For the simulation of the system mounted on fixed annual fixed angle structure facing south, consisting of 15 modules. Black mono-crystalline and an IG15 Fronius inverter, we proceeded to the capture of weather data of the site on a horizontal plane.

Figure: 1. Photovoltaic system mounted on the sun tracker

The system is equipped with a meteorological station that monitors the meteorological parameters of the site (temperature, global irradiation on the module plan); as well as an input and output electrical data acquisition chain of the inverter (current and voltage of the DC input, and current and voltage of the AC output). All meteorological and electrical data is captured at a pace of 10 minutes and stored on a micro computer. These data allowed us to monitor and analyze the performance of the PVSGC. The system is in total sales mode; during the first year (May 2016 to May 2017) of operation, all the energy produced (3.614MWh) is injected into the internal grid of the REARU, helping to reduce the unit electricity bill.

FIG. 2 represents the daily irradiation on the modules plan with real time solar tracking and on the modules plan without solar tracking and the ambient temperature during all the day of February 08, 2017. The maximum powers are reached between 9h and 16h, for the tracker 1152W / m², while for the fixed 785.67W / m². At the beginning of the day, at 7:30, the ambient temperature is 10.6 ° C and at the end of the day, at 16:00 the temperature reaches 19.7 ° C.

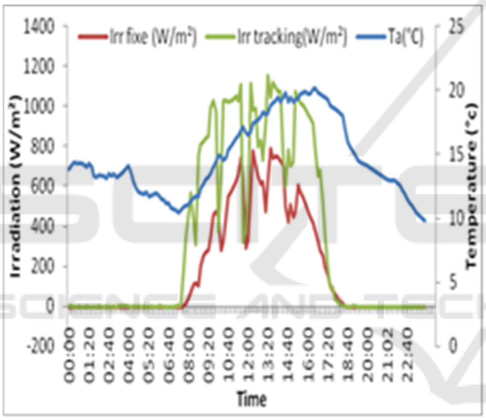

Figure: 2. The daily irradiation with sun tracking and fixed slope, and the ambient temperature of the site, 08.Fubrary.2017 .

FIG. 3 shows the different parts of the photovoltaic system connected to the grid in total sales mode of the energy produced:

- The photovoltaic field consisting of photovoltaic modules connected in parallel series in order to obtain the voltage and the current in adequacy with the inverter. A photovoltaic field is characterized by its efficiency, and either its peak power or its surface.

- The inverter is the driver element of the system; it transforms the continuous input energy into output alternative energy injected into the grid. An inverter is characterized by its power rating and its load yield.

- The load for our case is the electrical grid, which is characterized by its voltage 220V and a frequency of 50Hz.

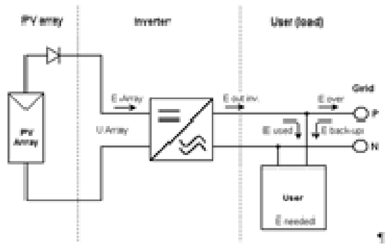

Figure: 3. Power plant grid-connected PVSGC

2.1. Photovoltaic Field Modelling

The most likely photovoltaic cell equivalent mathematical model is the one composed of 5 parameters with only one probe, the equivalent system is presented on figure 4.

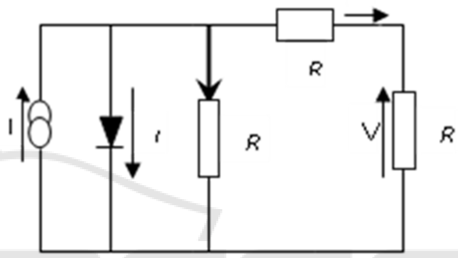

Figure:4.Photovoltaic cell model

The expression of the current is (Ali et al, 2002), (Koussa et al, 2012), (Habbati et al, 2013), (Azzedine et al, 2016), (Attou et al, 2015), (Miric et Nedeljkavic, 2015), (Amrani et DDib, 2016), (Ozcelik et Serdar, 2016), (Sarothi et Pal2, 2017) :

$$I = I_L - I_0\left[\exp\left[\frac{q(V+IR_S)}{mKT}\right]-1\right]-\frac{V+IR_S}{R_{Sh}} \quad (1)$$

I_L: photo generated current or photocurrent; I_0: saturation current of the diode; K: Boltzmann's constant ($K=1.38*10^{-23}$ $J/°K$); e: electron charge ,($e=1.6\ 10^{-19}$ C); m: ideality factor of the diode ($m=1\text{-}1.3$); T: junction temperature (°K); R_s: series resistance due to the resistivity of grid, (Ω); R_{sh} : shunt resistance due to a leakage current, (Ω).

Neglecting the effect of different resistances (very high Rsh, very small Rs), le electric current is expressed by :

$$I = I_L - I_0\left[\exp\left[\frac{qV}{KT}\right]-1\right] \quad (2)$$

As example if $I_0 = 10^{-12}$ A.cm^{-2}, kT/q = 0,025 V, and Isc = 4 x 10^{-2} A.cm^{-2}, Voc = 0,6 V

2.2 Photovoltaic Field Yield

We introduce the photovoltaic field yield model thanks to the measures taken of the field PV. It is function of the maximum power of the field PV P_{max}, the received irradiation on the surface of the field PV G, and the total field surface PV Apv, following the formula (Koussa et al, 2012) :

$$\eta_{PV} = \frac{P_{max}}{G * A_{PV}} \tag{3}$$

On the other hand, the commonly used relationship to measure the photovoltaic field yield is function of the reference temperature T_{ref} = 25°, the junction temperature TC and the coefficient of temperature is (Macagnan et Lorenzo, 1992) :

$$\eta_{PV}\,th = \eta_{ref}[1 - \beta * (Tc - Tref)]$$
(4)

Where

η_{ref}: is the reference efficiency of the PV field (given at standard conditions);

$$\eta_{ref} = \eta_{refModule} * \eta l_{losses} \tag{5}$$

$\eta_{losses} = 0.95$, returns linked to losses in the PV field (diodes, cables ...)

$$\eta_{losses} = 0.085 * 0.95 = 0.08075 \tag{6}$$

The literature about systems PV studies shows that the parameter β range of values is :

$\beta = 0.0025K^{-1}$ and $\beta = 0.008K^{-1}$. $\beta = 0.0043K^{-1}$.

The equation of the cell internal temperature is function of ambient temperature Nominative Operating Cell Temperature (NOCT) (Koussa et al, 2012) and (Poggi, 2007) is :

$$Tc = Ta + \left(\frac{NOCT-20}{800}\right) * G \tag{7}$$

The figure 5 graphs the yield evolution during the day of 08/02/2017, and shows clearly the temperature effect on the yield. Indeed, the theoretical field PV yield perfectly fits the real field PV yield as long as the junction temperature is high, that is, between 7:40 AM (sunrise) to 6:20 PM (sunset). The following tab reports it clearly :

Table 1:

Time	Real yield PV	Theoretical Yield PV
07 :40	0.0139	0.1467
13 :20	0.1188	0.1215
18 :20	0	0.1472

We deduce that the theoretical yield of the equation (4) perfectly describe the evolution of system PV during the day.

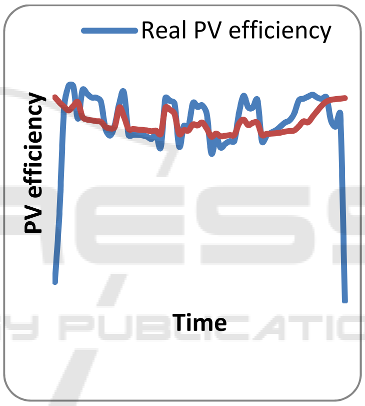

Figure: 5. Evolution of theoretical and experimental efficiencies during the day 08.Fubrary.2017.

On the Figure 6 is reported the irradiation and the junction temperature of the stationary modules, and the irradiation and junction temperature of the modules mounted on solar tracker.

Table 2:

Time	Stationary Irradiation [W/m²]	Stationary Tc [°]	Tracker Irradiation [W/m²]	Tracker Tc [°]
07 :40	15.36	11.013	183.85	17.31
13 :20	785.67	46.28	1152.49	58.53
18 :20	11.69	18.48	19.16	18.137

The cumulated irradiation received by the stationary field PV is 4.42 (kWh/m^2), and the cumulated irradiation received by the solar tracking field PV is 7.95 (kWh/m^2), that is, double for the day partially covered 08/02/2017.

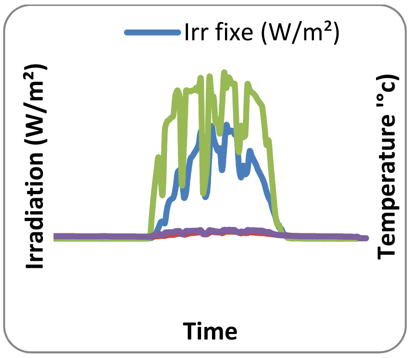

Figure: 6. Evolution of the irradiation and the junction cell temperature on the fixed slope and real time sun tracking, during the day on 08.Fubrary.2017.

After the modelling of the photovoltaic field described by its yield, its peak power and its solar irradiation collecting surface, we focus now on the inverter modelling, which is the photovoltaic systems' core.

2.3 Inverter Modelling

The Inverter is completely defined by its instant yield, which is function of the power determined by the charge.

The Inverter yield is defined as follows (Poggi, 2007) , (Macagnan et Lorenzo, 1992) , (Schmid et Shmidt, 1991):

$$\eta_{DC/AC} = \frac{P_{out}}{P_{in}-P_{out}} \qquad (8)$$

Where the denominator represents inverter losses:

$$P_{lost} = P_{in} - P_{out} \qquad (9)$$

According to ref. [20], the power loss is given by:

$$p_{lost} = p_0 + kp^2 \qquad (10)$$

Where

p_0 : is a constant on-load loss, it is independent of the power demand, : is a constant which expresses the resistive losses of the inverter, p : the inverter nominal power, Then the efficiency becomes:

$$\eta_{DC/AC} = \frac{p}{p+p_0+kp^2} \qquad (11)$$

Specific constants P_0 and k of the inverter are expressed function of inverter yields at 10/100

($\eta_{10} = 87\%$)and 100/100 of its nominal charge $\eta_{100} = 93.5\%$).

So: $p_0 = \frac{1}{99}\left(\frac{10}{\eta_{10}} - \frac{1}{\eta_{100}} - 9\right)$, and $k = \frac{1}{\eta_{100}} - p_0 - 1$ (12)

In this case $p_0 = 0.01439$, and $k = 0.0055129$.

The correlation coefficient is 99.7%, so the calculated values and the measured values are identical.

The type of the inverter is limiting so the output power cannot exceed the inverter nominal power. So we can instantly measure the output power and calculate the system production.

then,

$$\begin{cases} p = 1 & if\ p \geq 1 \\ p = 0 & if\ \ P\_(out - PV)/P\_(nom - inverter)\ \leq p\_0 \\ kp\hat{}2 + p + (p\_0 - P\_(out - PV)/P\_(nom - inverter)\ ) = 0 & if\ p\_0 < p < 1 \end{cases}$$
(13)

On the figure 7, is reported the efficiency of the inverter according to the DC voltage. In the beginning of the day when the DC voltage is 212.6V , the efficiency is 22%, and when DC voltage is 272V the efficiency becomes 94% for the day, but at 16:30 (h) the efficiency decrease to off the inverter.

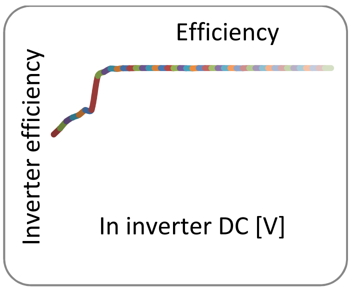

Figure: 7. Inverter efficiency [%], according to the in voltage DC [V], during the day on 08.Fubrary.2017.

The figure 8 shows the instant yields evolution on typical days of all months of the year, between May 2016 and April 2017. As soon as the sunrise, and when the input voltage DC reaches the start value of the inverter, the yield range of values is about 94% from 9:00 AM to 4:00 PM, and can rise depending on seasons.

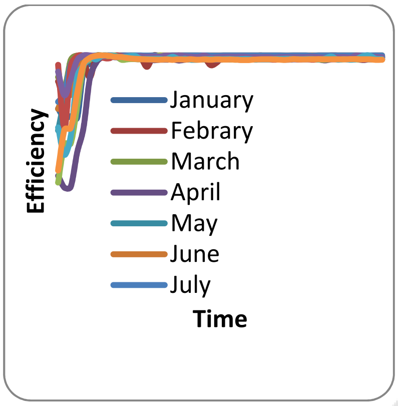

Figure: 8 Yield performances for each typical day of each month of the year

The Figure 9 shows the monthly average value of the yield. The yield is higher in cold period, because the temperatures of warm periods lower the yield.

The yearly average yield of the inverter is 93.33%.

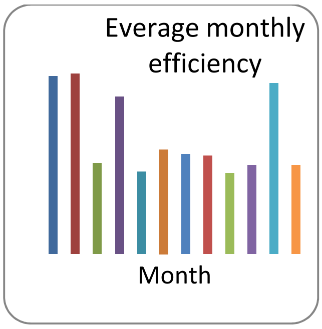

Figure 9: Average monthly efficiency of the inverter

3 STUDY OF THE SYSTEM PERFORMANCES

To conduct the study of the energy performances of PVSCG, the evolution of the predicted and real energy produced by horizontal fixed slope and real sun tracking system are measured.

3.1 Comparison between Sun Tracking System and Horizontal Fixed Slope

Figure 10, we report all real values of daily month average irradiation on the surface of PV modules of horizontal fixed slope and on the surface of PV modules of sun tracking system.

The table 3: reports all specific values of the energy:

	Epv fixe	Epv sun tracking
January(low alues)	4.42kWh/m²	7.954kWh/m²
June(high values)	6.635kWh/m²	10.265kWh/m²

The sun-tracking configuration is capable to provide significant increase in the energy production over horizontal fixed system of equivalent characteristics.

The annual daily average horizontal fixed slope irradiation is (5.6215kWh/m²), and the annual daily average sun tracking is (9.227kWh/m²). The energy produced by system fixed on sun tracking structure is higher than one fixed on horizontal fixed slope structure, by 64%.

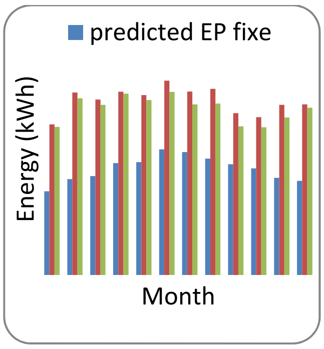

Figure: 11 Daily month average of real DC energy and predicted DC energy of PVSGC, and predicted Ep fixe.

In figure 12, the monthly energy produced by the real PV system with the intelligent control of DEGERtraker, and the monthly energy injected to the network. The report between the Epv and the Eac is equal to (93%), so this is the inverter efficiency.

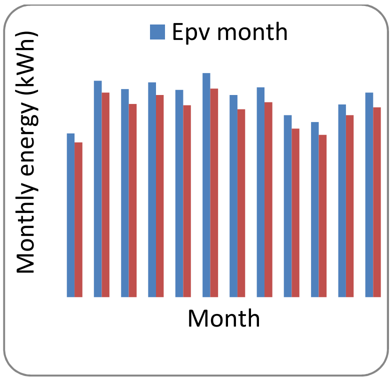

Figure12 Monthly energy produced by PV field Epv; monthly energy injected into the power grid Eac.

3.2 Performance of the System

For normal operation, the change in the production of electric energy from a PV system follows the change in the sunshine. A detailed study of parameters that describe clearly and precisely how the various components of the system for the duration of the study is necessary. For this, the normalized performance parameters (standard IEC 61724) (IEC, 1998) are used to define the overall performance of the system in terms of energy production, solar resource and the overall effect of the system losses. The normalized performance parameters were established to provide the necessary information on the design of the PV system, the evaluation of their performance. They are normalized to compare the performance of PV systems, according to the geographical location, technology and design. These parameters (Haeberlin and Beutler, 1995); (Marrion et al, 2005), are (Schmid et Shmidt, 1991), (Hadj Arab et al, 2005), (Haeberlin. et Beutler, 1995), (Marion et Hayden , 2005):

- Array yield Y_A, Fig: 13, it is a system productivity in a period of time (day, week, month, year…). This parameter is defined as a ratio of the energy produced by PVSGC plants in a period of time t to the installed PV power.

$$Ya = \frac{EGPV,t}{Pom,G} \qquad (14)$$

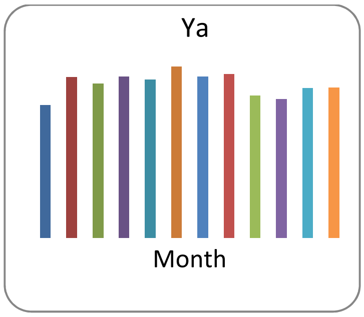

Figure : 13 Array yield Ya.

- Field Yield YF, Fig:14, defined as the ratio of the useful energy generated by the system in a period of time with a rated power installed.

$$Y_f = \frac{EGPV,t}{P_{nom,G}} \qquad (15)$$

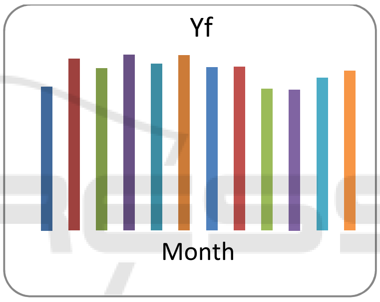

Figure: 14 Normalized final productivity of PV generator

- Reference Yield Y_R, Fig:15, is the ratio of solar irradiance received by the PV array to the solar irradiance at the standard conditions.

$$Y_R = \frac{Ginc,t}{Gstc} \qquad (16)$$

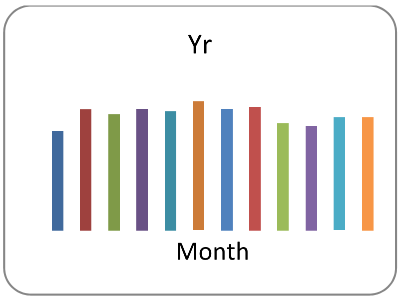

Figure : 15 Normalized reference productivity

- Performance ratio PR, Fig:16, defined as the global efficiency of the system. It is determined by the ratio of the final yield to the reference yield. This parameter is independent of the PV plant size and its emplacement. Also, it is used to compare the behavior.

$$Pr = \frac{Y_f}{Y_R} \qquad (17)$$

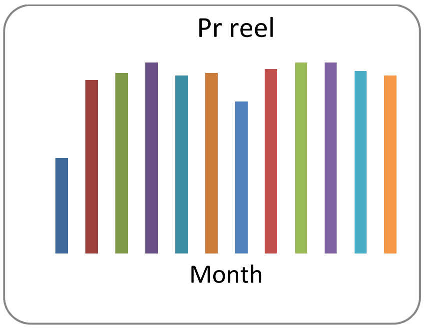

Figure:16: Pr performance index

PR is therefore an estimate of all the losses that distinguishes the real system without theoretical loss system. We find that this PVSGC system gives very satisfactory results. Based on the Fig. 16, the average yearly value of Pr is 80%, for the installed system.

In the table 4, is recorded the PV module efficiency, the inverter efficiency and the performance index Pr, for installed PV systems all around the world. The parameters of our PV system are as well as other systems.

Table 4: Comparison with other installed systems in the world.

Country	η_{pv} **(%)**	$\eta_{inverter}$ **(%)**	**Pr**	**Reference**
Spain	13.7	89.5	0.69	(Miguel et al, 2002)
Italy	3.7	90-91	0.66	(Dunlop et al, 1997)
Brazil	3.7	91	0.5-0.81	(Ruther et Dacoregio, 2000)
Ireland	7.5-10	87	0.6-0.62	[27] (Mondol et al, 2006)
Malaysia	10.11	95.15	0.77	(Farhoodnes et al, 2015)
North Algeria	7-10	87-96	0.62-0.82	(Cherfa et al, 2015)
South Algeria	11-15	92-94	0.44-0.88	Present system

4 CONCLUSION

The first PV plant connected to the grid based on polycrystalline modules, installed in the Algerian Sahara, has been investigated during the period of May 2016 to May 2017, all energy generated was fed into the low voltage net work supply to the URAER building. During this period are measured and analyzed daily and monthly parameters of system, thanks to real time climatic and performance measurements for all 5 minutes. The average annual Daily energy of 9.89kWh is injected on the grid.

The annual daily average horizontal fixed slope irradiation is (5.6215kWh/m²), and the annual daily average sun tracking is (9.227kWh/m²). The energy produced by system fixed on sun tracking structure is higher than one fixed on horizontal fixed slope structure by 64%.

PR is therefore an estimate of all the losses that distinguishes the real system without theoretical loss system. We find that this PVSGC system gives very satisfactory results compared to PV systems installed all around the world. The average yearly value of Pr is 80%, for the installed system.

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ANNEXES :

Table 1 Module Performance under standard test conditions (STC): SW150

Maximum power	Pmax	150W
Open circuit voltage	Uoc	22.5V
Maximum power point voltage	Umpp	18.3V
Short circuit current	Isc	8.81A
Maximum power point current	Impp	8.27A

Table 2 Inverter Fronius IG15 :

Specifications Input:	**IG15 :**
Recommended connection power	1300 – 2000 Wp
MPP voltage range	150 – 400 V
Max input voltage at (STC)	500V
Max input current	10.75 A
Output characteristics:	**IG15 :**
Rated output power	1.3kW
Max output power	1.5kW
Rated network voltage	230V +10 / -15%
Nominal output current	5.7A
Rated frequency	50 +/- 0.2 Hz
Distortion	< 3%
Power factor	1
maximum efficiency	94.2 %
Euro yield	91.4 %