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Measurement and Simulation of 2.25 kWp grid-connected amorphous photovoltaic station in a hot desert environment

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Abstract

This work investigates measurements and simulations of a 2.25 kWp grid-connected amorphous photovoltaic power plant mounted on a parked car in a hot desert environment. This power station is located at applied research unit field (URAER), in the Ghardaia region, southern region. The simulation is carried out using PVSYS software. This includes evaluation of meteorological and electrical parameters performance of studied PV system such as reference PV system, PV array yield (YA), Final yield (YF), PV array and system losses, array and system efficiency, performance ratio (PR). The array nominal energy estimated at STC is 5695 kWh/year. The energy estimated injected into the grid is 4648 kWh/year.

Keywords: Performance, grid connected, Measurement and Simulation, PVSYS software, hot desert environment.

1. Introduction

The use of grid-connected photovoltaic systems has been adopted more and more in the world during the last decade in order to meet the growing demand for electrical energy given several factors such as the reduced cost of solar panels as well as the maturity of this technology in global markets.

The main factors influencing the efficiency of these plants are the intensity of solar radiation, shading, aging, degradation temperature, and storage techniques. In this context, the objective of our work is the study of a photovoltaic solar power plant tied to the electricity network and their behavior in the arid environment.

2. Material and method

The article should be divided, clearly defined and numbered into sections

2.1 PV station description

The power plant consists of 18 amorphous silicon modules (thin films), each with a power of 110 Wp, mounted in series in 9 branches of two modules, two inputs 150 V, 15 A and one 220 V 50 sinusoidal single-phase output in Hz. this plant, covering a total area of 23 m² and inclined at 32 ° toward the south, ensures the full injection of the electricity produced into the URAER's inner network (see Fig 1). This achievement is part of the research work of the Applied Research Unit in Renewable Energies (URAER) affiliated to the Center for the Development of Renewable Energies.

Fig 1. A PV sation installed in Applied research unit Ghardaia

In order to evaluate the overall performance of the solar power plant, it is necessary to understand the main technical specifics of the photovoltaic array and the inverter (see Table 1 and 2).

Table 1. PV module technical specifications

PV Module : Micromorphe (a-Si/µc-Si) thin film Inventux Solar technologies	
Type	X3-125
PV module power	127 Wp
PV Voltage (Vmp)	127 V
PV current (Imp)	1.01 A
Short-circuit current (Isc)	1.22 A
Open-circuit voltage (Voc)	168 V

Table 2. Sunny Boy SB 3000TL-20 inverter specifications

SB 3000TL-20 Inverter	
Max DC power	3200 W
Max DC voltage	550 V
PV voltage range, MPPT (UPV, max)	125 V – 440 V
nominal voltage	188 V – 440 V
Max input current (IPV, max)	17 A
Number of MPP trackers	1
Max number of strings	2

I-V and P-V characetrestic at different irradiation and at difirrent temeperature are depicts in Figure 2 and 3 respectively.

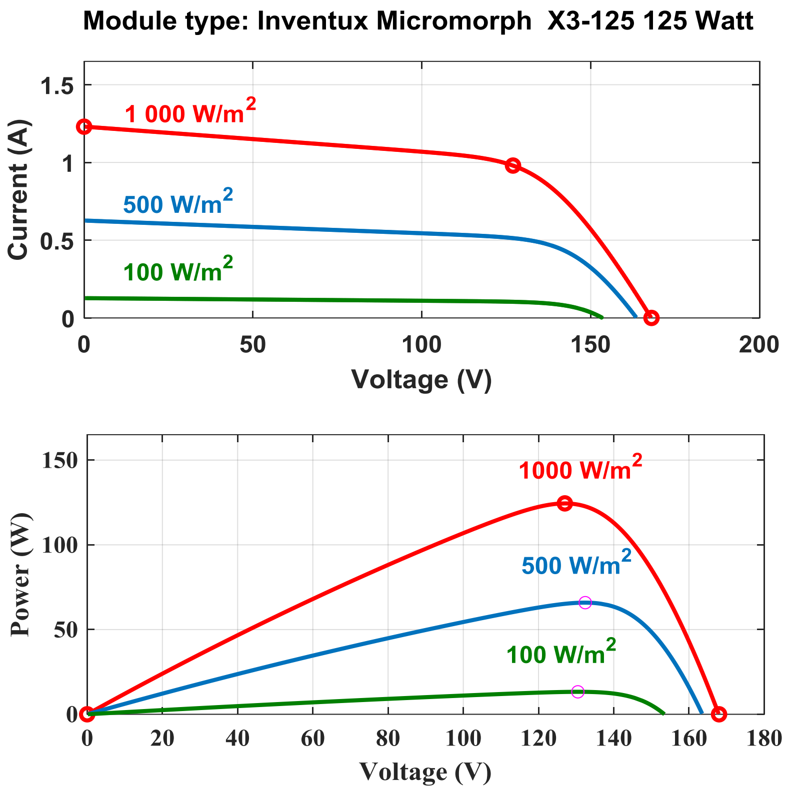

Fig 2. I-V and P-V characetrestic at different irradiation

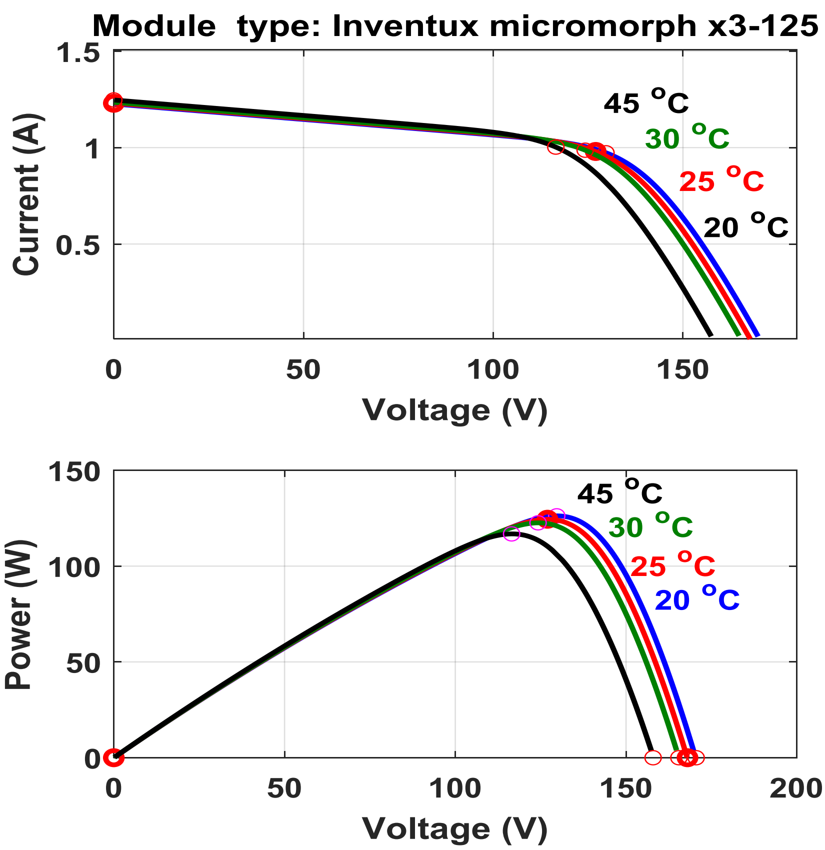

Fig 3. I-V and P-V characetrestic at different temperature

In recent literature, there are several models and methodologies that propose to assess and predict PV output power. Empirical models using experimental data on specific tests such as irradiation and temperature [10][11].

$$P = P_{stc}\eta_{stc}A[1-\delta(T_c-25)] \tag{01}$$

$$P = P_{stc}f_{PV}\frac{G}{G_{ref}}\left[1-\delta\left(T_c-T_{ref}\right)\right] \tag{02}$$

$$P_{dc} = \eta_{stc}\eta_{Inv}Af_{DC}f_{AC}f_{Age}f_{Ext}\frac{G}{G_{ref}}\left[1+\delta(T_c-T_{ref})+\gamma_{P_{mp}}ln(\frac{G}{G_{ref}})\right] \tag{03}$$

$$P_{dc} = P_{stc}\frac{G}{G_{ref}}[1+\delta(T_c-T_{ref})]\left[1+\gamma_{P_{mp}}ln(\frac{G}{G_{ref}})\right] \tag{04}$$

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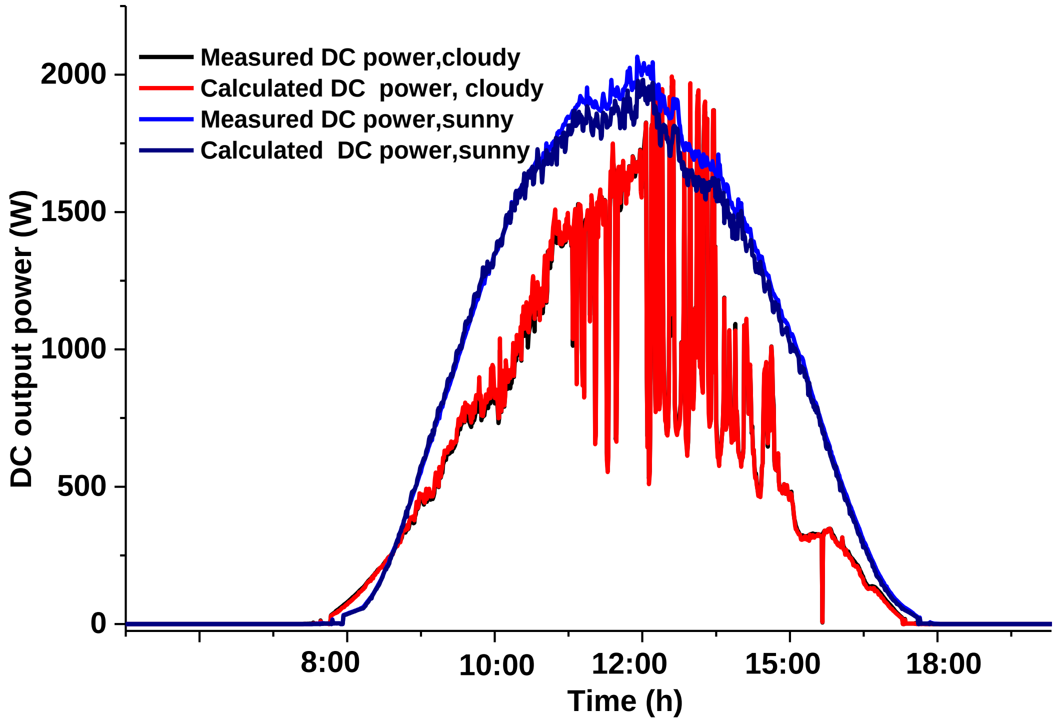

Fig 4. Calculated and measurement DC output power (PV array) on clear day and cloudy day

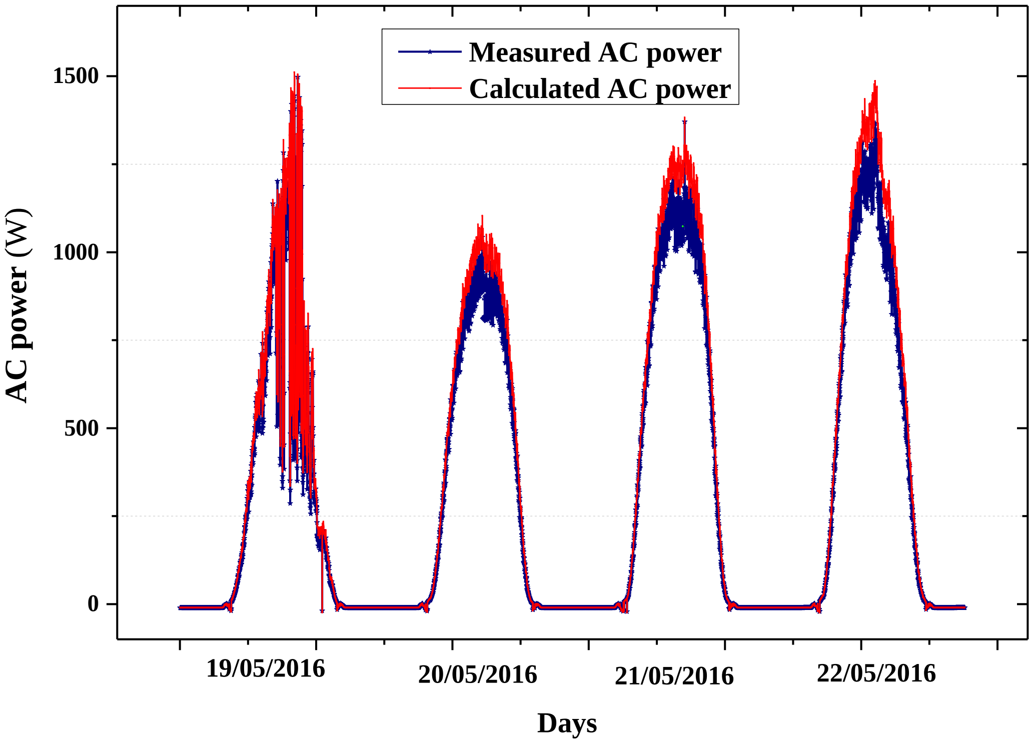

Fig 5. Calculated and measurement AC output power (inverter) on clear day and cloudy day

2.2 PV system performance analysis using PVsys software

To carry out an evaluation of the performance of the PV system tied to the study network, the international standards IEC 61724 by the International Electrotechnical Commission which defined the parameters were adopted. The most essential parameters include (see Table 3).

1- DC& AC energy	4- Efficiency - PV field efficiency - Inverter and system efficiency du
2- Yield - Reference yield (YR) - Array yiel PV (YA) - Final yield (YF)	5- Capacity factor (CF)
3- Energy loss - Array loss (LC) - System loss (LS),	6- Performance ratio (PR)

Table 3. The performance indicators of photovoltaic plants

Performance indice	Expression	Units	Equation	Reference
Energy output				
• Daily ($\boldsymbol{E_{AC,d}}$)	$E_{AC,d} = \sum_0^{24} E_{AC,t}$	kWh/kWp/day	(06)	[01]
• Monthly ($\boldsymbol{E_{AC,m}}$)	$E_{AC,m} = \sum_0^{24} E_{AC,d}$	kWh/kWp/day	(07)	[02]
Energy yield				
• Reference yield ($\boldsymbol{Y_R}$)	$Y_R = \frac{H_t(\frac{kWh}{m^2})}{G\left(\frac{kW}{m^2}\right)}$	kWh/kWp/day	(08)	[03]
• Array yield($\boldsymbol{Y_A}$)	$Y_{A,day} = \frac{E_{DC,day}}{P_{pv,rated}}$ $Y_{A,month} = \frac{1}{N}\sum_{d=1}^{N} Y_{A,day}$	kWh/kWp/day	(09)	[04]
• Final yield($\boldsymbol{Y_F}$)	$Y_R = \frac{H_t(\frac{kWh}{m^2})}{H_r\left(\frac{kW}{m^2}\right)}$	kWh/kWp/day	(10)	[05]
Efficiency				
• PV module efficiency ($\boldsymbol{\eta_{PV}}$)	$\eta_{PV} = \frac{P_{DC}}{G.A}(\%)$	(%)	(11)	[06]
• System efficiency ($\boldsymbol{\eta_{sys}}$)	$\eta_{sys} = \frac{P_{AC}}{G.A}$	(%)	(12)	[07]
Energy loss				
• Array capture loss ($\boldsymbol{L_A}$)	$L_A = Y_R - Y_A$ KWh/kWp)	kWh/kWp/day	(13)	[08]
• System loss ($\boldsymbol{L_S}$)	$L_S = Y_A - Y_F$ KWh/kWp)	kWh/kWp/day	(14)	[09]
• Temperature loss ($\boldsymbol{L_T}$)	$L_T = Y_R[(1 - \alpha(T_c - 25)]$ $T_C = T_a + \frac{(T-20)}{800} xG$	kWh/kWp/day	(15)	[10]
• Miscellaneous capture loss ($\boldsymbol{L_{CM}}$)	$L_{CM} = L_A - L_T$	kWh/kWp/day	(16)	[11]
Capacity utilization factor ($\boldsymbol{CUF}$)	$CUF = \frac{E_{AC}}{P_{PV,rated} \times 8760}$	kWh/kWp/day	(17)	
Performance ratio ($\boldsymbol{PR}$)	$PR = \frac{real\ production\ (kWh)}{theoritical\ production\ (kWh)}$ $PR = \frac{Y_F}{Y_R}$	(%)	(18)	[7][8]

These indicators are generally used for define the overall performance of the system. Also, they provide precise information on the energy production of the PV system taking into account: Solar resources, energy production and all effects of system losses (Fig 6).

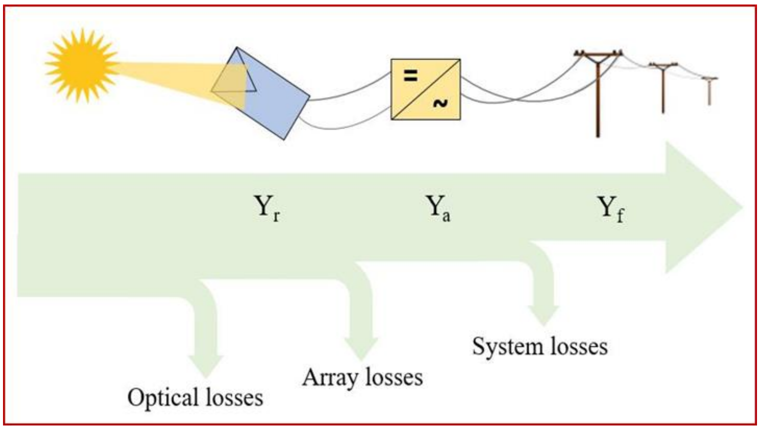

Fig 6. Energy conversion chain of grid connected PV system

3. Results and discussion

Simulation of grid connected PV system by PVSYS software is shown in Figure 7,8 and 9.

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Grid-Connected System: Simulation parameters

Project :	**Grid connected PV system Ghardaia**			
Geographical Site	**Ghardaia**		Country	**Algeria**
Situation	Latitude	32.0°N	Longitude	3.7°E
Time defined as	Legal Time	Time zone UT	Altitude	450 m
	Albedo	0.20		
Meteo data:	**Ghardaia**	MeteoNorm 7.1 - Synthétique		

Simulation variant :	**Nouvelle variante de simulation**			
	Simulation date	08/06/21 10h24		

Simulation parameters				
Collector Plane Orientation	Tilt	32°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	No Shadings			
PV Array Characteristics				
PV module uCSi-aSi:H	Model	**X 125 / 125**		
Original PVsyst database	Manufacturer	Inventux		
Number of PV modules	In series	2 modules	In parallel	9 strings
Total number of PV modules	Nb. modules	18	Unit Nom. Power	125 Wp
Array global power	Nominal (STC)	**2250 Wp**	At operating cond.	2104 Wp (50°C)
Array operating characteristics (50°C)	U mpp	234 V	I mpp	9.0 A
Total area	Module area	**25.7 m²**		
Inverter	Model	**Sunny Boy 3000 TL-21**		
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	175-500 V	Unit Nom. Power	3.00 kWac
Inverter pack	Nb. of inverters	2 * MPPT 50 %	Total Power	3.0 kWac
PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	444 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	1.5 %
Module Mismatch Losses			Loss Fraction	0.8 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
User's needs :	Unlimited load (grid)			

Fig 7. Grid connected System:Simulation parameters

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Grid-Connected System: Main results

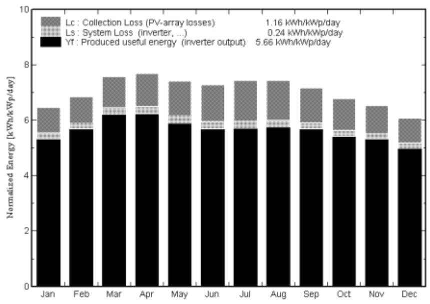
Project : **Grid connected PV system Ghardaia**

Simulation variant : **Nouvelle variante de simulation**

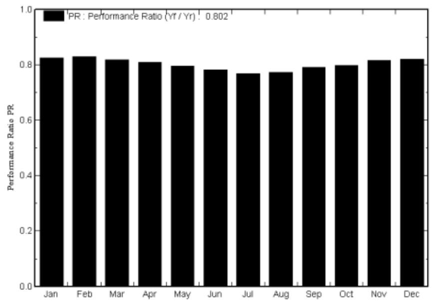
Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	32°	azimuth	0°
PV modules	Model	X 125 / 125	Pnom	125 Wp
PV Array	Nb. of modules	18	Pnom total	**2250 Wp**
Inverter	Model	Sunny Boy 3000 TL-21	Pnom	3000 W ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**4648 kWh/year**	Specific prod.	2066 kWh/kWp/year
	Performance Ratio PR	80.2 %		
Investment	Global incl. taxes	6222 €	Specific	2.77 €/Wp
Yearly cost	Annuities (Loan 5.0%, 20 years)	499 €/yr	Running Costs	0 €/yr
Energy cost		**0.11 €/kWh**		

Normalized productions (per installed kWp): Nominal power 2250 Wp



Performance Ratio PR



Nouvelle variante de simulation

Balances and main results

	GlobHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	EffArrR	EffSysR
	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	%	%
January	122.8	10.70	200.3	196.4	387.1	372.0	7.51	7.22
February	135.1	13.20	191.6	187.8	372.0	357.8	7.54	7.25
March	193.6	18.00	235.0	230.3	450.7	432.6	7.45	7.15
April	220.5	21.30	230.9	224.8	438.8	420.7	7.38	7.08
May	245.7	26.50	229.6	222.8	429.9	411.3	7.27	6.96
June	246.9	31.10	218.5	211.6	402.2	384.3	7.15	6.83
July	254.6	35.50	230.9	224.1	417.7	399.0	7.03	6.71
August	230.1	34.00	230.4	224.2	419.4	401.4	7.07	6.77
September	188.1	28.30	215.2	210.0	399.9	383.4	7.22	6.92
October	157.5	23.70	210.1	205.5	393.9	377.8	7.28	6.98
November	126.7	15.90	195.6	192.0	374.1	359.3	7.43	7.14
December	111.5	12.09	188.3	184.4	362.2	348.3	7.47	7.19
Year	2233.1	22.58	2576.5	2514.0	4847.9	4647.9	7.31	7.01

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

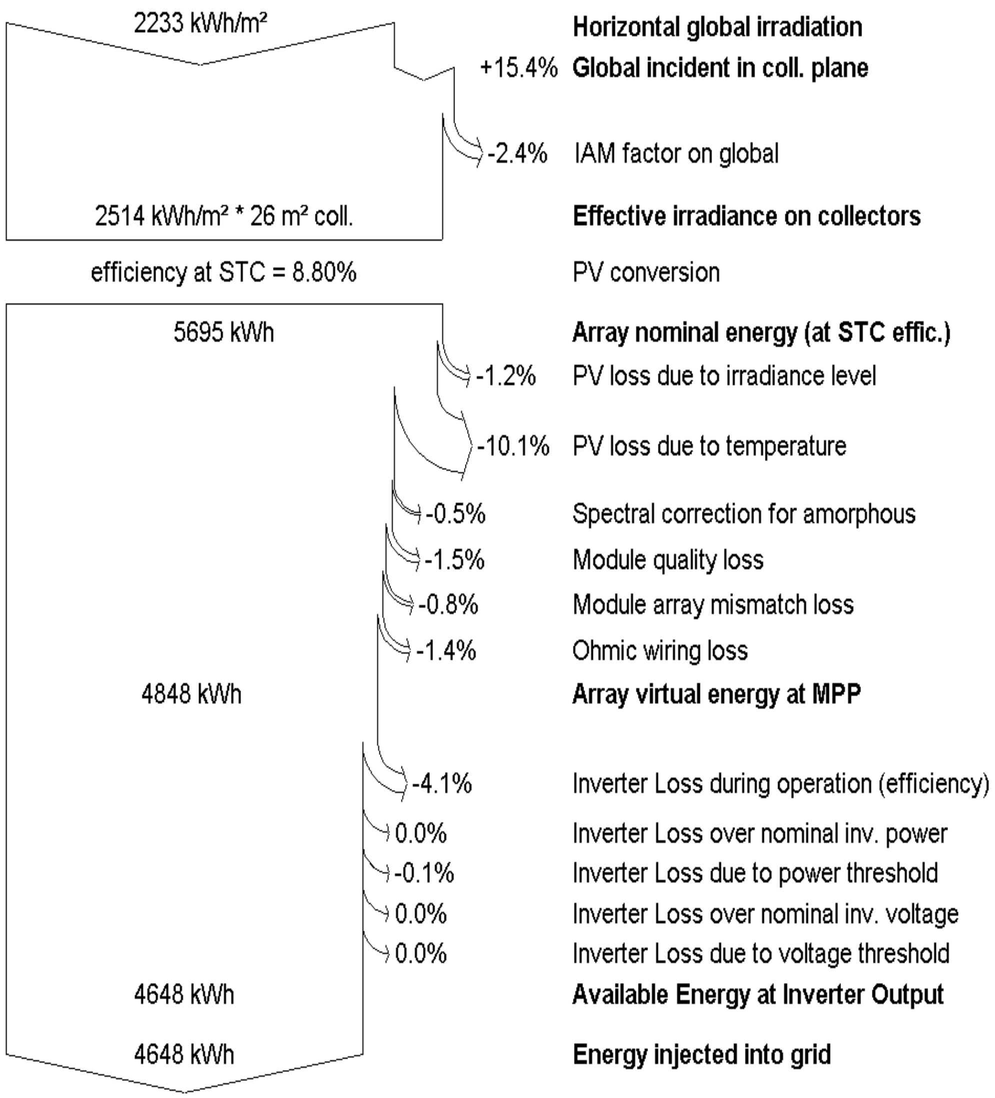


Fig 8. Grid connected System: Main results and losses

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Grid-Connected System: Economic evaluation

Project : **Grid connected PV system Ghardaia**

Simulation variant : **Nouvelle variante de simulation**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	32°	azimuth	0°
PV modules	Model	X 125 / 125	Pnom	125 Wp
PV Array	Nb. of modules	18	Pnom total	**2250 Wp**
Inverter	Model	Sunny Boy 3000 TL-21	Pnom	3000 W ac
User's needs	Unlimited load (grid)			

Investment

PV modules (Pnom = 125 Wp)	18 units	164 € / unit	2952 €
Supports / Integration		10 € / module	180 €
Inverter (Pnom = 3.0 kW ac)	1 units	2278 € / unit	2278 €
Settings, wiring, ...			0 €
Substitution underworth			0 €
Gross investment (without taxes)			**5410 €**

Financing

Gross investment (without taxes)		5410 €
Taxes on investment (VAT)	Rate 15.0 %	812 €
Gross investment (including VAT)		6222 €
Subsidies		0 €
Net investment (all taxes included)		**6222 €**
Annuities	(Loan 5.0 % over 20 years)	499 €/year
Annual running costs: maintenance, insurances ...		0 €/year
Total yearly cost		**499 €/year**

Energy cost

Produced Energy	4648 kWh / year
Cost of produced energy	0.11 € / kWh

Fig 9. Grid connected system: Economic evaluation

4. Conclusion

In this work, the measurements and simulation outcomes of 2.25 kWp grid-tied PV station, carried under real outdoor desert environmental conditions, are discussed. The energy is injected into internal grid. The PV station is mounted on the roof of a parking at the URAER, Ghardaia applied unit, located in Algeria. The array nominal energy estimated at SRC is 5695 kWh/year. The energy estimated injected into grid is 4648 kWh/year. The performance ratio is 80.2 % and the energy cost is 0.11 euro/kwh. The simulation results confirmed the feasibility of installing this type of system in the Algerian Sahara. This work can be used as a guide to wish to install PV station, particularly in arid and semi-arid regions.

5. Acknowledgements

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