Data Monitoring and Performance Analysis of a 1.6kWp Grid Connected PV System in Algeria

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Abstract- The present study deals with the performance of a 1.6kWp grid connected PV system installed at Batna University, in Algeria. The average solar energy received was 5.21 kWh/m².d, the grid connected PV system seems to be a good candidate for generating electricity in this region. The system was monitored during one year of continuous operation and data analysis to evaluate the performance of the grid connected PV system. The performance ratio of the system ranged between 51 and 61%. Furthermore, the total produced energy by the PV array was 1931.7kWh and the supplied energy to the grid was 1705kWh. The annual final yield was 1065.6kWh/kWp. Moreover, an analysis of the energy losses in the system was performed, this makes it possible to determine the effect of the capture and system losses on the total energy balance of the system. All the electricity generated by the system was fed into the internal electrical grid of the university.

Keywords Grid connected PV system; Photovoltaic performance; PV yields and losses analysis; PV system comparative results.

1. Introduction

Nowadays, it is well established that solar energy is the best option to meet the electricity demand in the near future. Algeria is facing a real dilemma. A recent survey has shown that the internal energy demand is increasing steadily, whereas, energy production is decreasing at a very critical rate. Thus, in 2008 the energy production was 175.13Mtoe, which decreased to 148.7Mtoe in 2013 [1,2]. It is well known that the main source used to generate the electricity is natural gas and according to the regulation commission for electricity and gas (CREG), the amount of the natural gas consumed by the electricity generation systems was 13.895Gm3 in 2013 [3].

In addition, the same survey showed that from 2008 to 2013 the electricity consumption increased from 40.18 to 50.8 TWh [1,2] because of the demographic expansion and economic growth. It is interesting to notice that the number of low voltage customer increased from 5.57 to 7.7million between 2008 and 2013 [3,4].

The highest value of the power demand was reached in 2013 (10463MW against 6995MW in 2008 [3,4]) when the weather conditions of a particular hot summer (temperature exceeded 48°C) which required the use of air conditioners at a large scale [5].

Photovoltaic systems seem to be a good alternative for generating electricity in Algeria. The estimated potential of solar radiation is about 2000 kWh/m²/y [6], however, the grid connected systems are not widely used. The most important site is located in southern region in Ghardaia, with a nominal power capacity of 1MW. In this plant, four technologies are involved (monocrystalline, poly-crystalline, amorphous and thin film) . The plant became operational in 2014, but no data about its performances is available. Also, other PV systems of 400 MW capacity are planned in the near future [7].

The main goal of the present study is to determine the performances of a grid connected PV system in the Batna region during one year of continuous operation. In the .this study, we consider a PV system that incorporates modules which have been operating for the last ten years which makes this study even more interesting since degradation effect due to aging is taken into account.

2. System description

"Figure 1" shows the PV generator installed on the roof top (20m) of the laboratory building at Batna University. The nominal power installed capacity of the PV array (PG0) at the standard test conditions (1kW/m², 25°C and AM1.5) is 1.6kWp. The PV array consists of 40 mono crystalline modules (PHOTOWATT PW400 type) of 40Wp "Table 1" [8] which form 8 strings of five modules each one. The modules are connected in serial and the 8 strings are connected in parallel. Also, the PV generator is connected to the monitoring system via four cables (H07RN-F CENELEC HD22 4G6 type) with up to 30m of length. The inverter used in this system is the NEG1600 which is characterized by an input DC power of 1.6kW and an operational voltage ranging between 54 to 95V and a maximum input DC voltage of 110V [9].

Also, a power meter analyzer LMG 310 was used in order to analyze both the DC and AC electrical parameters of the PV array (e.g. energy, power, current, voltage, frequency, etc.). The electrical parameters of loads are measured using a power meter LMG450. All the measured parameters are sent to the PC via the GPIB ports as shown in "Figure 2" [10,11]. Also, the ambient temperature (Ta) and global radiations (Gi) were measured using a thermocouple (KTY type) and a pyranometer (KIPP&ZONEN CM11 type) respectively. The daily solar energy received was recorded using a solar integrator. The PV module temperature (Tm) was measured with KTY thermocouple. These sensors were connected to a data acquisition unit (Data Taker DT50) which was linked to the PC via a serial port [12]. Information about climatic parameters (Humidity, global radiation on horizontal and ambient temperature) were obtained from the weather forecast station.

Fig. 1. The view of the PV generator.

Table 1. Technical data of the PV modules at 1 kW/m² and AM 1.5

Junction temperature	°C	25	45	60
Nominal voltage	V	12	12	12
Maximum power	W	40	36.8	34.5
Voltage at P_{max}	V	16	14.6	13.6
Current at P_{max}	A	2.5	2.52	2.53
Short circuit current	A	2.73	2.76	2.78
Open circuit voltage	V	20	18.5	17.4
NOTC (0.8kW/m², 20°C, 1m/s)	°C	45	45	45

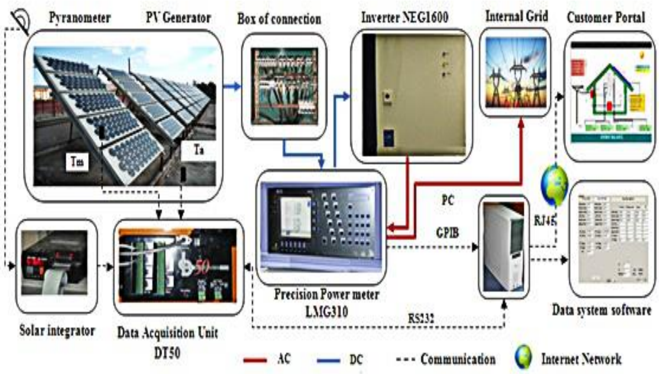

Fig. 2. Architecture of the smart home system installed at Batna University

3. Methodology

3.1. Monitoring and Data acquisition

In order to collect and save the electrical and the weather parameters, a program was developed for this purpose under the integrated development environment Visual Basic program 5. All the system parameters were stored in the Access database by the software.

The system parameters were processed and were shared online via a software interface and data acquisition was done every 30 seconds. Also, a website was developed under php programming language in order to show online all the system parameters, the website was accessible via this address http:/smart.univ-batna.dz/joomla/.

3.2. Data analysis

According to the IEC 61724 standard, IEA PVPS task 2 and the several research works on grid connected PV systems [13—17], the indicators used to evaluate the grid connected PV systems performances are the performance ratio, final yield, reference yield, array yield, capture losses and system losses. Moreover the analysis of the system, PV generator and the inverter efficiency are essential to evaluate the behavior of each system component. These indicators were calculated using the following relations:

$$Y_r = \frac{H_G}{Gi,_{STC}} \quad (1)$$

Where:

The reference yield Y_r is the ratio between the total in-plane solar radiation H_G and the reference irradiance 1kW/m², it indicates the number of peak sun-hours during period τ (d: day, m: month or y: year), the measuring unit is kWh/kWp/τ or h/τ.

$$Y_a = \frac{E_{DC}}{P_{G0}} \quad (2)$$

where:

The array yield Y_a is the net energy produced by the PV generator E_{DC} during period τ divided by its rated power P_{G0}, the measuring unit is kWh/kWp/τ or h/τ.

$$Y_f = \frac{E_{AC}}{P_{G0}} \quad (3)$$

where:

The final yield Y_f is the net energy supplied to the electrical grid E_{AC} during period τ divided by the PV generator rated power P_{G0}, the measuring unit is kWh/kWp/τ or h/τ.

$$L_C = Y_T - Y_a = L_{CT} + L_{CM} \quad (4)$$

where:

The array capture losses L_C is the energy losses due to the PV array operation, in other hand it is the sum of the miscellaneous capture losses L_{CM} and thermal capture losses L_{CT}, during the reference period τ, the measuring unit is kWh/kWp/τ or h/τ.

$$L_{CT} = Y_r - Y_T \quad (5)$$

where:

L_{CT} is the thermal capture losses caused by the cell temperature higher than 25°C.

The Y_T is the temperature corrected reference yield during the reference period τ, the measuring unit is kWh/kWp/τ or h/τ which is given by the following relation:

$$Y_T = Y_r \times \left[1 - CT \times \left(T_C - T_0\right)\right] \quad (6)$$

where:

CT: is the temperature coefficient and CT = 0.44%/°C for crystalline cells.

T_0: is the cell temperature under standard test conditions (25°C).

T_C: is the cell temperature and it is given as follow:

$$T_C = T_a + \left[Gi \times \frac{(\mathrm{NOCT-20})}{800}\right] \quad (7)$$

where:

NOCT: is the Nominal Operating Cell Temperature (45°C)

The miscellaneous capture losses L_{CM} summarized the different types of losses caused by the PV array operation, during the reference period τ, it contains the losses of wiring, string diodes, low irradiance, partial shadowing and mismatch other factors. The measuring unit is kWh/kWp/τ or h/τ. It is given as follows:

$$L_{CM} = Y_T - Y_a \quad (8)$$

The L_S is the energy losses due the inverter conversion task DC to AC during the reference period τ, the measuring unit is kWh/kWp/τ or h/τ, and it is given as below:

$$L_s = Y_a - Y_f \quad (9)$$

The performance ratio PR is the ratio between the final yield Y_f and the reference yield during the reference period τ, it strongly depends on the energy losses in the system, especially the losses due to PV array temperature higher than 25°C and the inefficiencies or failures of the system component [18], this factor represents the ratio between the useful energy and the energy which would be produced without losses, the performance ratio is obtained using the relation below:

$$PR = \frac{Y_f}{Y_r} \quad (10)$$

The system, PV generator and inverter efficiencies are calculated using the following equations:

$$\eta_{inv} = \frac{E_{AC}}{E_{DC}} \quad (11)$$

$$\eta_G = \frac{E_{DC}}{H_G \times A_G} \quad (12)$$

where:

A_G: is the PV generator area (m²)

$$\eta_s = \eta_{inv} \times \eta_G \quad (13)$$

4. Performance analysis

4.1. Solar radiation potential

It is well known that the PV system performance is strongly dependent on the weather conditions [19—21]. “Figure 3” shows the monthly average solar radiation (HG). As it is seen the daily average value was 5.21kWh/m²/d. The total annual solar radiation on the surface plane of the modules was 1831.4kWh/m², which was found very close to other regions like Greece, Egypt and Morocco[22—24] and higher than some other Mediterranean locations like Spain [25].

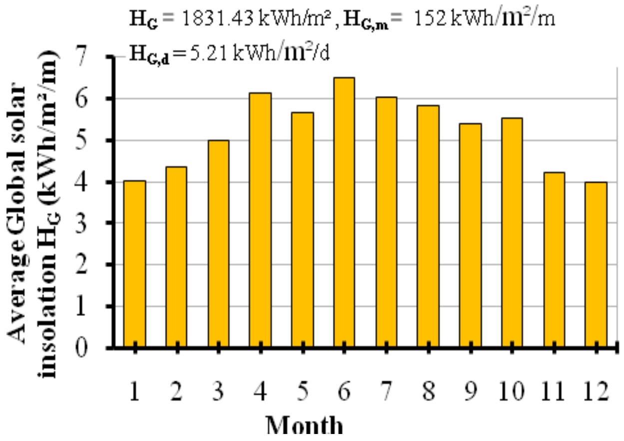

Fig. 3. Monthly average daily solar radiation on the PV modules plane (HG), ambient air temperature (Ta) for the year of 2013 at Batna University.

4.2. The I-V and P-V curves Analysis

“Figure 4” shows The I-V and P-V curves during the day of 20th, November, 2014. The solar irradiance (G_i) was about 900W/m² and the ambient temperature (T_a) reached 25.4°C. The modules and cell temperatures, (T_m) and (T_C), were 43.22°C and 53°C respectively. The maximum power (P_{MAX}) generated by the PV generator was 857.3W. This test indicated that the PV generator performance decreased by about 26% in comparison with that found in 12th of, November 2011 [5]. This decrease is caused by the delamination, superheated contact on several PV modules “Figure 5–6”.

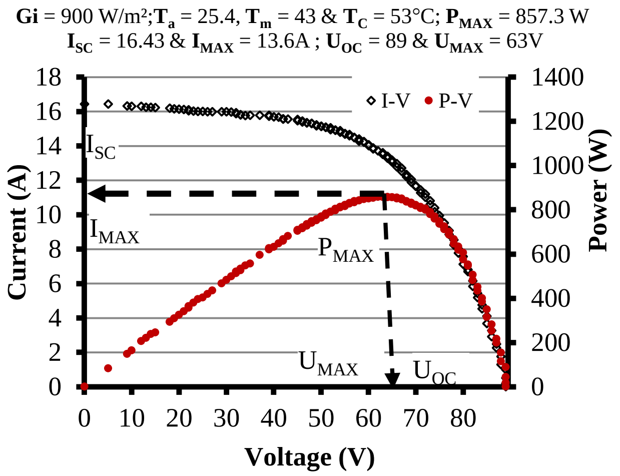

Fig. 4. The I-V and PV curves of the PV array (P_{G0}=1.6KWp) at 900 W/m² of solar irradiance and the cell temperature is 53°C, 11/20/2014.

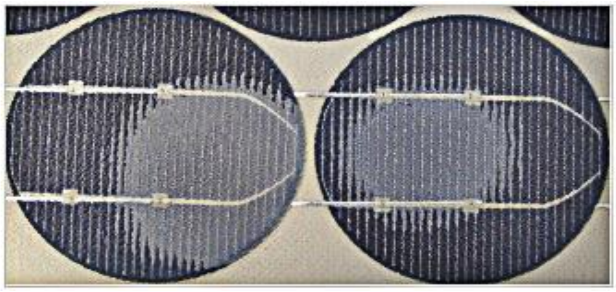

Fig. 5. The view of the delamination.

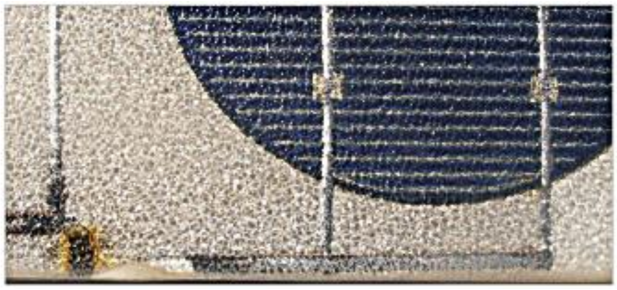

Fig. 6. The view of the superheated contact.

Consequently, a test was carried out to investigate the degradation effect of the PV modules by comparing the I-V curves of the old modules with that of the new ones. In this connection, five old modules (G1) of the investigated generator were considered and they were connected in series and five identical new ones (G2) which have never been used before, having the same configuration, were investigated. The nominal power of each string is 200Wp. The results showed that the powers generated by G1 and G2 were 113.6 and 123.9W respectively “Figure 7”, leading to a deviation of about 8.31% “Table 2” [26,27].

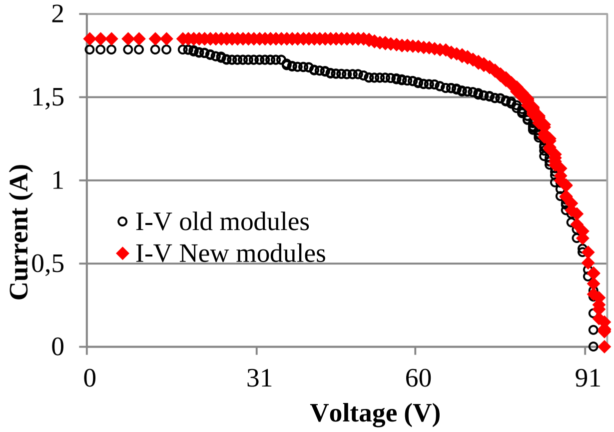

Fig. 7. The I-V curves of new and old PV modules at 800W/m² and cell temperature 27°C, 12/01/2014.

Table 2. Comparison between old PV modules (G1) used in the present study and new PV modules (G2) of PHOTOWATT PW400 type.

	P_{MAX}	I_{MAX}	U_{MAX}	I_{SC}	U_{OC}	**Degradation ratio**

G 1	113 W	1.4 A	77.3 V	1.7 A	92.6 V	**8.3%**
G 2	123 W	1.6 A	74.8 V	1.8 A	94.5 V	

4.3. The Inverter, PV generator and system efficiencies

The inverter efficiency varied between 86.7% and 89.3% with an average value of 88.2%. Also, the PV array efficiency was found to be between 8.62% and 10.4% with an average value of 9.93%. The system efficiency varied between 7.69% and 9.13% "Table 3".

4.4. The grid connected PV system normalized indicators evaluation

"Figure 8" illustrates the variation of the average monthly and daily values of the reference, array and final yields. The monitoring of the system parameters indicated that the monthly average daily value of the reference yield ($Y_{r,d}$) was 5.21kWh/kWp/d, the total reference yield (Y_r) for the year 2013 was 1831.4kWh/kWp with an average of 152.6kWh/kWp each month. The monthly average daily values of the array yield ($Y_{a,d}$) ranged from 2.7233kWh/kWp (December) and 4.33kWh/kWp (June) with an average value of 3.44kWh/kWp/d. The annual array yield (Y_a) generated in this year was 1207kWh/kWp, giving a monthly value of 100.6kWh/kWp/m². The monthly average daily values of the final yield ($Y_{f,d}$) ranged from 2.433kWh/kWp (December) and 3.78kWh/kWp/d (June) "Table 3". The annual final yield (Y_f) was 1065.6kWh/kWp. Furthermore, it is worth noticing that the maximum of the produced energy by the installed PV system was in June and the minimum occurred in December, this indicates that the system is affected by the climatic conditions.

Other indicators are used in order to evaluate the performance of grid connected PV system (performance ratio, capture losses and system losses). As shown in "Figure 9" the monthly average daily value of the capture losses ($L_{C,d}$) varied between 1.233kWh/kWp/d and 2.26kWh/kWp/d. The total of capture losses (L_C) through the whole year was 610.77kWh/kWp.

The main reasons of these losses are the high levels of ambient temperatures during the summer period and the ageing factor related to the PV modules, also, the connections between strings of the PV generator and the wirings are responsible for a part of these losses. The length of each wire used to relate the PV generator to the connection box was up to 30m with a measured resistance of about 50.4 Ohms.

The monthly average daily value of the system losses ($L_{S,d}$) ranged between 0,32kWh/kWp/d and 0.54kWh/kWp/d. The annual system losses (L_S) was 141.33kWh/kWp and the monthly average value was 11.77kWh/kWp/m. These losses are due mainly to the system conversion (DC-AC).

Thus, the performance ratio (PR) of the system during this period of the test ranged between 51% and 61% as indicated in "Figure 9". It is obvious that the PV system is affected by the site climatic conditions as well as the component technology.

The month of October of the same year showed the lowest performance ratio, which makes this study interesting in a way to get information about the losses occurring during this month. These losses are related to thermal capture losses, miscellaneous capture losses and system losses.

Thus, the daily performance ratio in the month of October, ranged between 49.1% and 59%. Also, the daily average final yield ($Y_{f,d}$) was 2.83kWh/kWp/d. Moreover the daily average system losses ($L_{S,d}$) were 0.34kWh/kWp/d, the system losses indicate that the inverter was in good state of operation. The other hand, the daily average value of the capture losses ($L_{C,d}$) were found to be 2.26kWh/kWp/d.

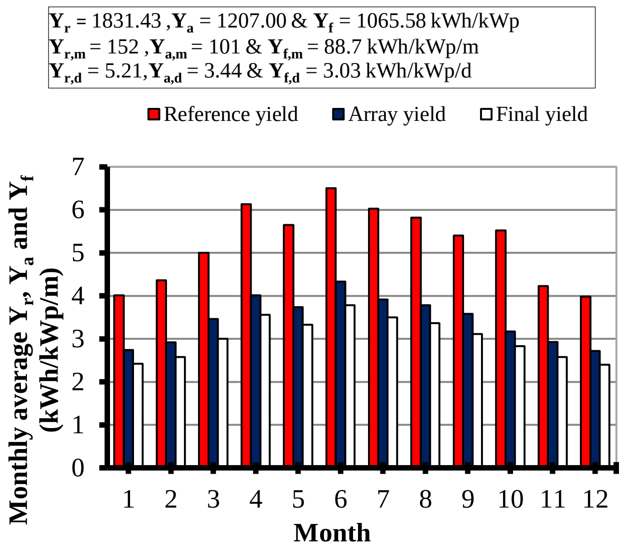

Figure. 8. The I-V curves of new and old PV modules at 800W/m² and cell temperature 27°C, 12/01/2014.

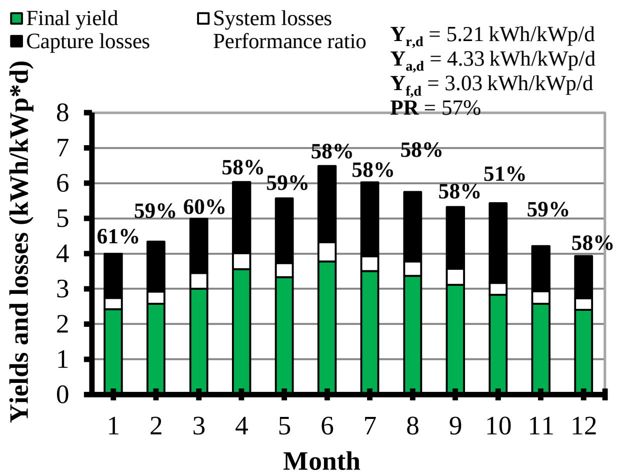

Fig. 9. Monthly daily average values of the Performance ratio, capture losses and system losses for 1.6kWp grid connected PV system at Batna region during the year 2013.

Table 3. The Annual and daily average values of the grid connected PV system parameters at BATNA region for the year 2013, global solar insolation , ambient temperature , Energies (produced, supplied to the grid), yields (reference, array and final), losses (capture and system), efficiencies (generator, inverter and system) and performance ratio.

Month	Meteorological parameters		Energies (kWh/d)		Yields and energy losses (kWh/kWp/d)					PR %	Efficiencies		
	H_i kWh/m²/d	T_a °C	$E_{DC,d}$	$E_{AC,d}$	$Y_{r,d}$	$Y_{a,d}$	$Y_{f,d}$	$L_{C,d}$	$L_{S,d}$		η_G %	η_{inv} %	η_S %
Jan	4.01	7.430	4.40	3.87	4.01	2.74	2.42	1.26	0.32	60	10.26	88.15	9.04
Feb	4.36	6.780	4.67	4.12	4.36	2.92	2.58	1.42	0.34	58	10.05	88.18	8.86
Mar	5.00	12.92	5.53	4.80	5.00	3.46	3.00	1.54	0.45	60	10.37	86.78	9.00
Apr	6.13	14.60	6.42	5.70	6.13	4.01	3.56	2.02	0.45	58	9.820	88.81	8.72
May	5.65	16.82	5.98	5.33	5.65	3.74	3.33	1.84	0.40	59	9.920	89.12	8.84
Jun	6.50	22.72	6.93	6.05	6.50	4.33	3.78	2.17	0.54	58	9.980	87.44	8.72
Jul	6.03	26.95	6.28	5.61	6.03	3.92	3.50	2.10	0.42	58	9.760	89.29	8.72
Aug	5.82	25.42	6.05	5.39	5.82	3.78	3.37	1.97	0.41	57	9.750	89.07	8.68
Sep	5.40	21.87	5.73	4.98	5.40	3.58	3.11	1.75	0.46	57	9.990	86.69	8.66
Oct	5.52	19.72	5.08	4.53	5.52	3.17	2.83	2.26	0.34	51	8.620	89.22	7.69
Nov	4.23	9.480	4.70	4.12	4.23	2.93	2.58	1.28	0.35	59	10.40	87.80	9.13
Dec	3.98	5.520	4.35	3.82	3.98	2.72	2.40	1.20	0.33	58	10.24	87.90	9.00
Annual daily average value	**5.21**	**15.85**	**5.51**	**4.86**	**5.21**	**3.44**	**3.03**	**1.73**	**0.4**	**57**	**9.93**	**88.20**	**8.75**

As it is shown in "Figure 10", the daily average value of the miscellaneous capture losses ($L_{CM,d}$) ranged between 0.63kWh/kWp/d (30th, October) and 2.8kWh/kWp/d (14th, October), and the daily average thermal losses varied between -0.004kWh/kWp/d (30th, October) and 0.883kWh/kWp/d (4th, October).

The L_{CT} losses are proportional to the PV module temperature (T_m) which ranged between 23.48°C (7th, October) and 55.86°C (4th, October), during these two days, the L_{CT} were 0.015kWh/kWp/d to 2.045kWh/kWp/d respectively. The miscellaneous capture losses, thermal capture losses and system losses are estimated to be about 34%, 8% and 6% respectively. Thus, during this month the final yield accounted for 52% of the total energy balance.

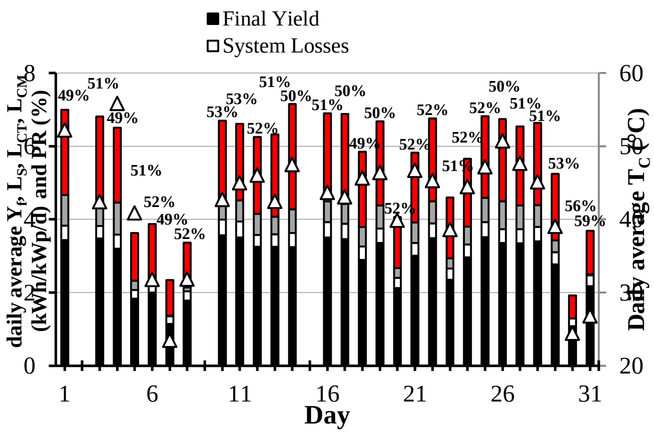

Fig. 10. The normalized daily final yield, system losses, thermal capture losses, miscellaneous capture losses and performance ratio, thus the daily average cell temperature variations during October 2013 in Batna region.

5. Results analysis and discussion

In this section, a regional comparison of the grid connected photovoltaic systems performances is carried out. The comparison is done on the basis of various parameters. The final yield (Y_f) and the performance ratio PR and system efficiency are the most normalized factors that are needed to evaluate and compare PV systems17.

The annual daily average final yield of the system under study was 3.03kWh/kWp/d and the performance ratio was found to be about 57% "Table 4". Thus, the final yield of the system installed in Batna region was found to be higher than that of the PV grid systems installed in Germany and Netherlands (1.8kWh/kWp/d), Italy (2.0kWh/kWp/d) and Japan (2.7kWh/kWp/d). Israel has a significantly higher final yield (3.5kWp/kWh/d) this may be attributed to the higher received solar radiation (6.6kWh/m²/d) [28].

In terms of performance ratio, the investigated system was found to be in a good agreement with the results obtained and reported in other countries. In fact, in the case of Germany, the PR of 106 systems varied between 42% and 85%, with an average value of 67%. In the same way, Austria reported an average performance ratio related to 22 systems to be in the order of 63% and 69% for 62 investigated systems in Switzerland.

Furthermore, the overall efficiency of the system investigated was found to be very close to the results of PV systems reported in literature, especially with those using similar technology (MC-Si).

Table 4. The comparison of the performance of various grid connected PV systems thought the world and the results obtained from the present work in Algeria (PS).

Location	PV type	Yields and losses kWh/kWp/d					PR	Efficiency %			Ref
		$Y_{f,d}$	$Y_{r,d}$	$Y_{a,d}$	$L_{C,d}$	$L_{S,d}$	%	η_G	η_{inv}	η_s	
Dublin, Ireland	MC-Si	2.4	2.8	2.6	0.2	0.2	81.5	14.9	89	12.6	18
	MC-si	1.6-1.7	2.6-2.9	1.8-2	0.3-1.3	0.08-0.4	60-62	7.5-10	87	6–9	29
Jaén, Spain	MC-Si	2.74	4.27	3.10	1.16	0.37	65	9.21	87	8.08	25
	MC-Si	2.32	4.01	2.42	1.59	0.10	58	7.5	95	7.20	
	MC-Si	2.74	4.20	3.35	0.85	0.61	65	9.96	80	8.04	
	PC-Si	1.60	3.26	1.83	1.43	0.24	49	5.71	87	4.96	
Phitsanulok, Thailand	-	3.84	5.21	4.32	0.90	0.47	73	-	-	-	30
Poland	A-Si	-	-	-	-	-	60-80	4-5	91-99	-	31
Bangi, Malaysia	A-Si	-	-	-	-	-	93-101	-	-	-	32
Selangor, Malaysia	PC-Si	3.8-4.3	4.2-5.5	-	-	-	67-89	-	11.8	8-11	33
	A-Si	1.9-3		-	-	-	88-102	-	9.8	6.1-6.9	
	MC-Si	1-3.8		-	-	-	72-85	-	6.5	9.9-11.7	
Daejeon, Korea	MC-Si	-	-	-	-	-	75.1	10.1	89	9.0	34
	PC-Si	-	-	-	-	-	63.3	9.2	86	7.9	
	MC-Si	-	-	-	-	-	67.3	9.5	83	7.9	
	PC-Si	-	-	-	-	-	71.8	9.5	87	8.3	
Austria	-	-	-	-	-	-	42-79	-	-	-	35
Germany	-		-	-	-	-	42-85	-	-	-	
Italy	-	-	-	-	-	-	44-82	-	-	-	
Netherlands	-			-	-	-	58-79	-	-	-	
Switzerland	-	-	-	-	-	-	49-85	-	-	-	
Cairo, Egypt	-	4.35	5.6	-	-	-	-	4.22	94.5	4.02	23
France	-	-	-	-	-	-	52-75	-	-	-	17
Belgium	-	-	-	-	-	-	52-93	-	-	-	
Taiwan	-	-	-	-	-	-	30-90	-	-	-	
Crete, Greece	PC-Si	1.9-5.0	5.43	2-6.6	0.5-1.3	0.2-1.5	58-73	-	-	-	22
Jayapura, Indonesia	MC-Si						78				36
	MC-Si						79				
	A-Si						91				
	MC-Si						54				
Jodhpur, India							16-98				38
Batna, Algeria	**MC-Si**	**3.03**	**5.21**	**3.44**	**1.73**	**0.4**	**57**	**9.9**	**88.2**	**8.75**	**PS**

6. Conclusion

In this study we present the results of an investigated grid connected PV system. This system consists of PV modules which have been used for the last 10 years and which are located in remote area where regular tests for evaluation were not possible. To remedy this situation, a laboratory work was undertaken and which consisted of an experimental set up that allowed to conduct a series of regular tests. The system power capacity is 1.6kWp and was operating during the whole year of 2013. This investigation was carried out according to the standard IEC 61724. This analysis showed that the annual average PR of the system was 57%, which was relatively low because of the high capture losses (L_C). These losses accounted for 33% of the total PV system energy balance and the losses were related to the degradation factor of PV modules. Consequentely, the PV generator efficiency obtained varied between 8.62% and 10.40%, knowing that the PV generator efficiency at STC was 15%. Also, the final yield of the system (Y_f) was 1065.6kWh/kWp with an average daily value of 3.038kWh/kWp/d. It accounted for 59% of the total PV system energy balance.

The results of the survey of previous work undertaken elsewhere and reported in literature show that a good agreement is found in terms of energy yields and system components efficiency.

The future works will be focused on the energy management in smart home concept and the economic evaluation.

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