Photovoltaic installation for a roofed car park in Egypt as an example of effective use of solar energy

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Abstract. Photovoltaic installations are becoming an increasingly important player in the global renewable energy production market. The biggest disadvantage of photovoltaic installations is their high price, and relatively low efficiency. Photovoltaic cells achieve a theoretical efficiency of 30%, but in real conditions this efficiency is much lower at roughly 15%. Photovoltaic installations are particularly recommended in locations where the amount of solar radiation is high and where photovoltaic installations will be able to work at full capacity for most of the year. The paper presents an analysis of the work of a photovoltaic installation built for a roofed car park located in eastern Cairo, the capital of Egypt. The installation is built for a car park located at the Schlumberger company. The installation is built of 1344 Hanwha Q.Power L-G325 silicon polycrystalline cell modules, each module has a power of 325 Wp, and the total area of the installation is 2,611 m². Effective irradiance on collectors is 1922 kWh/m². The array's nominal produced energy was 840 MWh/year, the amount of electricity injected into the grid was 587 MWh/year, which means that the calculated performance ratio was 0.62.

1 Introduction

Renewable energy is currently a very dynamically developing field of the economy. 2016 was the year in which there was more than a 50% growth in installed solar installations in the world, year by year. In 2016, the total power of installed solar installations was over 76.6 GW. Since 2011, the number of photovoltaic installations has increased by more than 36.6 GW [1]. The largest market for solar energy was China, where in 2016 34.5 GW were connected, which means an increase of over 120% compared to 2015 (15.1 GW) [2]. The second largest market was the United States, where in 2016 14.8 GW were installed, an increase of 97% compared to 2015 (7.5 GW). The third place was Japan with 6.7 GW of connected solar installations. The European Union was only in fourth place at 6.7 GW, which means a decrease by 21% compared to 2015 (8.6 GW) [1]. Among the

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EU countries, the largest market for solar installations was Germany (over 38,000 MW), Italy (over 18,800 MW) and the United Kingdom (over 5,200 MW). According to one of the scenarios for the development of the photovoltaic (PV) installation after 2017, the total number of installed PV installations in 2021 will be about 105.7 GW [1, 3]. The rapid development of the PV installation is also associated with a significant reduction in the cost of electricity production from this type of installation. Within two years (from April 2015 to February 2017), the average price of electricity from solar installations in Germany decreased by more than 28% (from 9.2 eurocents/kWh to 6.6 eurocents/kWh) [1].

Particularly intense development of solar energy takes place in countries where climate conditions favours such investments. Such countries are the countries of North Africa and the Middle East. One of these countries is Egypt. Demand for electricity in Egypt is steadily growing and in the years 1985–2016 it has increased from 30 TWh to over 180 TWh. The growth rate of electricity consumption was high and amounted to around 3.4% in 2005–2015, and in 2016 it was already 4.7%. However, most of Egypt's electricity is produced from non-renewable fuels, especially from oil and gas. This is primarily due to the proximity of the Middle East countries, which have a huge resource of these fuels. The share of renewable energy sources in the total production of electricity is small, it mainly consists of hydroelectric power plants. The share of solar installations is very small and does not exceed 2.6 TWh [4,5]. However, the weather conditions prevailing in Egypt predestine this country for the development of these types of installations. The average number of sunny hours per year is 3,451, the shortest day of the year lasts 10h:03min, and the longest 13h:56min [6, 7]. The number of sunny hours during the day is over 78%. The average amount of solar radiation reaching the surface of the earth varies from 5.4 to 7.1 kWh/m². The estimated annual solar radiation potential is about 74 billion MWh/year and many times exceeds the demand of Egypt for electricity [3, 7]. According to Ibrahim [5], in 2004–2005, approximately 26.5 kW of PV installations were installed in Egypt every year [8]. Most of them were low power installations used in communication (32%), advertising lighting (24%), and in lighting (20%). The aim of this article was to describe the presentation of an effective photovoltaic installation and compare its parameters with other such installations.

2 Description of photovoltaic installation

This article presents the PV power plant which was installed as a roof of car park. This car park is located in the east part of Cairo, at Schlumberger company (Fig.1). One of the authors was the assistant project manager at Solar Shams in Cairo. His tasks were analysing the actual energy production from the installation and assisting in creating the operation and maintenance plan for the location. The installation began work at the end of 2017, the article presents the design assumptions of the installation. After a full year we will be able to assess how these assessments have been confirmed in real conditions.

Fig. 1. PV installation for roofed car park at Schlumberger company.

The grid connected park consists of 1,344 polycrystalline silicon solar modules, Hanwha Q.POWER L-G5 325, 325 Wp each. Technical data of PV module are given in Table 1. Overall installed capacity of 437 kWp covering a total surface area of 2,355 m². The installation is inclined at 45° toward the south and inclined at an angle 5°. The PV modules are arranged in 14 parallel strings with 96 modules in each string. Each strings are connected to a 25 kW inverter Schneider Electric model Conext CL 25000E feeding directly into the grid. Technical data of inverter are given in Table 2. The main PV installation parameters are given in Table 3.

Table 1. PV module speciation in STC and NOCT conditions [9].

PV module	Specification
Model	Q.POWER L-G5 325
Power at MPP at STC* conditions	325 W
Current at MPP at STC conditions	8.67 A
Voltage at MPP at STC conditions	37.5 V
Efficiency	16.74%
Power at MPP at NOCT** conditions	239 W
Current at MPP at NOCT conditions	6.93 A
Voltage at MPP at NOCT conditions	34.5 V

* - STC - Standard Test Condition;

** - NOCT -Normal Operating Cell Temperature

Table 2. Inverter speciation [10].

Inverter	Specification
Model	Conext CL 25000E
Unit nominal power	25 kWac
Operating voltage	430–800 V
Numbers of inverters	14 units
Total power	3,650 kWac

Table 3. Main PV system parameters [11].

Main system parameters	Specification
System type	Grid-connected
PV field orientation tilt	5°
Number of modules	1,344
Array global power at STC conditions	437 kW
Array global power at operating conditions (50°C)	393 kWp
Array operating characteristic U_{mpp}	537 V
Array operating characteristic I_{mpp}	732 A
Module area	2,611 m ²
Cell area	2,355 m ²

3 Results and discussion

The photovoltaic system used for this study is installed as a car park roof in 6th of October City near Cairo with a latitude 29.95°N and longitude 30.90°E and about 149 meters above the sea level. The horizontal global irradiation for the localization of PV installation was from 93.9 kWh/m² (in December) to 252.2 (in June). During the whole year the horizontal irradiation was 2112.5 kWh/m², horizontal diffuse irradiation was about 25-30% of horizontal irradiation –and the yearly total was roughly 500 kWh/m². Average ambient temperature in PV installation localization was 22°C (Table 4). Effective energy at the output of the array was total 632.69 MWh and it varies from 33.04 MWh in December to 68.42 MWh in July. Energy injected into the grid was roughly 8% less than effective energy at the output of the array, in total it was 587.45 MWh. Performance ratio (PR) for the whole year was 0.62, and it was varying from 0.597 in June and July to 0.727 in January and 0.726 in December (Fig.2). Lower PR in summer months was caused by weather conditions as ambient temperature and horizontal global irradiation. In summer in Cairo temperature can achieve over 38°C [6], the PV cells are tested in STC conditions

(20°C) and NOCT conditions (25°C), the lack of efficiency for Si-poly cells are 0.41% per °C above 25°C [24]. The lack can also be caused by the covering of PV modules by a layer of speck and dust. Performance ratio was calculated from equation (1) [12].

$$PR = \frac{Y_f}{Y_r} [-]$$

(1)

where:
Y_f - Final yield, defined as total AC energy during a specific period divided by the rated power of the installation [kWh/kWp/day],
Y_r - Reference yield, is the ratio of the global solar radiation and the PV's reference irradiance [kWh/kWp/day].

Performance ratio in similar localization in North Africa adduced by Attari et al. [12] (Tangier, Morocco 35,75°N, 8,34°W) was form 0.58 in December to 0.98 in January. Total Performance ratio for the whole year was 0.79. For other PV installations the Performance ratio varies from 0.7 to 0.9 (Thailand) [13], from 0.38 to 0.88 (Germany) [14], and from 0.5 to 0.8 (Poland) [15].

Table 4. Balance and main results for tilt 5° in Cairo [11].

Month	GlobHor	DiffHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m ²	kWh/m ²	°C	kWh/m ²	kWh/m ²	MWh	MWh	[-]
January	102.3	32.90	13.60	109.8	96.4	36.05	34.88	0.727
February	120.4	35.00	14.30	126.7	111.9	40.51	39.12	0.707
March	173.3	45.60	17.10	179.7	159.3	54.91	52.90	0.674
April	204.6	49.20	21.70	208.3	184.8	60.66	58.38	0.642
May	237.2	53.60	25.20	238.1	211.7	66.90	64.28	0.618
June	252.2	46.50	27.90	250.8	223.5	68.20	65.44	0.597
July	251.7	49.00	29.50	251.7	224.2	68.42	65.65	0.597
August	232.5	45.30	29.40	235.0	208.8	64.52	62.01	0.604
September	191.4	40.20	27.40	196.5	174.2	55.79	44.41	0.517
October	148.8	39.40	23.40	156.1	138.2	47.33	38.21	0.560
November	107.1	33.00	19.10	114.4	100.9	36.34	30.20	0.604
December	93.9	30.70	14.89	100.8	88.5	33.04	31.96	0.726
Year	2115.2	500.40	22.00	2168.0	1922.5	632.69	587.45	0.620

GlobHor - Horizontal global irradiation,
DiffHor - Horizontal diffuse irradiation,
T Amb - Ambient Temperature,
GlobInc - Global incident in coll. Plane,
GlobEff - Effective Global, corr. for IAM and shadings,
EArray - Effective energy at the output of the array,
E_Grid - Energy injected into grid,
PR - Performance Ratio.

Fig. 2. Performance ratio [11].

Comparison of various PR for different PV installation were shown in Fig 3. For the most of selected installations performance ratios were above 0.7. The highest PR was for Morocco 5 kWp installation 0.79 [12]. The lowest performance ratios were for India 1816 kWp installation [27] – 0.637, and for present in this article Egypt PV installation – 0.62.

Fig. 3.Comparison of PR for selected PV installations, according literature data [12,16, 23, 25-27].

The installation average monthly final yield was shown in Fig. 4. On this figure also shown are the collection and system losses over the mentioned period. The average system losses were 0.28 kWh/kWp/day, the biggest system losses were in September, October, and November. The average collection losses were 1.97 kWh/kWp/day, the biggest losses were between April and September. Such big losses in summer period might be due to soiling, dust and lack of maintenance during these months. Attari et al. [12] reported that for mentioned Tangier installation system losses were between 0.14 (January) to 1.89 (May) kWh/kWp. Capture losses were varying from 0.025 kWh/kWp in February to 0.76 kWh/kWp in September. The final yield, defined as production of the useful energy, vary from 2.2 kWh/kWp during winter months (November-January), to roughly 5.0 during summer months (May-August).

Fig. 4. Installation final yield and corresponding capture and system losses per month [11].

Figure 5 shows final yield comparison of PV installation in different counties. The highest final yield was achieved by installation located in Oman (5.1 kWh/kWp/day) [21], also very high final yield was for PV installation located in Kuwait (4.5 kWh/kWp/day) [22] and Morocco (4.4 kWh/kWp/day) [12]. The PV installation’s final yield presented in this article was 3.7 kWh/kWp/day, which was on the same level as in India (3.8 kWh/kWp/day) [17] and Spain (3.8 kWh/kWp/day) [20] and higher than in other localizations.

Fig. 5. Comparison of final yield for selected PV installation,according literature data [12, 14, 17 -22].

The annual losses from the installation were shown in the Fig. 6. The biggest losses were caused by soiling factor (about 10%), and ohmic wiring (about 16.3%). Also, losses caused due to temperature were high (about 7.3%). Much smaller were losses caused by light induced degradation (2.0%), and inverter loss during operation (2.2%). The losses for the presented installation were very similar to those presented in the previously mentioned publication Attari et al. [12]. For their Morocco PV installation PV degradation losses were high (5%), but other losses were particularly the same: temperature losses (7.2%), soiling losses (8.75%), inverter losses (5.43%). The highest losses were, similar to the Egypt PV installation, ohmic wiring losses (16%). Shiva Kumar and Sudhakar presented a loss diagram for an 10 MW PV installation in India, in that case the biggest were losses caused by temperature (10.7%), irradiance level (3.1%), and soiling losses (2.1%) [23].

Fig. 6. Diagram of estimated losses in the PV system [11].

4 Conclusion

In this paper was showed a PV installation which was localized in Egypt. The PV installation was made by Si-poly modules, and the total module area was 2611 m². Module efficiency at STC conditions was 16.74%. This installation was able to produce about 587 MWh of energy into the grid per year. Average annual final yield achieved was about 3.7 kWh/kWp, which was lower than the installation from Morocco or Oman, but similar to

installations in India and Spain. Average annual performance ratio was 0.62, the lowest was on September 0.517, the highest was on January (0.727) and December (0.726). Total losses for this installation were roughly 30%, over half of them were caused by ohmic wiring (16.3%).

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