A real life analysis of small scale photovoltaic installations

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Abstract: One of the measures taken by the Flemish region in Belgium to reduce the greenhouse gas emissions and to stimulate the market penetration of renewable energy was the introduction of a support arrangement for photovoltaic solar installations on building. This paper describes the analysis of the measuring results of the real-life monitoring of 13 financed photovoltaic solar installations in the Flemish Region in Belgium. All systems are grid-connected with installed powers between 0,85 kWp and 5,7 kWp, angles of inclination between 14° and 45° and orientations between 142° and 235°. The following parameters were measured during 6 to 12 months: PV-electricity production, electric energy from the grid and from the PV-panels effectively used in the building, solar radiation in the plane of the panels and the part of the PV-energy that goes back into the grid. In addition, for 7 installations, both the DC and AC-power generated by the panels was measured in order to evaluate the efficiency of the modules and the inverters separately. Several conclusions were made regarding system efficiency, performance ratio, impact of orientation and angle of inclination, inverter problems, shadow effects and dimensioning problems.

Key-Words: In-situ monitoring, photovoltaic installation, solar energy

1 Introduction

As a solution for the depletion of conventional fossil fuel energy sources and serious environmental problems, focus on the photovoltaic (PV) system has been increasing around the world [1]. In this context, a lot of research has been done regarding photovoltaic installations. Measuring campaigns has been set up [2,3], special features have been designed both for the roofs and the modules [4], new converters for have been designed [5] and new materials have been developed [6].

The Flemish government in Belgium has introduced among other things a support arrangement for photovoltaic solar installations in the built environment. This was one the measures taken by the Flemish Energy Agency (VEA) to reduce the Greenhouse gas emissions and to stimulate the market penetration of renewable energies.

In order to gain an insight into the yearly electricity production of the supported photovoltaic solar panels, Vito monitors and evaluates 16 of these installations for VEA during a measuring period of 6 to 12 months.

In this paper, the results of the evaluation of the measuring data of 13 of these installations will be evaluated.

2 Measuring set-up

The complete measuring set-up for the evaluations of the photovoltaic installations is shown in Fig. 1.

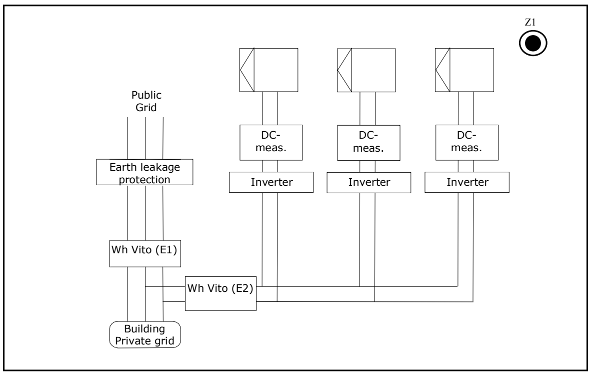

Fig. 1: Measuring set-up

Two energy meters are used for measuring the production of the PV-installation. The electric energy going from the grid to the building and the part of the energy produced by the PV-installation that goes back into the grid are both measured with a three-phase energy meter (E1). The total production of the PV-installation is measured at AC-side of the inverters with a mono-phase energy meter (E2). Both energy meters E1 and E2 are class 1 instruments of the type VIP ENERGY and VIP ONE from ELCONTROL Energy.

The total (direct and diffuse) solar energy in the plane of the panels is measured by a pyrometer type CM11 of SCI-TEC Instruments (Z1).

For 7 installations, also the PV-power at the DC-side of the inverters is measured. To do this, different DC-measuring boxes were made to measure DC-voltage and current by respectively a shunt resistance and a voltage divider.

The electric energy is counted by pulses generated by the energy meters and stored each 5 minutes in a Datataker type DT50. The analogue signals for the solar radiation and the DC-current and voltage are read each 30 seconds by the logger and the average is stored each 5 minutes in the Datataker.

3 The photovoltaic installation

Table 1 shows the type of modules, the cell type and the type of inverter that has been used for the grid connection for the different installations that are all located in Flanders in Belgium. 4 of the installations have modules with monocrystalline Si solar cells, while the other installations all have polycrystalline Si cells. The panel of 1 installation is semitransparent.

PV	Type of modules	Type of cells	Type of inverter
1	9 x Kyocera KC120	PC*	1 x Sunny Boy SWR850
2	40 x Atersa A85	PC	4 x Sunny Boy SWR700
3	10 x BP 585 F	MC**	1 x Sunny Boy SWR700
4	30 x Solglass BT	PC, semitransparant	2 x Sunny Boy SWR2500
5	20 x Kyocera KC 120	PC	1 x Sunny Boy SWR2000
6	28 x Siemens/Shell SP75	MC	2 x Sunny Boy SWR850
7	30 x Atersa A120	MC	3 x Sunny Boy SWR850
8	18 x Kyocera KC 120	PC	Sunny Boy SWR 1700E
9	10 x Kyocera KC120	PC	1 x Sunny Boy SWR850
10	20 x shell RSM105	PC	1 x Sunmaster QS3200
11	10 x Kyocera KC120	PC	1 x Sunny Boy SWR850
12	12 x BP Solar 585	MC	1 x Sunny Boy SWR 1100E
13	16 x shell RSM105	PC	1 x Sunmaster QS2000

Table 1: Type of PV inverter for the 13 installations (*PC: Polycrystalline; **MC: Monocrystalline)

Table 2 shows more detailed parameters of the different installations: orientation, inclination, panel area, cell area, installed power and power density. The cell area is calculated based on the specifications of the manufacturer, while the panel area is measured.

	Oriënt. [°]	**Inclin. [°]**	**Panel area* [m²]**	**Cell area** [m²]**	**Installed power [kWp]**	**Power density [kWp/m²]**
1	142	30	8,4	7,29	1,08	0,129
2	160	38	25,3	23,2	3,4	0,134
3	180	32	6,3	5,8	0,85	0,135
4	225	14	56,7	38,36	5,7	0,1
5	210	32	18,6	16,2	2,4	0,129
6	235	45	17,7	15,7	2,1	0,119
7	224	25	29,2	25,9	3,6	0,123
8	160	29	16,7	14,6	2,16	0,129
9	200	41	9,29	8,1	1,2	0,129
10	200	45	20,74	16,9	2,08	0,100
11	160	32	9,29	8,1	1,2	0,129
12	200	37	7,56	6,75	1,02	0,135
13	170	35	16,36	13,5	1,68	0,103

Table 2: Parameters of the 13 installations (*Panel area is measured; **cell area is calculated (manufacturer specifications))

For the specific cost of the installations, values in between 6800 €/kWp and 9860 €/kWp have been registered. The installation with the semitransparent panel has a specific cost of more than 10100 €/kWp.

4 Measuring results

4.1 Measuring period and solar irradiation

Table 3 shows the measuring period, the solar radiation in the plane of the panel (I_S) and the reference yield (Y_r) for each installation. The solar irradiation is the sum of the direct, the diffuse and the ground-reflected radiation on the tilted plane of the PV-installation. The reference yield is defined as solar irradiation on the tilted plane normalized to the solar irradiance under Standard Temperature Conditions of 1000 W/m².

	Measuring period	Solar irradiation I_s [kWh]	Reference yield [h or kWh/kWp]
1	01/00 – 12/00	8.736	1.045
2	01/00 – 12/00	26.750	1.059
3	07/00 – 08/01	5.545	880
4	07/01 – 06/02	37.032	965
5	01/02 – 12/02	19.726	1.061
6	05/02 – 04/03	23.295	1.316
7	12/01 – 11/02	28.573	979
8	01/03 – 12/03	22.622	1.355
9	08/03 - 07/04	10.631	1.144
10	07/04 - 12/04	20.878	1.007
11	07/04 - 12/04	8.746	941
12	01/05 - 06/05	9.478	1.254
13	07/05 - 12/05	18.738	1.145

Table 3: Measuring period, solar irradiation and reference yield for the 13 installations

It's difficult to compare the solar irradiance of installation 4 with that of the other installations, since for this installation, the solar irradiance is measured by a reference cell instead of by the pyrometer described in the measurement set-up. Moreover, for this semi-transparent installation, all calculations are done with the cell area, while for the other installations the panel area is used. When the panel area is used for the calculations, the reference yield is 653 kWh/kWp. This value is remarkable low because of the very large glass surface of the semi-transparent modules.

The lower reference yield of some of the installations can be explained by shadow on the panels and the pyrometer. The lower reference yield of installation 3 is explained by trees in the near surrounding that cause shadow on the panels and the pyrometer during some moments of the day. Also the pyrometer and the panel of installation 4 and 7 is being shadowed during the day by surrounding building constructions

Regarding the inclination, orientation and measuring period of installation 10 and 11, one should expect approximately the same reference yield for both installations. However, the reference yield of installation 10 is almost 7% higher. No explanation could be found for this.

4.2 PV production and efficiency

Table 4 shows the AC production of the PV-installations, the overall efficiency (AC production divided by solar irradiation on the tilted plane), the overall yield (AC production normalized to the rated power of the PV array under STC) and the performance ratio for the installations during the different measuring periods. To compare the performance of the PV-installations over the different measuring periods and for different locations, the performance ratio has been calculated, which is the overall yield normalized to the reference yield

	AC production [kWh]	Overall efficiency [%]	Overall yield [kWh/kWp]	Performance ratio PR
1	545	6,2	505	0,48
2	2.356	8,8	693	0,65
3	501	9	589	0,67
4	3.263	8,8	572	0,59
5	1.971	10	821	0,77
6	442	1,9	210	0,16
7	2.448	8,6	680	0,69
8	2.107	9,3	975	0,72
9	10.631,00	9,3	825	0,72
10	20.878,00	7,9	788	0,78
11	8.746,00	10,1	737	0,78
12	9.478,00	10,8	1001	0,80
13	18.738,00	9,0	999	0,87

Table 4: AC production, overall efficiency, overall yield and performance ratio for the 13 installations

According to the International Energy Agency's Photovoltaic Power System Program (IEA PVPS), average annual PR values of higher than 0,75 are to be achieved for well-planned PV systems [7]. For 5 installations, the performance ratio reaches this value of 0,75. For installation 8 and 9, the value of 0,75 is almost reached by 0,72. For all the other installations, the performance ratio is less than 0,69.

For 7 installations, the DC current and voltage were measured separately. Table 5 shows the panel efficiency, the inverter efficiency and the overall efficiency of these 7 installations.

The small panel efficiency of installation 10 is noticeable: this can be explained by the fact that for this installation the cell area contributes to a smaller part of the panel area.

	Overall efficiency	**Panel efficiency**	**Inverter efficiency**
	[%]	[%]	[%]
7	8,6	10,3	82,8
8	9,3	10,1	92,4
9	9,3	10,5	88,4
10	7,9	9,0	87,0
11	10,1	11,8	88,9
12	10,8	12,3	87,9
13	9,0	9,8	91,3

Table 5: Overall efficiency, panel efficiency and inverter efficiency for 7 installations

In global, all inverter efficiencies turn out to be smaller than expected, especially the inverter efficiency of installation 7 is very small. This can be explained by the heating up of the inverters during the summer months because they are placed outside without any protection against the sun. Especially for days with a large solar irradiance, shortly after noon, the AC production and the system efficiency of the installation shows a dip during a few hours (figure 2).

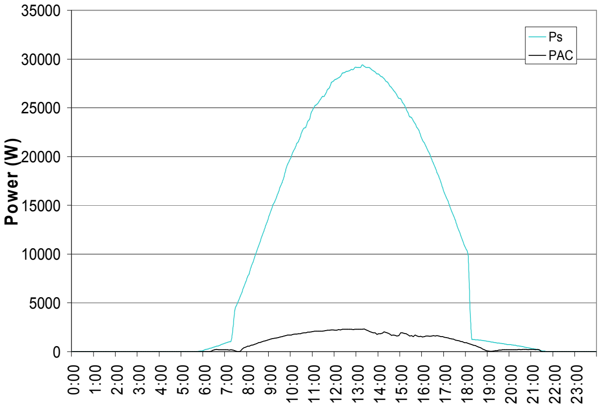

Fig. 2: Solar power (Ps) and AC power (PAC) of installation 7 on 01/06/2002

Fig. 2 also shows that shadowing of the panel and the pyrometer does not always occur simultaneously.

For some installations a clear relation could be noticed between the efficiency of the PV-array and the solar irradiance. The inverter efficiency is lower in the cold months because of partial load working, while the panel efficiency is higher in the cold months because of the negative temperature coefficient.

5 Troubleshooting

A lot of the problems that occurred were already mentioned before [8].

The bad performance ratio and low efficiency of installation 1 can partially be explained by a regular fall out of the inverter especially during the winter months.

Also for installation 4 there was no electricity production (fall out of the inverter) during 26 days of the measuring period. Besides this, the roof of the building of this installation causes that the modules are partially shadowed from morning till early noon. Calculations show that the overall efficiency would increase with at least 1% when there was no shadow effect for this installation.

A lot of problems can be mentioned for installation 6: going from a dimensioning problem and a problem with wrong electric interconnection to one of the inverters to be defect.

It is remarkable that the first installed installations perform less well than the latest ones. This can be a typical problem of the lack of experience of the installer by the installation of the first installations. The last 4 installations all have a good performance ratio.

6 Conclusions

Thirteen grid-connected PV-installations in the Flemish region with an installed power between 0,85 kWp and 5,7 kWp, an angle of inclination between 14° and 45° and an orientation between 142° and 235° were measured during a measuring period of 6 to 12 months.

Several important conclusions could be made based on the measuring results:

- For the overall efficiency of the PV-installations values were measured between 1,9 % and 10,8 %.
- The overall yield of the different installations was measured between 210 kWh/kWp and 1001 kWh/kWp. The value of 1001 kWh/kWp was reached during the first half of 2005, which was extremely sunny. The second best value of 999 kWh/kWp was reached at a location near the sea.
- The performance ratio values varied between 0,16 and 0,87.
- The lower productions figures are mainly caused by partially shadowed panels, a regular fall out of the inverter, wrong dimensioning of the installation and the warming up of the inverter and the PV-modules.
- The installations that are installed more recently, all have a good performance ratio.

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