1 kW grid-connected PV system after two years of monitoring

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The paper describes performance of the grid-connected 1-kW PV system installed on a grammar school in Warsaw after two years of operation. The system consists of twenty Millennia MST-50 MV modules and inverter Sunny Boy GCI 1200. The performance of the system is continuously monitored according to guidelines in IEC 61724.

Energy production in the first year was about 740 kWh and it was slightly higher than expected with respect to the simulation done before installation. In the second year, the energy production was about 680 kWh. The measured efficiency of the PV modules is about 5%, efficiency of the inverter is about 92% and efficiency of the entire PV system exceeds 4%. The performance ratio is in the range from 0.5 to 0.8.

Keywords: photovoltaics, PV system, grid-connected, monitoring.

1. Introduction

It is an appropriate time to highlight the potential of solar photovoltaic (PV) technologies due to the increased awareness in energy and environmental issues in the general public in Poland [1,2]. The goal of the project was to show potential of solar technology through the installation of PV system and to prepare analysis of conditions for integrating PV systems with buildings and power grid. This was the pioneer work done on photovoltaics in Poland.

Because of the lack of information about some major solar energy options, such as photovoltaics, there is a need for more education and public information on the energy and environment through demonstration projects, in the media, and in schools. PV is a rapidly developing technology with a very high potential in coming decades. Demonstration projects are crucial in Poland. They will show the public the benefits of the solar energy. Introducing a newly developing technology, building-integrated photovoltaics (BIPV) will affect the local economy through beneficial economic, environmental, and social impacts.

Thanks to US Ecolinks Program, local authorities of Warsaw-Wawer (suburb of Warsaw) and BP Solar, 1-kW grid-connected PV system was installed on the roof of the grammar school. The PV system installed on the school’s roof was one of the first implementations of BP Solar’s trademarked Solar Energiser concept in Europe. It was also one of the first grid-connected PV systems in Poland.

The 1-kW system (Fig. 1) was installed in December 2000 on the roof of the Public Grammar School No. 76 in the Municipality of Warsaw-Wawer. The system consists of 20 BP Solar double-junction thin-film amorphous silicon PV modules (MST-50 MV) in the universal frames. The inverter Sunny Boy GCI 1200 is connected to the public grid via a single-phase connection with an electrical energy meter. The installation is located in Warsaw (21° 12’ E, 52° 09’ N), facing south and tilted at 30. Such value of tilt angle was chosen to maximise a yearly energy production.

During the first year of operation, two PV modules got damaged – the laminate got broken. We rearranged the connections of PV array to get an array with a nominal power 900 W.

The monitoring system was designed to meet guidelines of the standard IEC 61724 [3,4]. It consists of the data ac-
quisition system (DAS) build into inverter, a cluster of meteorological sensors, controller sunny boy control plus and a computer that collects and visualizes the measured data. The following parameters are measured:

- electrical parameters (measured by the DAS build into the inverter installed on the PV system supporting structure):
  - DC and AC voltage, current, power and energy production,
  - cumulated AC energy supplied to grid,
  - utility grid impedance and frequency,
  - resistance of isolation of PV array,

- meteorological parameters (installed on the top of the PV array):
  - irradiance in horizontal plane and in plane of PV array (Spectron 100),
  - ambient and PV module temperature (PT 100),
  - wind velocity.

The electrical parameters of the PV system have been recorded since the day of its installation in the end of December 2000, meteorological data have been recorded since the second half of February 2001. The calculations presented below were made assuming that nominal power of the PV system from January to June 2001 was 1 kW, and from August 2002 the nominal power was 900 W.

3. Analysis of the PV system performance

During the first year of operation the system generated about 740 kWh and during the second year about 680 kWh. Energy production was higher than that expected from the simulation, even though the in-plane irradiation was lower than this taken to the simulation. Decrease in the generated energy in 2002 was caused by malfunction of two PV modules.

The efficiency of the system in good irradiance conditions during the months from May to August exceeds 4% (Fig. 2). The efficiency of inverter is about 92% and the efficiency of PV modules goes up to 5%. The smaller efficiency than expected can be caused by: difference in spectrum of sunny irradiance in the specific location and spectrum defined as STC (Standard Test Conditions), dirt accumulation on the front surface of PV modules.

For more detailed analysis of the PV system performance, the following normalised parameters were used:

- $Y_A$ is the array yield, it is the array daily energy output per 1 kW of the installed PV array, $Y_A = E_d/P_o$, $Y_A$ is in h/d (hours per day), it represents the number of hours per day that the array would need to operate at its rated power $P_o$ to generate the same daily energy $E_d$ that was measured by monitoring system,
- $Y_f$ is the final yield, it is a daily portion of energy supplied to the grid per 1 kW of the installed PV array, $Y_f = E_d/P_o$, $Y_f$ is in h/d (hours per day), it represents the number of hours per day that the system would need to operate at its PV array’s rated power $P_o$ to generate the same daily energy that was supplied to grid $E_d$,
- $Y_r$ is the reference yield, it is total daily in-plane irradiance normalised to the PV module’s in-plane reference irradiance $G_i$, $Y_r = \sum_{day} G_i/G_{i_r}$, $Y_r$ is in h/d (hours per day), it represents the number of hours per day which the solar radiation would need to be at reference irradiation levels in order to contribute the same incident energy as it was measured. Usually $G_i$ is equal to the STC irradiation of 1000 W/m²,
- $L_c$ are the capture losses in h/d (hours per day), they are the losses due to PV array operation, $L_c = Y_r - Y_a$,
- $L_s$ are the system losses in h/d (hours per day), they are the losses due to operation of power conversion unit (inverter), $L_s = Y_o - Y_f$.
- PR is the performance ratio, it indicates the overall effect of losses, $PR = Y_f/Y_r$.

In the presented PV system, the PR during the days with the daily irradiation higher than 2 kWh/m² is in the range between 0.55 and 0.8 (Fig. 2). In Fig. 3, the final yield versus reference yield is presented. Most of the points are between the solid line representing PR equal to 0.55 and the dashed line representing PR equal to 0.8 [3].

In summer days, the PR reaches its maximum possible value, during some winter days the PV array is covered by snow and power generated is too low to run the inverter. In these days, there is no energy production so PR is equal to 0.
In Fig. 4, one can observe an effect of decrease of PR, in the second year of operation of the PV system most probably due to degradation of the parameters of amorphous silicon. During the first year in the most of days PR was in the range from 0.7 to 0.8. In the next years, the PR rarely exceeds the value of 0.7.

The system losses \( L_s \) are usually about 6% of the PV system’s energy balance with no seasonal deviation. Proportion between the capture losses \( L_c \) and the final yield change during the year in range from 25% in spring and summer up to 95% in winter months due to snow accumulation. The final yield reaches up to 80% in summer time, but in winter it may fall down to about 5% (see Fig. 5).

As show the presented above results, in Polish conditions, the PV system works efficiently. Solar irradiation is good enough to produce electrical energy which can be used to supply a small load or to sell it to the utility grid. Since the PV is a rapidly developing technology with a very high potential in the coming decades, demonstration projects are necessary in Poland to show the public the benefits of solar energy.

In this project, we also focused on demonstration and social aspects which, in the future, may help to introduce photovoltaics in Poland.

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References

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