AMORPHOUS SILICON MODULES ON FACADES WITH NON-OPTIMAL ORIENTATIONS

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ABSTRACT
An existing office building has been retrofitted with a PV-system on each of the four vertical façades. The façades are facing north, south, east and west. The applied system consists of single-junction amorphous silicon modules. The paper presents monitoring data obtained from August 1999 to April 2000. Although the monitoring period is not yet adequate for a complete assessment of the performance of the PV-systems, some conclusions can be already drawn.
Keywords: Amorphous silicon - 1: Vertical façades - 2: Monitoring - 3.

1. INTRODUCTION

An existing office building of ECN has been retrofitted with four identical PV-systems, each consisting of 42 single-junction amorphous silicon modules with a total nominal power of 500 Wp and a 700 W inverter. The PV-systems are positioned on vertical façades facing north, east, south and west respectively. The performance of the PV-systems is monitored since August 1, 1999. The aim of the monitoring programme is twofold: assessing the performance of the PV-systems and obtaining a set of data to be used for the validation of numerical models. This paper addresses the first item: the performance of the PV-systems.

The monitoring programme is supported financially by the Netherlands Agency for Energy and Environment (Novem).

2. PV-SYSTEMS

Each of the four PV-systems consists of 42 single-junction amorphous silicon modules, connected as 6 strings of 7 modules. The modules are manufactured by Fortum (former Neste) and have a nominal power of 12 Wp. Each PV-system is connected to the grid through an SMA Sunny Boy 700 inverter with a nominal power of 700 W. Simple aluminium profiles have been mounted against the four vertical façades of the building in which the frameless modules are positioned. The total thickness of the construction is 9 cm. The façades of the building that are referred to as north, east, south and west have azimuth angles of -7, 83, 173 and 263 degrees with respect to north. East of the building a neighbouring building is shielding part of the irradiance. Towards west the view is free from obstacles.

3. MONITORING SYSTEM

The monitoring system is based upon a measurement-PC connected to two groups of decentralised data acquisition units. One group of DAQ-units consists of five sub-units: one for data from the roof of the building and one for each of the four façades. These five DAQ-units are connected to the measurement-PC through a Local Operating Network (LON). The other group of DAQ-units consists of the four monitoring devices of the Sunny Boy 700 inverters, connected to the measurement-PC through an RS485/232 network.

The DAQ-unit of the roof measures meteo-data on the roof : horizontal global irradiance and its diffuse component (using two Kipp pyranometers of which one is equipped with a shadow ring), wind speed, wind direction and ambient temperature.

The DAQ-units of the façades measure the in plane irradiance (using a Kipp pyranometer and a reference cell), the module temperature and a number of wall temperatures. The reference cells are made of crystalline silicon with a filter glass (manufacturer Schott Nederland, type KG5). This combination of cell and filter results in reference cell with a spectral response similar to the spectral response of amorphous silicon modules. The reference cells have been calibrated in the ECN-laboratories.

The monitoring devices of the inverters measure the electrical quantities such as DC-voltage, DC-current and AC power.

All DAQ-units sample the measurement channels once per 10 seconds. The measurement-PC calculates the DC-power of the four inverters by multiplying the DC-voltage with the DC-current and then it calculates during consecutive measurement periods of 10 minutes the averaged values of all measurement channels. The 10-minute averaged data are stored for subsequent off-line evaluation.

4. MONITORING RESULTS

4.1. Irradiation

The monthly irradiation, obtained by integration of the irradiance data from the pyranometers on the façades and on the roof, is presented in figure 1.

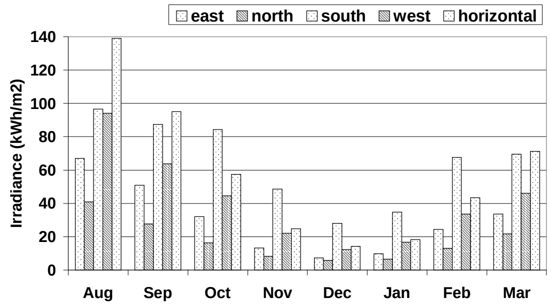

Figure 1 Monthly irradiation on the facades and on the roof (pyranometer data)

The irradiation values have been determined using the reference cells on the façades as well. The ratio between the results from the pyranometers and the reference cells are given in figure 2. This figure shows also the diffuse fraction of the horizontal irradiance.

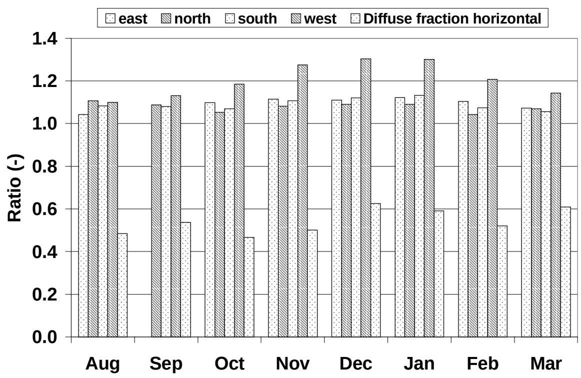

Figure 2 Ratio between the irradiance measured with the pyranometers and with the reference cells plus the diffuse fraction of the horizontal irradiance

Figure 2 shows significant differences in irradiation data from the pyranometers and the reference cells. These differences are caused by differences in the response of the reference cell and the pyranometer for non-normal incidence angles and for deviations from the Air Mass 1.5 spectrum. This is illustrated in figure 3, showing a time series of the irradiance on the west-façade on March 22.

Figure 3 gives the irradiance measured with the pyranometer and the ratio between the pyranometer data and the reference cell data. A large difference is observed around noon, caused by the grazing angle of incidence on the west-façade. Also at the end of the day a large difference is observed. To investigate this the spectrum has been measured on the west-façade on March 22 on 13.30 h and on 17.45 h. The spectra, normalised to a total irradiance of 1 kW/m^2 below 900 nm, are given in figure 4.

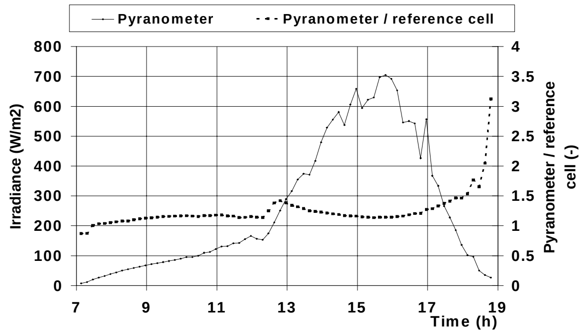

Figure 3 Irradiance on the west facade(22/3/00)

Figure 4 shows also the standard (AM1.5) spectrum and the response of a-Si in that spectrum. A shift of the spectrum towards red at the end of the day is observed. This part of the spectrum contributes to the irradiance measured by the pyranometer but remains unnoticed by the reference cell, having the main spectral characteristics of a-Si.

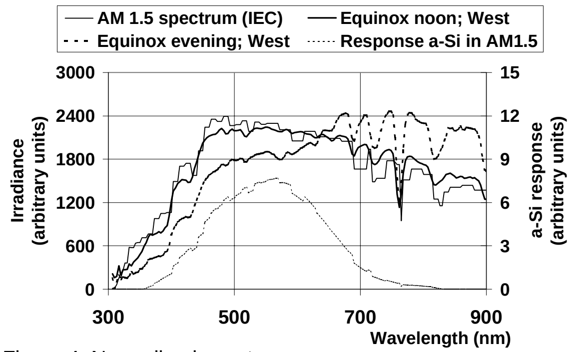

Figure 4: Normalized spectra

The observed difference between the data from the reference cell and from the pyranometer leads to the question which is the proper irradiance sensor to be used in monitoring programmes of a-Si systems. The answer to this question depends on the purpose of the monitoring. In case the monitoring focuses on spotting possible anomalies in the PV-system (such as partial shading effects, ageing of the modules, malfunctioning strings etcetera) a reference cell is more appropriate. In case the monitoring is intended to gather performance data to be used in the prediction of the energy production of similar systems on other locations a pyranometer will be more appropriate since irradiance data on various locations are (almost) always obtained with pyranometers.

4.2. Performance

The performance ratios of the four PV-systems have been calculated using monthly irradiation data from the reference cells and the monthly AC-energy from the inverters. The used value for the array power at STC is 435 Wp. This value has been obtained by measuring the IV-curve of the array on the south-façade (figure 5).

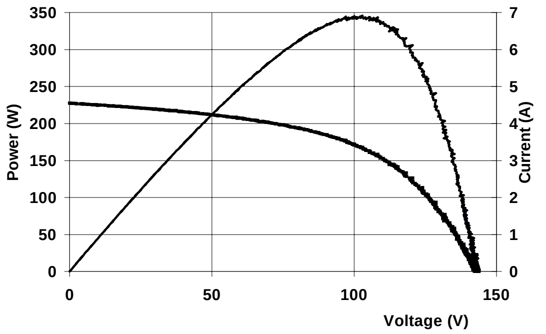

Figure 5 IV-curve at 42 º C and 820 W/m2

The PR-values are given in figure 6. This figure shows low PR-values for the east- and west-façades during the winter period and for the north-façade during all monitored months. This is caused by the low conversion efficiencies of the inverters due to the severe partial load operation.

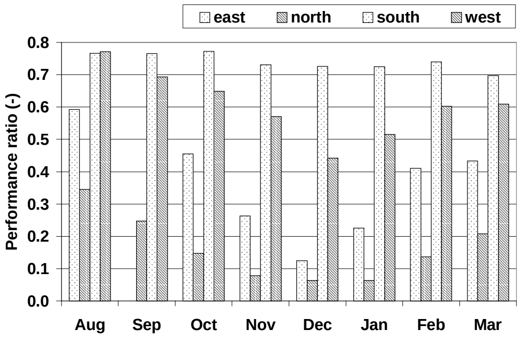

Figure 6 Monthly performance ratios

The efficiencies of the four arrays have been measured as a function of the irradiance. No significant differences have been observed between these four curves. Unfortunately the DC-current data obtained from the monitoring device of the inverters proved to have large measurement errors. A correction has been made for this by an in-situ calibration of the monitoring device of the inverter on the south-façade. After this correction the efficiency of the south-array has been determined as presented in figure 7.

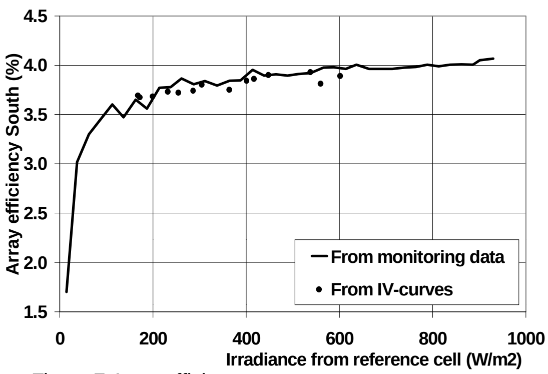

Figure 7 Array efficiency

Figure 7 shows also efficiency data obtained with some short measurement campaigns with an IV-tracer. With the efficiency curve of figure 7 and the monthly measured frequency distribution of the irradiance on the south- and north-façade the monthly DC-energies have been calculated. This resulted in the array-efficiencies in figure 8. If the inverter of the individual PV-systems would have been optimised to the actual power of the arrays, rather than chosen the same for all orientations, the range of the PR-values of 0.1 to 0.8 (figure 6) would be limited to a range of 0.4 to 0.8.

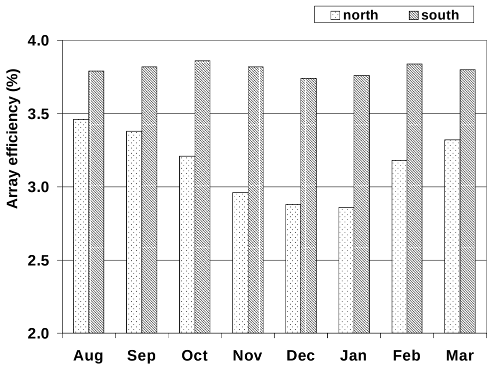

Figure 8 Monthly array efficiency

5. CONCLUSIONS

- A detailed set of measurement data is becoming available for the validation of models for irradiance and performance of a-Si modules on various façades
- Differences are observed between the response of the reference cells, designed for monitoring a-Si modules, and pyranometers. The differences are most significant during grazing incidence angles and at moments with spectra deviating from AM 1.5. The reference cells facilitate the assessment of the PV-systems with respect to anomalies and the pyranometers facilitate the prediction of energy production of similar systems at other places.
- The performance ratio for the PV-systems ranges between 0.8 (south) and 0.1 (north in the darkest month). A more appropriate choice of the inverters nominal power would improve the performance ratio very much.

6. ACKNOWLEDGEMENT

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