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Building Integrated Photovoltaic (BIPV) systems in Romania. Monitoring, modelling and experimental validation

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The study is dedicated to the performance analysis of a BIPV (Building Integrated Photovoltaic) system developed in Romania and mounted on the building of the Polytechnic University of Bucharest (PUB); such systems highly depend on the fluctuation of incoming solar radiation reaching the PV system's surface. The estimation of the energy production of the BIPV system, on a short term period (two days), is considered as the main objective of the article. In the first part of the article, the BIPV demonstrative system is presented, as well as the meteorological station used. In the second part of the study, short-term solar irradiation forecasts are elaborated in two ways, based on the meteorological experimental datasets. First, forecasting tests are run using Autoregressive Integrated Moving Average (ARIMA) models. Second, artificial neural network (ANN) techniques are also evaluated (based on meteorological variables) in order to enhance the forecasts of solar irradiation. Finally, we conclude by validating the obtained results by real measurements determining the error range of forecasted values quantifying by the root-mean-square error (RMSE), as well as an estimation of energy production between forecasted and measured values.

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Keywords: building integrated photovoltaic, short term radiation forecast, meteorological experimental datasets, simulation platform.

1. Introduction

The BIPV systems are represented by the PV modules, which substitute some façade or roof components. Along with the construction of new buildings – mainly residential parks and office buildings - the activity of retrofitting the existing stock is intense. Incorporating energy efficiency, renewable energy and sustainable green design features into the buildings has become a top priority in recent years for facility managers, architects, real estate owners, designers etc., supported by current international policies and directives that are already aiming towards zero-energy buildings [1-2]. To promote the use of photovoltaic (PV) technology in buildings, international research programs encourage solutions that support the integration of PV devices as architectural elements, BIPV. New materials, components and systems integrating the PV element with the construction element open still unknown new areas of development.

Different studies regarding BIPV systems have been approached by researchers, considering the various uses and particularities of BIPV systems, such as recovery of historical heritage [3], comfort performance studies [4] as well as design strategies and technological solutions [5, 15-18].

The influence of the external climatic conditions and temperature on the electrical characteristics of PV modules, as well as their possible contribution to total building energy consumption, has not been well investigated so far. In addition, further insights into the internal environmental comfort in buildings, using BIPV technologies are needed to open new research perspectives.

For the close analysis of such systems, a demonstrative BIPV system was built at the Polytechnic University of Bucharest in 2008, within the NANO-PV laboratory, consisting in a PV window. The system aimed at the development of a multifunctional modelling and simulation platform for BIPV systems.

2. Description of the BIPV system at UPB

Fig. 1 shows the diagram of the external structure of the BIPV installation in the NANO-PV laboratory windows.

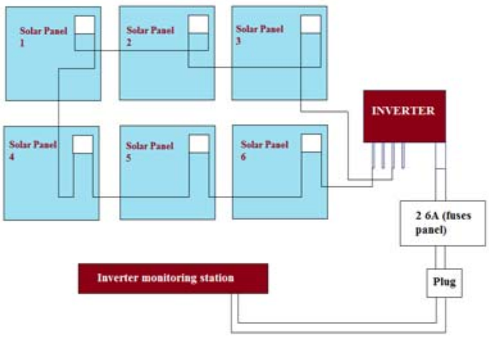

Fig.1 BIPV system structure.

Two types of PV panels were chosen for this installation. Three panels type 1 and three panels type 2 were installed. Table 1 shows the characteristics of the selected photovoltaic panels.

Table 1. Characteristic of photovoltaic panels

Features	**Type 1**	**Type 2**
Dimensions	1550 x 800 x 6 mm	1050 x 800 x 6 mm
Weight	14 kg	9 kg
Number of cells in series	50	35
Cell size	12,7 cm	12,7 cm
Electrical:		
Maximum power	120W ± 5%	85W ± 5%
Current al maximum power	4,31 A	4,31 A
Voltage at maximum power	27,5 V	19,25 V
Design:		
Cell type	Crystalline Si, textured and covered with an anti-reflector	
Contacts	Redundant contact to ensure high reliability	
Rolling	Ethylene-vinyl acetate	
Rear	Tedlar, multi-layer	

In order to analyse the BIPV system performances depending on the meteorological parameters, a weather laboratory station was installed to monitor the evolution of the system.

The centre for the measuring of the meteorological parameters is located in the above-mentioned NANO-PV laboratory.

3. The monitoring system: hardware and software

The basic components of the monitoring system are a weather monitoring station (for the meteorological parameters measurement) and a data logger (for the BIPV production data), plus two computers for data acquisition and a Web server used to process and present the data in a format that can be easily understood by the user.

3.1 Hardware structure

3.1.1 Hardware structure of the BIPV system data acquisition

In terms of communication, the connection between the monitoring devices and the computers that download the data, is done via a standard RS232 serial communication, whilst the connection between the inverter and the data logger is done through the power grid

Once new data are available, the computers send the data to a server that plugs them into a database. The hardware structure of the BIPV system is presented in Fig.2

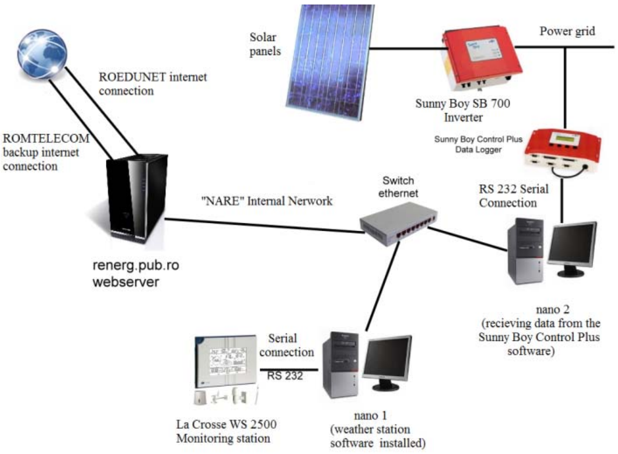

Fig. 2. Hardware structure of the BIPV demo system.

The monitoring equipment, Sunny Boy Control Plus, offers many facilities for storage (up to one year of measurements) and data processing from the inverter. Sunny Boy Control Plus can display the total energy in the network, and the energy that is generated by the solar panels. It can also display the inverter's operating parameters in real time.

3.1.2 The hardware structure of the methodological parameters monitoring station

The station that is used to measure the meteorological parameters is a commercial one, called LaCrosse WS2500 Weather Station. The basic package contains six external sensors for wind (speed and direction), temperature, humidity, atmospheric pressure, solar radiation and precipitation and two more internal sensors that measure temperature and humidity in the room where the weather station is installed. The data are read from the sensors every 5 minutes. The sensors are installed on an outside terrace, at a distance of about 5 m from the laboratory.

The solar radiation flux and the sunshine duration are recorded by another sensor. The measurement units for the solar radiation flow are klux and the sunshine duration is measured in hours. The brightness sensor detects the brightness at the current location in a range between 0 and 200 klux. It is supplied by an integral solar cell

3.2 Software structure

One of the notable things is the fact that we have used almost entirely an open-source software to achieve the monitoring system, the only exception being the software for communication - data logger that has been provided by the equipment manufacturer (SMA America). This approach determined zero cost for the software used in the monitoring system. For data storage, we have used a MySQL database distributed on three computers for redundancy, any change made by one computer in the database is replicated by the other two computers. The database's structure is created, so that queries and data processing take place as soon as possible. Thus, we must create a separate table with PV parameters (named: parameters __PV_ [month] _ [year]) and meteorological parameters (named meteo_parameter [month] _ [year]) measured each month.

In the case that the MySQL renerg.pub.ro server is overloaded, it can redirect its query to another computer. Data processing uses multiple PHP scripts running on the renerg.pub.ro server to meet the user's requests. The result, once obtained, is stored in a cache in order not to perform the same calculations again. A script is also used to run periodically (currently set to run every hour), designed to maintain data consistency and to eliminate the situations in which sensor data are erroneous.

The computer connected to the data logger also lays a script that continuously monitors changes in the data file of the monitoring software provided by SMA-America and introduces changes to this file in the MySQL database.

Graphs are automatically generated at the user's request, through a PHP script that uses the GDI library of the image processing. The operating principle of the monitoring system is shown in Fig. 3.

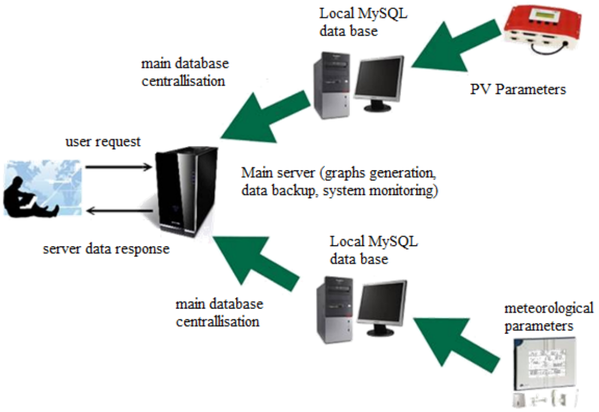

Fig 3. The operating principle of the monitoring system.

The software used is SMA Data Control and it uses a computer's serial port to connect the Sunny Boy Control Plus. It allows for the managing of several monitoring equipment Sunny Boy Control Plus, and their organization and network connected inverters. An Apache web server is also integrated in the software, allowing protected access from any computer on data gathered by Sunny Boy Control Plus and integration project website.

Data collected SMA Control Data can be exported to Excel for more detailed processing. Communication protocol used by the Sunny Boy Control Plus (SBCP) is SMA-NET and it can be implemented by any application that would take data directly from SBCP. Monitoring software allows data logging weather station forecast for any period of time and it can generate graphs according to any parameters desired by the user. It accesses the weather station to retrieve data through a serial connection. The time that is taken from the station data can be set for 3-30 minutes. The data are stored in a binary file's internal software, but they can be exported in a format familiar to any data processing. It is also possible to automatically generate the graphics for a certain period of time.

The monitoring software of the BIPV system and the monitoring system of the meteorological parameters are united through a specialized script for the purpose of the detailed analysis of the influence of meteorological factors on the performance of the photovoltaic system.

4. Influence of the meteorological parameters: experimental and simulated results

The combined monitoring system allows us to analyse the influence of every meteorological parameter measured by the weather station on the performance of the photovoltaic system, allowing us to compare data and to implement modelling and simulation software.

The meteorological parameter with the greatest influence on the BIPV system's performance is the solar radiation, whilst the other analysed parameters have not shown a determinant influence. Thus, in order to develop a forecasting model for the implemented BIPV system performance, we have applied different solar radiation forecasting models on our existing meteorological parameter database.

4.1 Building a database for forecasting and validation

With the above-mentioned technical resources, we gathered data regarding the Brightness (using the meteorological station) and the system performances, in terms of Pac – instant power generated (from the Sunny Boy controller), for a period of three days (for the forecasting process) and two more days for validation of the results. The period used is 14.06.2012 to 18.06.2012. Fig. 4 presents a graph, which illustrates the evolution of both Pac and brightness parameters during one day from the chosen interval.

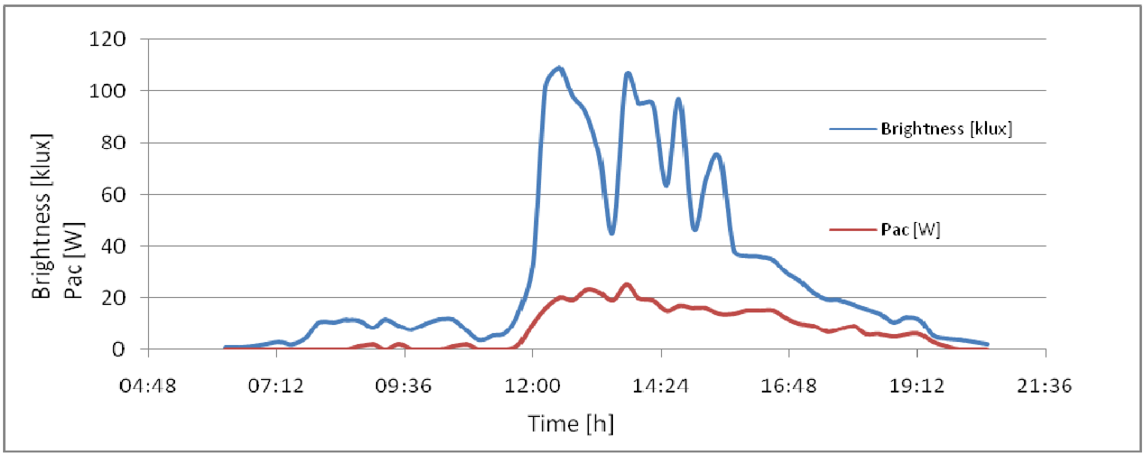

Fig.4. The evolution of Pac and brightness parameters on 14.06.2012

From the analized comparison (data gathered every 15 minutes), it can be observed that values for Pac decrease unexpectedly in the second part of the day. These results are due to:

- The PV window is faced **east,** so the most direct sunlight is during the morning time.
- The system is shaded in the afternoon, due to the building's architecture.

4.2 Short-term solar irradiation forecast by the statistical method of ARIMA

The Autoregressive Integrated Moving Average - ARIMA (1,0,0)(1,1,0) model was used in order to forecast solar radiation The input datasets for the model contain 3 days of hourly brightness data measured at the investigated area for the period of 13. 06.2012 –15. 06.2012, at the location of the analysed BIPV system. The forecast period consists in the next 3 days, with the same temporal resolution (hourly): 16.06.2012 –18.06.2012. The verification of the forecasted values are evaluated based on the measured data in the given period (the data are available only to 12:00 p.m. in the case of 18. 06.2012).

Fig. 5 represents the fitting of ARIMA forecasted and measured data for the period of 16.06.2012 –18.06.2012. The verification of forecast is quantified by MAE and RMSE: MAE = 9.77 klux, RMSE = 17.28 klux.

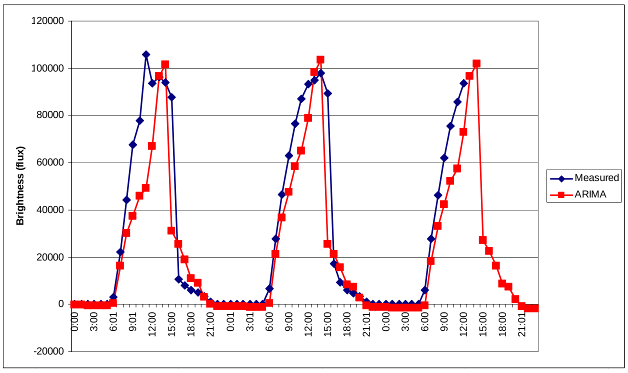

Fig. 5 Fitting of ARIMA forecasted and measured data.

4.3 Short-term solar irradiation forecast by artificial neural network techniques

In order to enhance the forecasts of solar irradiation, different Artificial Neural Network (ANN) techniques are also evaluated (based on 5 meteorological variables: air temperature, relative humidity, atmospheric pressure, wind speed and sunshine duration) [7-8], where the effect of each above-mentioned meteorological parameters as input variables are considered[9-10].

As a consequence the input parameters of the model were measured for 3 days at an interval of 15 minutes. Brightness data were completed with the other 5 parameters(temperature, relative humidity, atmospheric pressure, wind speed and sunshine duration), measured simultaneously at the investigated area, for the period of 13.06.2012 –15. 06.2012. The forecast period is the following after the measurements (16. 06.2012), with the same temporal resolution (15 min).

Fig.6 presents the fitting of ANN forecasted and measured data for the period of 16. 06.2012. The verification of forecast is quantified by MAE (Mean Absolute Error) and RMSE (Root Mean Squared Error): MAE = 7.96klux, RMSE = 13,879 klux.

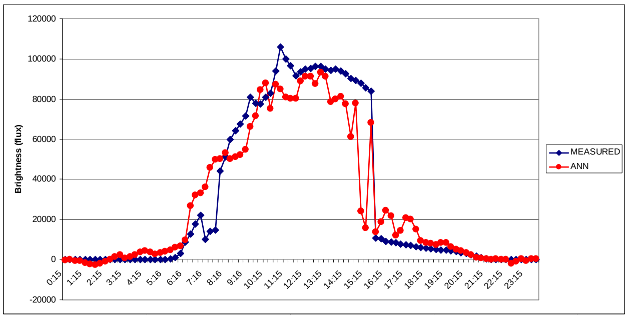

Fig.6. Fitting of ANN forecasted and measured data

4.4 Comparison between simulated and experimental data – validation of the model

The statistical relationship between the global radiation and the electricity production is determined by taking into account the technical parameters of the system. The dependence between the available radiation and the produced power was based on the experimental data gathered within the 3-days acquisition period for testing. It was determined using discrete transformation coefficients (for point-to point forecast) and specialized “Origin” software for the evaluation of the curve equations while fitting with the forecasted data process. The percentage of efficiency loss, due to the bad positioning of the system (facing east, $90s^0$ tilt angle and shading elements) of 56,5%, was taken into consideration. The forecasted values for Pac were compared to the ones measured for validation (Fig.7)

The calculated error for 17.06.2012, between the forecasted and measured values for Pac, based on ANN model is 8.8 %, a good percentage concerning the unforeseeable weather conditions [11]. The trend lines put in evidence are that both sets of values follow the same tendency, with regard to the major decrease in efficiency of the BIPV system.

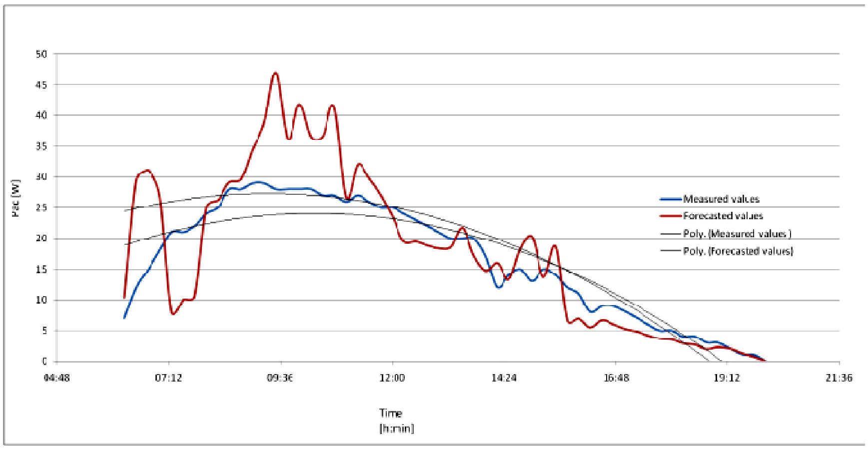

Fig.7. Comparison between forecasted and measured values for Pac on 17.06.2012.

5. Conclusions

The article presented the obtained results by the development of a modelling and simulation platform for BIPV systems. On this basis, the influence of the meteorological parameters on the BIPV system’s performance is possible to be studied.

A database for irradiation forecasting and experimental validation was created.

Short-term solar forecasts by the statistical method of ARIMA, as well as by ANN techniques were implemented. With an error percentage under 10%, the results obtained in this paper represent the first step in building a specialized software for short-term forecasting of a photovoltaic system production. Such software would be very useful and will meet perfectly the present Romanian legislation for on-grid solar systems.

In the future, the BIPV simulation platform could allow the analysis of the introduction of new types of advanced solar cells (MQW, QD, organic, etc.) for PV systems [12-14].

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