Intelligent Approach for Improvement of BIPV Systems Performance: Case Study

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Abstract. Building-integrated photovoltaics (BIPV) allows incorporating the photovoltaic panels in the roof, windows or facades of buildings in order to increase their energy performance. The authors considered the intelligent MPPT (Maximum Power Point Tracking) method in order to increase the BIPV efficiency for complex urban areas. A BIPV case study is analysed to establish optimize power and conversion efficiency for a residential construction featured by an installed capacity of 30 kW. A numerical modelling developed on MATLAB/Simulink and Excel working environment is introduced; the input data are obtained from Energy Plus software. This approach allows putting in evidence the resulted energy gain using the MPPT algorithm in real conditions for PV panels, especially due to increased shading.

1. Introduction
Nowadays distributed photovoltaic systems that provide electricity for buildings are considered as mature technology and are integrated in the buildings (BIPV systems) [1-6]. They provide saving in materials and electricity costs and add an architectural interest to the buildings [7, 8].

Building-Integrated Photovoltaic (BIPV) is a smart energy production system that incorporates solar PV panels as part of the roof, windows, facades and shading devices; various applications of BIPV are described forward [9-11]. Although BIPV systems represent now a niche technology they could developed impressively in the future. An important potential for them could be represented by the Nearly Zero Energy Building concept (nZEB).

Skylight structures [12] are considered to be ones of the most interesting applications of BIPV systems (see figure 1). In this case, PV elements provide both electricity and light to the building. The PV modules and support structures used are similar to those used in glass facades. These structures allow a stimulating architectural design of light and shadow.

Shading Systems [13] are characterized by BIPV modules of different shapes to be used as shading elements above windows. Such systems use one-way trackers to tilt the PV array for maximum power while providing a variable degree of shading.

An example of such shading systems is presented in figure 2.
BIPV Solar Facades [14] are of different types. Some of them are made from brickwork or stonework, other are curtain walling and precast concrete panels and other ones are tiles and stone veneer panels. The maintenance is essentially for such BIPV solar facades (see figure 3).

BIPV In-Roof Systems [15] are suited for BIPV integration in building roofs; usually there is less shadowing at roof than at ground level and we could obtain more power in this way. At the same time roofs could provide a large and unused surface for integration. That is why the conversion efficiency of BIPV in-roof system could be increased (see figure 4).

The main objective of this paper is to analyse a specific BIPV system for a complex residential building by numerical modelling. Using specialized simulation software, we could evaluate the influence of shading on BIPV performance: 1) using MATLAB/Simulink software [16-19] applied for a PV module; it will be established that temperature and solar irradiance could significantly influence the efficiency of the BIPV system, 2) for shading simulated conditions – there are two major causes that could determine the inaccuracy of the results without MPPT algorithm compared with the case with MPPT approach. Therefore, it would be possible to consider an operational optimization of the BIPV system using controller based on MPPT method.

2. Background: MPPT techniques for BIPV systems.
The non-linear I-V characteristic curve for a PV panel allows an unequal power distribution during its operation. Figure 5 shows the relationship between power, voltage and current for a PV panel. It can be
noticed that there is a point associated with certain values of voltage and current that have the highest value of power [20, 21].

When the PV panel corresponds to the maximum power point, its available maximum power \( (P_{\text{max}}) \) is provided. The values of the current and voltage at the Maximum Power Point are called the maximum power point current \( (I_{\text{mpp}}) \) and the maximum power point voltage \( (V_{\text{mpp}}) \). When operating conditions such as temperature and solar irradiance change, the \( P_{\text{max}}, V_{\text{mpp}} \) and \( I_{\text{mpp}} \) values change as well. We have considered Maximum Power Point Tracking techniques (MPPT) that are algorithms to find the maximum power point in any operating state of the PV panel/system. The output signal of the controller is directed to a modulation technique called Pulse Width Modulation (PWM), which generates control pulses that allow the system to operate at the maximum values [22, 23].

![Figure 5. The I-V and P-V characteristics for a PV panel, highlighting MPPT algorithm [17].](image)

### 3. PV generator characterization. Case study of a BIPV system

#### 3.1. PV generator
The analysed PV generator to be considered for numerical modelling/simulation is characterized by an array of connected PV modules based on SUNTECH polycrystalline silicon cells. The MATLAB/Simulink library software is used for its implementation and simulation. Solar irradiance was considered for three cases: 1) 30\% shading of PV array; 2) 40\% shading and 3) 50\% shading (corresponding to an average day in terms of solar irradiance over a year).

The characteristics and performance of the PV generator are analysed for a temperature range between 15-85 °C (see Figures 6a and 6b). At the same time the characteristics and performance of the PV generator are analysed from the point of view of solar irradiance in the range 100 -1000 W/m² (see figures 7a and 7b).

#### 3.2. BIPV system
It is considered a specific case study for BIPV complex residential building system of 30 kW power, placed in the Bucharest, urban area, Romania. The input data of the BIPV system are presented in table 1. This BIPV system was analysed in order to establish an optimized tool for its pre-dimensioning. In the next chapter the results of simulation based on MATLAB/Simulink software and a numerical modelling environment constituted from Energy Plus and Excel are presented.
4. Results and discussion on performance of the BIPV system

In order to establish an advanced design of BIPV systems it was developed numerical modelling of such systems based on the following approaches: 1) influence of shading on BIPV system and 2) application of an advanced method based on MPPT algorithm.

4.1. Conventional approach of PV modules shading

The power of the photovoltaic generator (totalling the 120 PV modules) was obtained by numerical modelling for a period of three days. It was analysed the power of the studied BIPV system (generated...
power of 30 kW) from the point of view of PV modules for different degrees of shading in three operation cases, respectively: 50%, 40% and 30% (see figure 8). As expected, the power variation is most strongly affected by 50% shading; in this case, an optimized operation of BIPV system is obtained at a power of 12kW.

Below the 50% BIPV shading, the performance of the system is drastically decreasing, making it virtually impossible to apply any optimization method. The authors have chosen the value of 30% shading in order to obtain an improved performance of the BIPV system.

![Figure 8. Generated Power system for different degrees of shading operation, conventional approach](image)

**4.2. Advanced approach of PV modules shading using MPPT algorithm.**

The analysis was further focused on the decomposition of the diagram of generated power system from figure 8 for three degrees of shading; for each case, the MPPT algorithm is applied in order to improve the operational optimization of the studied BIPV system.

![Figure 9. Generated Power system for 50% shading operation, MPPT approach](image)
The power variation of the BIPV system for a 50% shading degree is shown in figure 9. The generated power is indicated by blue line in the case without MPPT and by orange line in the case with MPPT. It is remarked a power gain of 4 kW when MPPT algorithm is considered. By this approach an optimized power value of 16 kW is obtained.

Figure 10 shows the operation of the BIPV system for a shading degree of 40%. It is noted that although the BIPV power does not exceed 19 kW compared to the proposed target of 30 kW, there is an improvement in the case of operation with MPPT (a power gain of about 6 kW is reached) compared with the case without MPPT. However, the shading still remains a factor in reducing of the BIPV system efficiency.

![Generated Power system for 40% shading operation, MPPT approach](image)

Figure 10. Generated Power system for 40% shading operation, MPPT approach

Figure 11 is characterized by the smallest shading degree (30%) from the three analysed cases. It is noticeable that the BIPV system has an important improvement for the both situations (operation without MPPT- represented by black line, and operation with MPPT - represented by the orange line). The maximum power obtained with the MPPT controller could manage and optimize the system at a level of power of 29 kW, a value very close to the target of 30 kW for the studied BIPV system (a power gain of about 9 kW is reached in the MPPT operation).

The authors believe that this value indicates a feasible approximation to be used in pre-dimensioning of a real BIPV structure.

For a clearer understanding of the method based on the MPPT controller, the influence of the method on the performance of the BIPV is represented in figure 12. It is noted that the use of the MPPT algorithm is a complementary method for achieving a gain over the entire duration of the simulation, represented by a sunny day. This is all the more relevant in the Near Zero Energy Buildings (nZEB) when it is necessary to extract all production capacity of the BIPV system.
Figure 11. Generated Power system for 30% shading operation, MPPT approach

Figure 12. The performance of the BIPV system using MPPT approach

Modelling and simulation of the analysed BIPV system is completed by determining its efficiency with respect to the electrical consumer. It is noted that the use of the MPPT algorithm leads to a security of power supply of the electric consumer and to a system stabilization. Figure 13 shows the efficiency of the BIPV system in relation to the electrical consumer.
5. Conclusions
The authors proposed a method for optimizing a BIPV system that uses the MPPT controller in order to improve its overall efficiency. It was considered a complex application characterized by a residential building.

The influence of the degree of shading on the generated power (PV), respectively on performance of the BIPV system was analysed. The minimum degree of shading has been determined for operational optimization of BIPV system operation, which is possible only using the MPPT method (the conventional approach not meeting this objective).

The analysis allows for a right pre-dimensioning of BIPV systems that can be applied to all types of BIPV applications on the building market. The method can be extended for hybrid PV systems (PV wind, PV diesel, etc.) as well as for thermo-photovoltaic systems (BIPVT).

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