An Outdoor Demonstrator of Building-Integrated Photovoltaics Applying Wireless Power Transfer

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***Abstract*—In building-integrated photovoltaics, solar panels function as structural elements of the building. However, electrical cables from the solar cells to the inside of the building penetrate the thermal envelope and can create thermal bridges and moisture issues. A possible solution might be applying wireless power transfer. In this work, an outdoor demonstrator of building-integrated photovoltaics that uses wireless power to transfer the energy is presented. It consists of a stand-alone housing, mimicking a facade configuration with vertical solar modules. By means of converters and vertical coils inside the structure, inductive coupling is applied to realize the energy transport. A setup has been constructed to log real-time field measurements and to study the influence of different insulation media on the performance.**

***Index Terms*—BIPV, wireless power transfer, energy conversion, photovoltaic energy**

I. INTRODUCTION

In building-integrated photovoltaics (BIPV) projects, the photovoltaic solar modules are an integral part of the building itself. The solar cells replace or are embedded in building components. For example, the integrated solar panels can act as roof, curtain walls, building facades, or are part of windows and skylights. These BIPV elements do not only provide electricity, but also function as structural element of the building. In other words, contrary to typical solar modules, detaching the photovoltaic part would require that it be replaced by a corresponding conventional building element in order to maintain the building envelope.

By serving two functions, BIPV elements can provide a significant decrease in material and electricity cost [1], [2]. They are in particular suitable for high-density urban areas, where the lack of area to install typical photovoltaic panels can be compensated by BIPV into facades and windows. Indeed, in tall buildings, the roof often serves as a location for the heating, ventilation and air conditioning equipment, making it unsuitable for solar cell modules [3]. As a result, the facade area becomes a viable option to use as area for photovoltaic generation. Moreover, the taller the building, the more facade area is available for BIPV, and the less shade is present from neighboring buildings, increasing the performance of BIPV [3]. In fact, about 50% of the BIPV systems are embedded in curtain walls [1], encouraged in many regions by government support, e.g., within the European Union to strive for energy-neutral offices [4].

As a result, the compound annual growth rate of BIPV globally is impressive, reaching about 40% in the last decade [5]. The total installed BIPV capacity increased sixfold in only 5 year, from 1.5 GW in 2014 to 8.8 GW in 2019 [1]. Projections estimate that the trend will continue in the next decade [5].

Fig. 1. Housing of the BIPV demonstrator: power generated by the vertical photovoltaic panel is transferred wirelessly via coupled coils to a load inside the housing. The roof solar panel is aesthetic and not electrically connected.

The practical use and installation of BIPV modules has some disadvantages [6], [7] which wireless power transfer (WPT) might solve or mitigate [8]–[10]. The electrical power generated by the solar panels must be transported into the building via electrical cables. These connections penetrate the thermal envelope of the building, which deteriorates one of the main functions of the BIPV elements: to protect the inside environment from the variable outside weather elements. The use of electric cables results in the creation of unavoidable thermal bridges, loss in air tightness of the indoor environment and undesirable heat losses or gains. Moreover, the required perforation of electrical cables can cause water ingress and condensation, This can lead to mold formation and moisture problems, resulting in a shorter lifespan of the BIPV system [6], [7].

By transferring the power wirelessly from the outside of the building to the inside, over the thermal envelope, both the thermal and moisture problems can be avoided. Indeed, the protective shell of the building remains intact, since no drill holes for the electric cables are necessary to transfer the energy. An improved indoor environment with less thermal bridges and moisture issues can arise by applying WPT.

Moreover, the use of WPT could have some other advantages. The practical installation of BIPV systems in the field requires collaboration between different professionals, from electricians to construction workers. Specialized (time-consuming) training is necessary, which could hinder the massive deployment of BIPV. The use of easy to install "plug-and-play" elements could facilitate the wide-scale adoption of BIPV [8], [9]. WPT could allow for such elements: modular components, fully embedded in a non-conductive housing, could be easily installed with a minimum of extra education.

Next, since a WPT system would ensure complete galvanic isolation, it could increase safety significantly, by reducing electrocution danger form incorrectly followed installation procedures.

Finally, the use of a micro inverter topology [8] for the converters has some advantages:

- A BIPV system often suffers from partially shaded solar modules, resulting in module mismatching. As a result, the optimal working point of the solar panel connected to the same inverter differs, resulting in an efficiency drop [4], [11]. A WPT solution with a converter installed per module avoids module mismatching and could increase the system efficiency [8].
- The malfunction of one converter would not jeopardize the operation of the entire system due to the galvanic isolation, but only switch off one WPT module.
- Finally, the immediate conversion to high voltage can be an advantage to the performance of the BIPV setup.

Given the possible advantages, it is deemed worthwhile to look into the application of WPT technology into BIPV. To date, the number of studies focused on this subject are sparse. The combination of photovoltaic energy generation and WPT was for example considered in [12] which proposes a modular WPT system with multiple photovoltaic subpanels. A simular study was done by [13] by implementing a photovoltaic battery charger with maximum power point tracking and a WPT interface. In [14], an energy management scheme is presented when solar energy and battery storage are integrated with WPT for emergency electrification. Another example is [15] where WPT is applied on a floating photovolaic solar plant in order to limit electrical hazards and increase the performance by reducing the exposure to humidity and salinity. More specifically aimed towards BIPV, the work [10] simulates the effect of the integration of photovoltaic panels and the corresponding variable irradiance with WPT system.

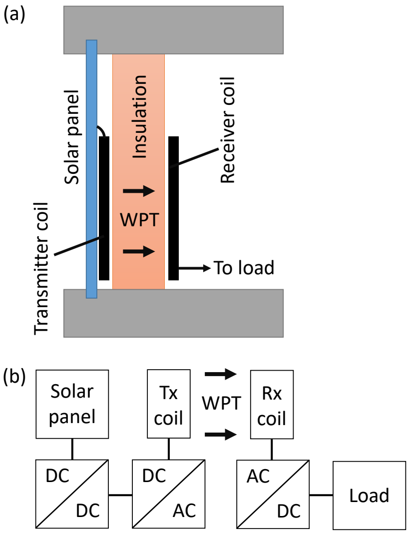

Fig. 2. Conceptual overview of the BIPV demonstrator: (a) Application of WPT in a BIPV curtain wall. (b) Overview of the required conversions for the realization of inductive WPT in the BIPV configuration.

Finally, it should be noted that the implementation of WPT into BIPV also has some drawbacks (e.g., large DC/AC converters), which are described in [8].

In this work, an outdoor BIPV setup has been built, featuring WPT to transfer the energy from the solar panel to the load. Real-time measurements were performed to assess the feasibility of the system. As far as we know, it is the first time a practical BIPV and WPT combined setup has been build and measured in the field. This work is an extension of our earlier work [9] where we limited ourselves to lab environment.

II. SET-UP

The outdoor demonstrator mimics a BIPV configuration for curtain walls: the photovoltaic panel is positioned vertically, similar as on the facade of a building. In order to facilitate access for measurements, and allow for a maximum visibility of the demonstrator to visitors and students, the setup was built as a standalone aluminum housing (Figure 1). One side of the construction consists of an off-the-shelf 180 W monocrystalline solar panel with dimensions 1145 x 840 mm. The demonstrator is located on the campus of the college university Odisee in Aalst, Belgium (coordinates: 50°55’54.3”N; 4°1’20.0”E).

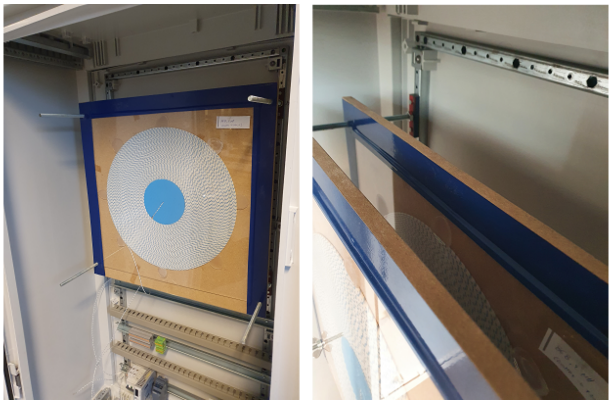

Fig. 3. The coils for the inductive WPT transfer installed in the BIPV housing (left), indicating the easily adjustable distance between transmitter and receiver coil (right).

Within the housing, two identical vertical mounted coils are installed to realize the inductive wireless power transfer (Figures 2a and 3). The planar coils have 35 windings, and were constructed from 0.75 mm^2 (No. 18 AWG) wire. The inner and outer diameter equal 140 mm and 290 mm, respectively, and were chosen to easily fit into a typical BIPV curtain wall [9], [16]. In the relevant frequency range, their inductance and quality factor equal 850 μH and 230, respectively. The setup allows for the easy insertion of insulation material between the coils in order to measure their influence. The distance between the transmitter and receiver coil can be easily adjusted.

Figure 2b illustrates the schematic overview of the realized (frequency) conversions. The DC power from the photovoltaic panel is via an intermediate boost converter (SZ-BT07CCCV Step-up Power Supply Module) converted to AC by a class D driver (LM5104 gate driver connected in synchronous buck configuration) to a frequency of 14.5 kHz in order to realize the WPT transfer. Series resonance in the circuits is created by a capacitor bank at both transmitter and receiver side of 231 nF. MPPT was not implemented. The output power is dissipated in a programmable DC electronic load (BK precision 8502). The input and output current and voltages are measured by an ESP32 module and stored on an SD card.

III. MEASUREMENT RESULTS

During two months (5 Sept. - 17 Nov. 2022), measurement data for the outdoor setup was gathered. Every 10 s, the input and output voltages and currents were measured and stored on the SD card. The measurements exclude the energy consumption of the gate driver and the ESP32 module, which were fed separately via a 12 V supply. The distance between the transmitter and receiver coils was 115 mm during the measurements, with air as medium.

Figure 5 shows the input and output power as function of time for four typical days, from 21st Sept. until 24 Sept. 2022. Due to safety reasons, the input voltage was limited to 40 V, resulting in a maximum output power of about 25 W. The first two days were sunny days, the third day was cloudy and the fourth day, almost no input power was registered since it was a rainy day. Due to the orientation of the outdoor setup, the vertical photovoltaic panel can only receive direct sunlight in the morning until 1:30 PM, which is for example visible in the shard decline of the power on the second day of Figure 5.

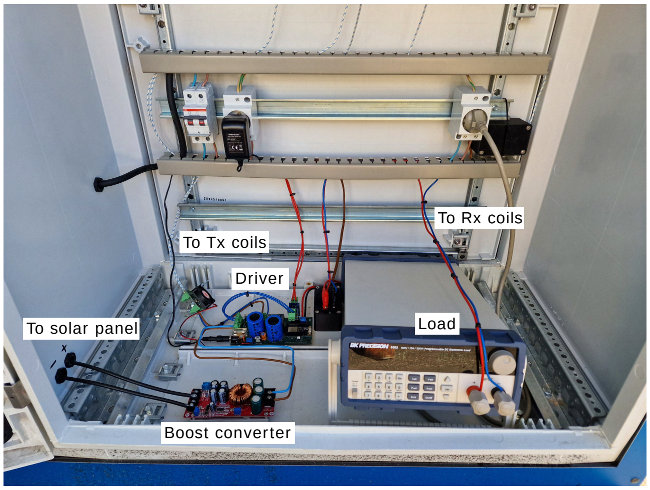

Fig. 4. Overview of the electronics within the BIPV housing.

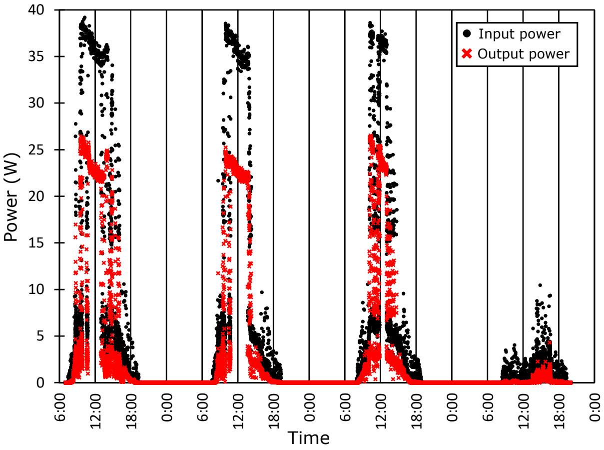

Fig. 5. Input and output power as function of time from 21st Sept. until 24 Sept. 2022.

Figure 6 depicts the efficiency (ratio output to input power) as function of time. Only the first three days (21 Sept. - 23 Sept.) are shown since almost no power was registered for the rainy day. It can be seen that consistently an efficiency of 60% is achieved during periods of high power transfer. Higher efficiencies were only recorded in phases with low power transfer.

Finally, preliminary measurements with typical insulation materials were performed: the power transfer was determined for configurations with different media between the transmitter and receiver coil, for a distance of 115 mm between the coils. The following thermal insulation materials were used as medium: rockwool, expanded polystyrene boards (EPS) and polyisocyanurate (PIR). The last one has a reflective aluminum foil.

Measurements were performed for a connected load value of 100 Ω. The input and output voltages were measured for the different media, for an imposed input voltage at the transmitter of 40 V. With air as medium, this results into an output power of 25 W at 69% efficiency.

As was to be expected, no significant difference was detected for the performance of the system with rockwool (10 cm thickness) or EPS plates (8 cm thickness). Indeed, no conductive materials are present to interfere with the magnetic fields. However, if PIR is inserted between the coils, the efficiency drops to 2 and 0.1% for layers of 4 and 8 cm, respectively. This is entirely due to the presence of the conductive aluminum foil, preventing the magnetic fields to transfer energy.

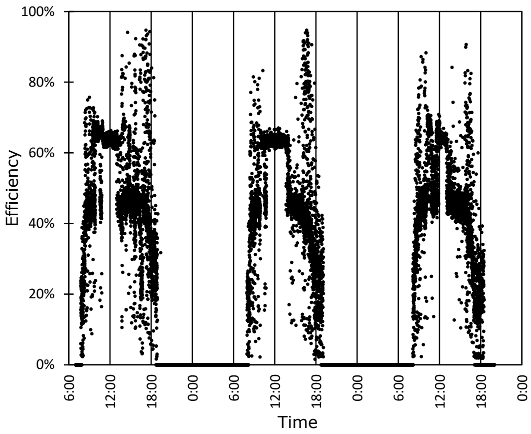

Fig. 6. Efficiency as function of time from 21st Sept. until 23 Sept. 2022.

IV. CONCLUSION

For the first time, an outdoor demonstrator of building-integrated photovoltaics has been built, implementing inductive WPT to transfer the energy over the thermal envelope of a building: from the solar panel outside the construction to the load inside. The configuration allows for the real-time logging and storing of the input and output voltages and currents. In time, these real-time measurements could allow to assess the feasibility of the system. Moreover, the demonstrator allows for the possibility to study the influence of different insulation media between the coils on the performance.

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