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Multifunctional Integrated Photovoltaic Window with advanced features of Energy Harvesting and Indoor Shading control: Hardware implementation

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Abstract – **The aim of this paper is to present the concept of the photovoltaic window (PVW) that uses PV cells on each element of the window blind. The window blind will be mounted inside of the window. The PVW potential to generate energy is up to 100 W/m^2. The preliminary tests show that this is possible to obtain this power based on advanced Maximum Power Point Tracking (MPPT) algorithm. The Multifunctional Integrated PVW (MIPVW) solution proposed here can control the entry of natural light as well. Furthermore, the MIPVW maintains the thermal and acoustic insulation features of the initial window. The goal of this paper is to shown the design of MIPVW concept.**

Keywords-energy harvesting, solar shading, photovoltaic windows

I. Introduction

The structure of our society is energy depended, we need energy to cook our food, to move us around, to keep us worm and ultimately to maintain our way of life. With this in mind researchers have looked to find new ways to power our world, but for now the ultimate power solution still elude us.

Solar energy has no territorial restrictions, so it will be widely used because it is an emerging green energy resource that has a price which continues to drop each year.

Building-integrated photovoltaics (BIPV) represent an application of the solar energy, where photovoltaic materials that are used have the essential role to replace conventional building materials in parts of the building envelope such as the roof, skylights, or facades. They combine solar cells with slate, metal, fiber-cement, even asphalt roofing [1].

Different types of PV windows are implemented (being available in the market: solar shingles, glazing windows, pitched roofs, and facades), but each has some disadvantages related to free view and indoor comfort [2].

- Solar shingles are also known as photovoltaic shingles. They are conventional asphalt shingles which have a laminated semiconductor layer composed of crystalline silicon that generates electricity when they are illuminated. That means that they have an additional layer that converts light into energy [3]. The advantages of solar shingles are: they provide clean energy, they are practically invisible, the excess energy can be sold and can benefit from tax incentives, and they are very resistant and increase the value of the home. Some disadvantages include: the cost of installation, inability to store the energy, may require building modifications if the roof isn't properly aligned with the sun, require the rebuilding of the roof, unlike solar panels which can be mounted on top.

- Window glazing implies applying a thin see-through material on windows in order to form a monolithic solar cell structure that you can see through. These structures will operate at the efficiency of solar panels. The advantages include reduced external noise, reflection of UV rays and resistance to impact. The disadvantages are: the position of the windows, relative to sunlight exposure, lower sunlight exposure than roof-mounted solar panels and inability to store the energy [4].

- Pitched roofs are a more efficient way to capture solar energy, using solar panels or solar shingles. However, it is often difficult to integrate solar energy features on existing roofs which do not have the required pitch or angle towards the sun. Some structural changes are usually required, which increases the cost of the procedure [5].

- Solar facades implement the same idea behind glazing windows, but applied to the entire building facade. This can only be implemented in areas where the building facade is not obstructed by neighboring buildings, in order to have enough sunlight. As with pitched roofs, heavy structural modifications are required and the installation costs are significantly increased [6].

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As the investments on advanced PV glazing windows are still expensive (besides the disadvantages mentioned that will be partially solved using advanced PV technologies), the main goal for the Multifunctional Integrated PV Window (MIPVW) proposed here is to harvest the maximum energy available based on advanced Maximum Power Point Tracking (MPPT) technique (which will be the challenge for next paper). Thus, every PV window will operate efficiently using an appropriate energy harvesting technique based on a MPPT control technique proposed by CO and P1. Since the operating point of the PV window mainly depends on the load power dynamic, irradiance and temperature, the PV window must have, in addition, at least an Energy Storage System (ESS) to assure the balance of the power flow on the DC bus [7]. It is obviously that a MPPT control will improve the PV window efficiency.

II. Design of a Multifunctional Integrated Photovoltaic Window

Multifunctional Integrated Photovoltaic Windows consists of the following blocks:

- The actual photovoltaic blind consisting of photovoltaic cells ;

- Photoresistor used to retrieve data about the solar irradiance on the blind surface;

- The temperature sensor is used for reading information about the temperature value at the surface of photovoltaic blind;

- Block driver for stepper motor control to implement the sun search algorithm;

- DC-DC converter connected to the output of photovoltaic blind to implement the MPP tracking algorithm

- Acquisition block for open circuit voltage and short circuit current of the photovoltaic blind.

- Transmission module: All the acquired data will be serially transmitted (RS232) to the Computer.

- Energy management unit

General block diagram is shown in Figure 1.

A. The PV window

The PV window consists of 36 photovoltaic solar cell type CIS Cells manufactured by Shell Solar 0.25 [9] each cell with the following parameters:

• 60mm x 60mm, 2mm;

• 5V voltage empty.

• 100mA short - circuit current.

• Maximum power 0.25W (80mA, 3.2V) .

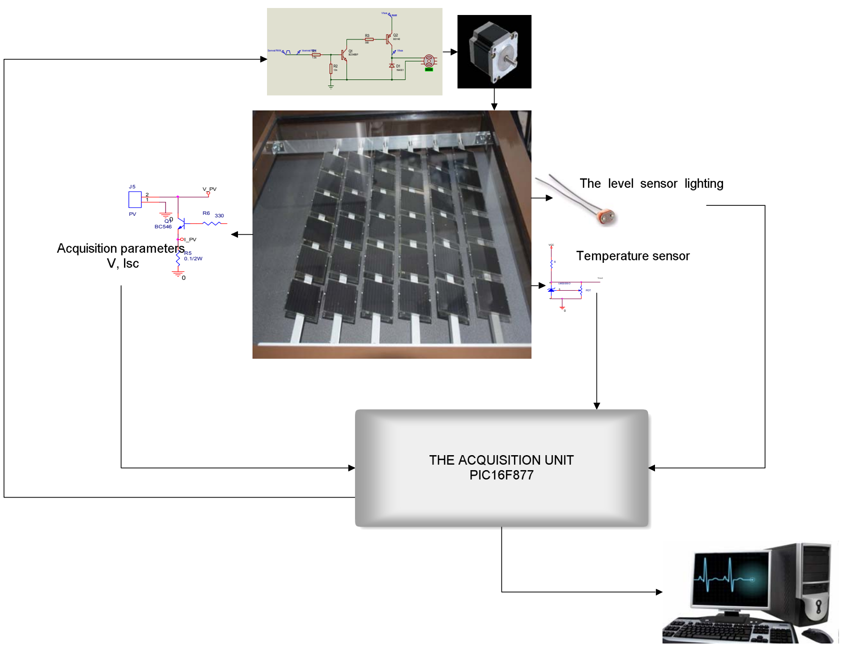

Figure 1. Bloc diagram of the Multifunctional Integrated Photovoltaic Window

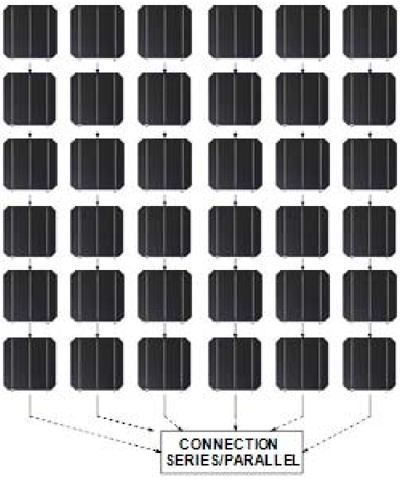

Figure 2. Photovoltaic curtain

These photovoltaic cells are connected in series, and series 6 are connected in parallel to the final output. At the same time there is the possibility that the six series to be connected in any configuration (series or parallel), through a block of connectors, depending on what we want to get to the exit of the curtain.

B. Block-level lighting and temperature sensors

To find out the level of illumination of the photovoltaic panel we used as a photoresist sensor VT90N2[10].

Parameters of Photoresistor are:

- Power consumption - 80mW;

- Resistance value at darkness - 100KΩ;

- The maximum amount of light resistance - 220Ω.

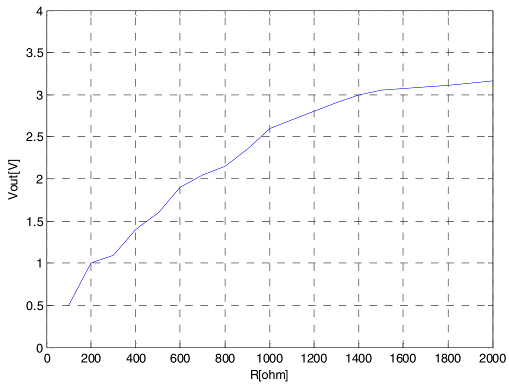

Figure 3. The response of VT90N2[12]

The temperature sensor used is LM335 integrated circuit. This sensor provides a voltage directly proportional to the ambient temperature measurement is mad temperature conversion function circuit LM335 voltage is linear, with a positive gap 10mV / K .

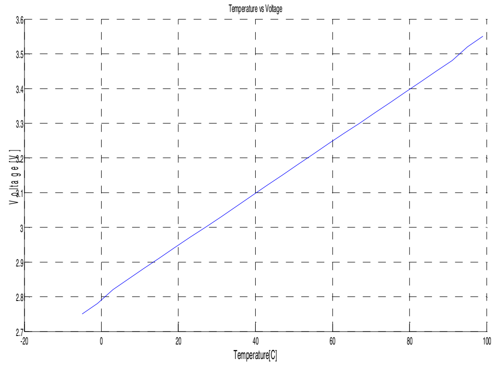

Figure 4. The response of the LM335[11]

The acquisition voltage from PV panel is via a resistive divider dimensioned so that the maximum voltage from 30V to achieve maximum PV blind at the entrance 5V microcontroller. Short-circuit current value is read from a resistor connected between terminal are "minus" to the blind and meals.

Blind control bar orientation is controlled by a stepper motor connected through a clutch mechanism. The stepper motor connected to photovoltaic blind mechanism allows shareholders. Driver stepper motor control is achieved with discrete circuits. It consists of four identical circuits, each commanding one phase.

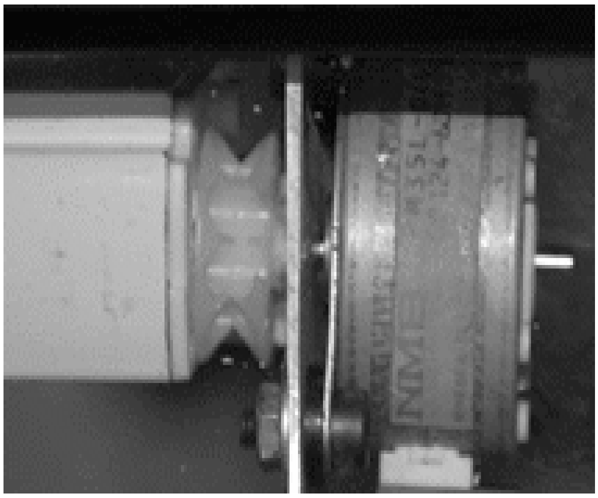

Figure 5. Driver stepper motor control

The stepper motor can be ordered both in a sense and in another sense. He is the type NMB PM35L with following parameters [12]

- 7.56 ° step angle;

Standard PM Step Motors PM35L-048-HHC7

Step Angle: 7.5°

Wire Length: 300mm fly lead (no connector)

Wire Holder: 90 deg. Left

Electrical: 24V, 600mA bipolar Constant Current

- Rphase = 15Ω;

- Current 600mA/phase;

- Frequency steps [100-800] pps;

C. Block acquisition, command and control

Block acquisition is accomplished with the microcontroller PIC 16F877A. Role is to purchase information from: temperature sensor and the level of enlightenment, the open circuit voltage, short-circuit current and voltage at the output of the dc- dc converter type. At the same time this block realizes the PWM converter command, and displaying the results on a LCD display and its transmission to PC. If you want to test different control algorithms, these will be implemented with the help of block acquisition, command and control and dc-dc converter.

Also this block performs and PWM control of the dc-dc converter, as well fastenings on display the results of an LCD display and transmit them to your PC. In the case in which we want to test different control algorithms, they will be set up along with the aid of the purchase block, command and control of the DC-DC converter.

III. THE CONCEPT OF MULTIFUNCTIONAL INTEGRATED PHOTOVOLTAIC WINDOW

The MIPVW design will be based on a PVW constructive solution that will have in comparison with the basic PVW some advanced features related to: (1) mechanical action of the window blind; (2) energy efficiency of the window blind that will track the sun through a micro-motor; (3) the energy harvested from the PVW based on advanced MPPT algorithms; (4) energy efficiency based on the use of the micro-inverter integrated on each PVW; (5) use of a friendly remote to command the indoor shading. Thus, the possibility to easy change an existing window (insulated or not) with one that will generate green energy at minimal investing cost will be a challenge for the designers. Note that the Energy Return on Investment indicator is of 3 years based on the initial feasibility study. So, the MIPVW proposed here may be a successful innovative product, which is different to other market solutions such as solar shingles, glazing windows, pitched roofs, and facades, but it can be used for these, too. The MIPVW proposed here can be easy integrated into day-lighting strategies or used as a curtain wall, offering view glass if is required. It is known that the window glazing affects not only the air-conditioning load in a building, but also thermal and visual comfort. Also, it is known that a vertical southward facing PV module will generate about 30% less power than a PV panel at the optimal orientation (i.e., about 40 degrees above the horizontal and facing due south). Thus, the sun-search-mode will solve this issue, offering the optimal energy harvesting solution.

The following improvements can be mentioned in comparison with the basic PVW:

(1) Mechanical improvements:

- Simplification of the action mechanism for the window blind;

- Improvement of the energy collectors and connectors;

(2) Electrical improvements:

- The use of an efficient PV film to obtain about 100 W/m2;

- The use of an electrical action for the window blind;

(3) Electronic improvement:

- The use of a MPPT controller to maximize the energy harvested from the PVW;

- The use of micro-inverter integrated into a PVW;

- The use of the remote control circuit to command the window blind for indoor comfort (the indoor shading feature requested by user) or for energy harvesting (the sun-search feature).

Thus, the innovative software programs for the above mentioned features of MIPVW will be implemented:

- The advanced Extremum Seeking Control (aESC) algorithm will be implemented in a cheaper microcontroller, instead of a DSP microcontroller, based a new proposal shown in [8].

- The indoor shading algorithm will set the angle of the PV window blind at user request

- The sun-search feature algorithm will automatically set the angle of the PVW that will not have indoor shading constrains.

- The user interface algorithm will set friendly all the features. .

The experimental model of the MIPVW will be implemented and tested to evaluate its preliminary performances.

IV. EXPERIMENTAL RESULTS

The 6 photovoltaic cells are connected in each series, and all series are connected in parallel to the MIPVW output. Also there is the possibility that the 6 series to be connected in any configuration (series or parallel) through a block of connectors, depending on what we want to get from blind to the MIPVW output.

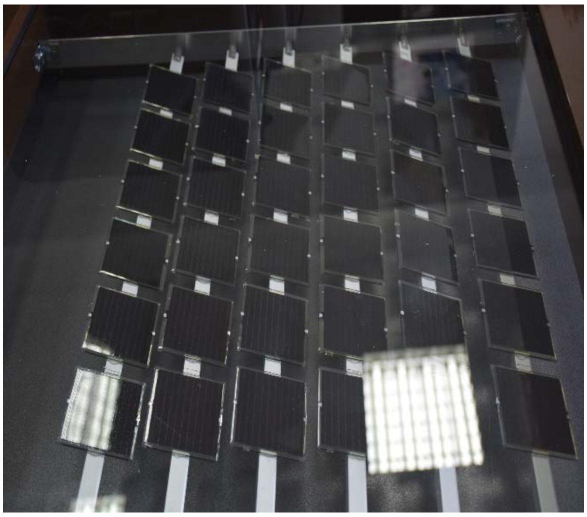

Figure 6. The MIPVW – 6 solar cells are mounted in each series

Figure 7. The MIPVW – control and data acquisition equipment

In the initial phase, different lighting conditions are used to test the MIPVW functionality, from uniform irradiance for all PV cells to partial shading conditions for different PV cells.

The shading effect on MIPVW (when are covered cells connected in series or parallel) is presented in Figures 8, 9, and 10. The measurements have been acquired for each condition mentioned in each Figure, and the experimental results are shown in following charts (Figures 8, 9, and 10):

Figure 8. PV voltage charts depending on series shaded

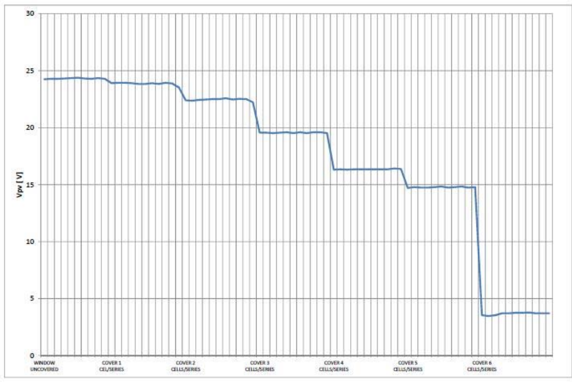

Figure 9. PV voltage charts according to cells shaded into a series

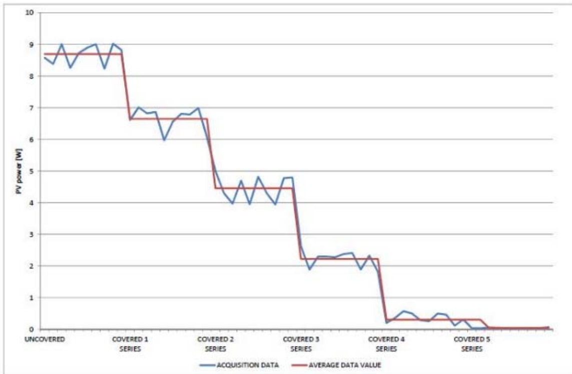

Figure 10. Power of the MIPVW with fixed resistance load depending on series shaded

Measurements validate the MIPVW operation for all its parts. Also, the graphs results are in accordance with the mathematical models existing for the photovoltaic panels in literature.

Acknowledge. The authors thank to Professor Nicu Bizon for his advices and permission to implement the aESC [8] in MIPVW.

V. CONCLUSION

- Energy generated will be with at lest 20% higher than that generated by a glazing PV widow (which use the same PV cells or thin film, but it is vertical fixed) based on the sun-search feature.

- Energy efficiency will be higher than 99.5% (which is reporter in data sheet for all PV inverter systems) based on use the micro-inverter solution and optimal management implemented for multi-MIPVWs;

- Flexibility in use is based on the green energy feature that will be implemented (remote control of each PV window to set independently the indoor shading feature or sun-search mode);

- The practical use as power hybrid source (which will use at a Energy Storage System) or back-up lighting system during the night or emergency cases based on energy management unit implemented.

- Friendly user interface algorithm for the local and remote control panel may be easy implemented.

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