ELECTRICAL BEHAVIOR OF A DOUBLE SIDED PV SOLAR PANEL

Authors: Ganescu, V., PhD, Harrisburg Area Community College, Harrisburg, PA – U.S.A., Technology Division, vcganesc@hacc.edu
Shoaff, R., Harrisburg Area Community College, Harrisburg, PA – U.S.A., Technology Division, rhshoaff@hacc.edu
Pascu, A., PhD, University "Politehnica" Bucharest, Romania, Department of Mechanical Engineering, apascu@ing.pub.ro

Abstract

An innovative low power (5W) consumer grade dual face PV solar panel assembly is presented in this research. The authors propose capitalizing indirectly on the shadowed face of a typical solar panel by augmenting the panel's total active area of exposure (via the panel's "back side" and respective "deflectors") and aiming at an increase in the overall efficiency of the assembly. Standard environmental operating conditions were taken into account. No CPV were used. The resulting power output profile of this unit is presented in detail and compared with the output of a single sided "standard" solar PV module configuration. In addition, under similar design and operating environmental variables, the behavior of crystalline cells panels is intended to be contrasted with thin film panels' as variants of this proposed solution.

Keywords: *solar, photovoltaics, cell*

Introduction

Solar cells/panels use light energy from the sun to generate electricity through the photovoltaic effect. The structural member of a module can either be the top layer or the back layer. The majority of modules use wafer-based crystalline silicon cells or thin film cells based on cadmium telluride or silicon. Crystalline silicon is the most commonly used semiconductor.

Photovoltaic panels based on crystalline silicon modules are being partially replaced in the market by panels that employ thin-film solar cells (CdTe [1], CIGS [2], amorphous Si [3], microcrystalline Si and so on), which are rapidly growing and are expected to account for 31% of the global installed power by 2013 [4]. Other developments include casting wafers instead of sawing [5], concentrator modules, "silver" cells, and continuous printing process, all aiming at improving the conversion rate (efficiency) of such elements.

The current market leader in solar panel efficiency (measured by energy conversion ratio) is SunPower, a San Jose, CA based company. Sunpower's cells have a conversion ratio of 24.2%, well above the market average of 12–18% [6]. However, advances past this efficiency mark are being pursued in academia and research and development labs with efficiencies of 42% achieved at the University of Delaware in conjunction with DuPont by means of concentration of light [7]. The highest efficiencies achieved without concentration include Sharp Corporation at 35.8% using a proprietary triple-junction manufacturing technology in 2009 [13], and Boeing Spectrolab (40.7% also using a triple layer design). A March 2010 experimental demonstration of a design by a Caltech group which has an absorption efficiency of 85% in sunlight and 95% at certain wavelengths is claimed to have near perfect quantum efficiency [14]. However, absorption efficiency should not be confused with the sunlight-to-electricity conversion efficiency.

Typically, for best performance, terrestrial PV systems aim to maximize the time they face the sun. Solar trackers aim to achieve this by moving PV panels to follow the sun. The increase can be by as much as 20% in winter and by as much as 50% in summer. Static mounted systems can be optimized by analysis of the Sun path. Panels are often set to latitude tilt, an angle equal to the latitude, but performance can be improved by adjusting the angle for summer or winter.

While the efficiency of a solar farm can be increased either by using one the solutions just described, increasing the exposure area of the solar panels is also a variant. This solution however, sacrifices valuable real estate (horizontal area) at the expense of energy production. The work summarized herein presents a simple dual facet thin film stand alone module and its performance characteristics. By using an arrangement of precisely positioned mirrors and a second PV module mounted on the "back face" of the module facing up, an increase in the overall output of this newly created "assembly" is obtained by saving the "expansion" of the setup on the horizontal and instead taking a vertical approach. Indirectly, the authors show here the effect of irradiance on the I-V behavior of a solar unit. Similar studies are under way for a crystalline setup.

Fig. 1 – *Top view of the 5 W thin film solar panel used in this study*

Note that a notable variant of a dual face solar panel is Sanyo's heterojunction with intrinsic thin-layer double bifacial solar photovoltaic panel.

Theoretical Assumptions

1. The model considered

PV cells can be modeled as a current source in parallel with a diode. When there is no light present to generate any current, the PV cell behaves like a diode. As the intensity of incident light increases, current is generated by the PV cell, as illustrated below.

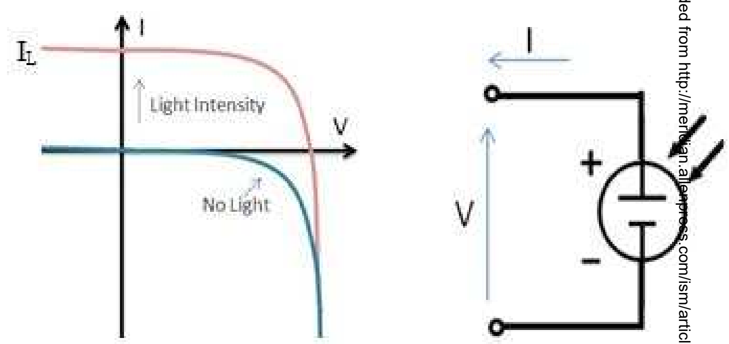

Fig. 2 – *I-V curve of a Photovoltaic cell*

In an ideal cell, the total current I is equal to the current I_ℓ generated by the photoelectric effect minus the diode current I_D, according to the equation:

$$I = I_\ell - I_D = I_\ell - I_o\left(e^{\frac{qV}{kT}} - 1\right) \quad (1),$$

where I_0 is the saturation current of the diode, q is the elementary charge $1.6x10^{-19}$ Coulombs, k is a constant of value $1.38x10^{-23}$J/K, T is the cell temperature in Kelvin, and V is the measured cell voltage that is either produced (power quadrant) or applied (voltage bias). A more accurate model will include two diode terms; however, we concentrated on the single diode model in this research.

Expanding equation (1) gives the simplified circuit model shown below and the following associated equation, where n is the diode ideality factor (typically between 1 and 2), and R_S and R_{SH} represent the series and shunt resistances that are described in further detail later in this section:

$$I = I_l - I_0\left(exp^{\frac{q(V+I\cdot R_S)}{n\cdot k\cdot T}} - 1\right) - \frac{V + I\cdot R_S}{R_{SH}}$$

(2).

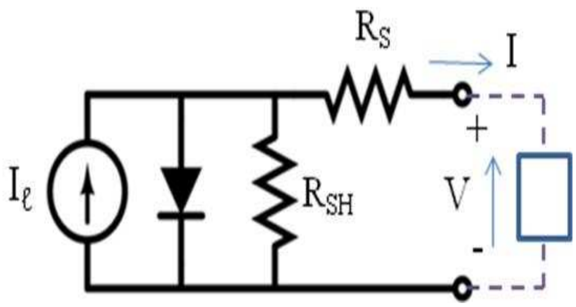

Fig. 3 - *Simplified equivalent circuit model for a photovoltaic cell*

2. Power measurements of the solar panel

A collection of power resistors of different values is used in a setup similar to the one shown below.

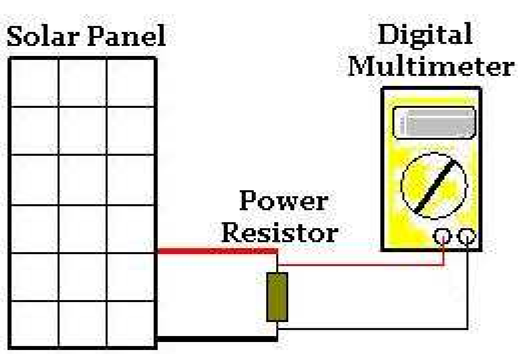

Fig. 4 – *Basic power measurement setup for a solar panel*

From a graphical standpoint, the results can be expressed as:

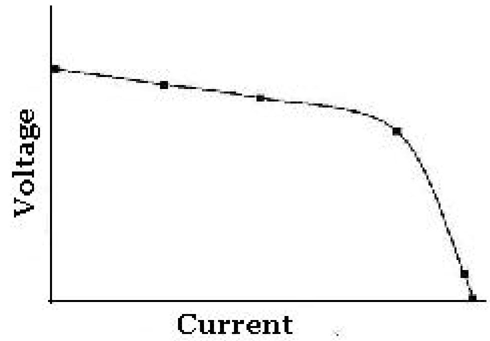

Fig. 5 – *I – V characteristic of a solar panel/s*

Setup and findings

Figure 6 below is a pictorial representation of the physical prototype.

In order for the back panel to be able of being exposed to the incoming sun light, horizontal area of the overall assembly needs to be larger than the surface of a single element to allow for the arrangement of deflecting mirrors to be positioned accordingly. Of course, wide variations, forms, shapes, angles and such of these deflectors could further be looked at.

Fig. 6 (a) – *Top view of the dual face physical module assembly*

Fig. 6 (b) – *Side view of the dual face physical module assembly*

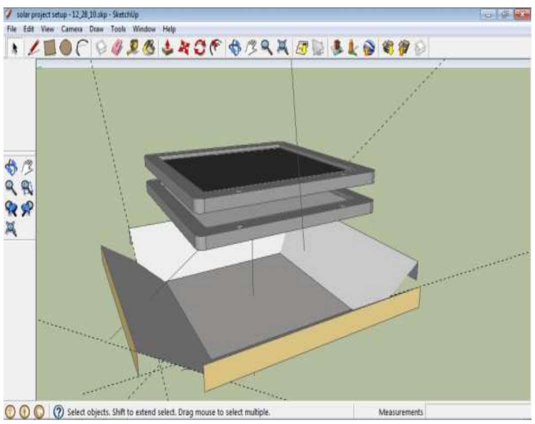

Fig. 6 (c) – *Modeled side view of the numerical model*

Please note the arrangement of mirrors placed around and beneath the second PV solar panel (facing down). The authors targeted an angle of inclination for these reflectors so the highest percentage of incident light rays could be captured and directly oriented towards the facing down panel at the "expense" of increasing the active area of exposure of this dual faceted overall assembly with no more than 50%.

Output values for each panel, as well as for the overall assembly are represented in Figure 7.

Theoretically, two such solar panels placed (side by side) horizontally facing up would yield twice the output of a single element. Consequently, and for instance, one and a half solar panel facing up would produce one and a half the output power generated by a single panel and so on. The analysis presented in this research article indicates that, in reality, the overall output generated by this dual faceted, dual panel overall solar assembly does not follow the pattern just mentioned with the overall expansion of the total horizontal area of exposure (facing up, that is) that allows incident solar energy to be captured and redirected on the module placed facing down.

Panel facin g up	Panel facing down (back panel)	Overal l assem bly	Horizontal area increase (via panel facing down)
8.1 V	3.31 V	11.41 V	10%
8.1 V	4.27 V	12.37 V	20%
8.1 V	4.93 V	13.03 V	30%
8.1 V	5.11 V	13.21 V	40%
8.1 V	5.39 V	13.49 V	50%

Fig. 7 (a) – *Output voltage of individual (face down and face up) panels in contrast with "overall" assembly and in relation to the increase in total horizontal area of exposure*

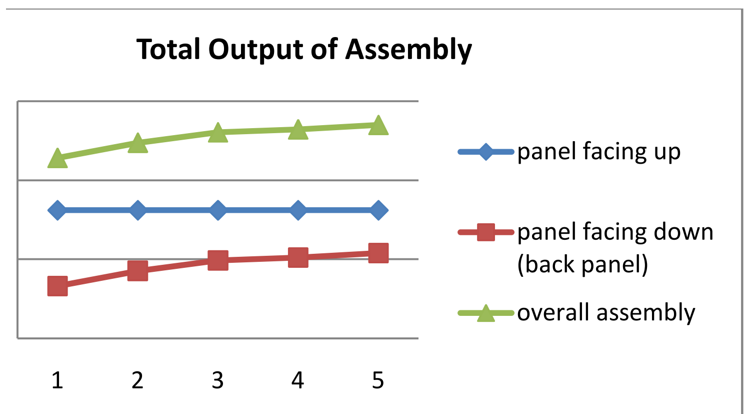

Fig. 7 (b) – *Graphical representation of data represented in Fig. 7 (a)*

The explanation behind the facts emphasized in this project is attributed to the fact that while increasing the horizontal surface (up to) 1.5 times of any one single solar panel in hopes of obtaining (respectively) up to 1.5 times the output, when a secondary panel is placed on the back side of a module facing the sun and while incident sun rays are captured and redirected on the secondary “back face” with an arrangement of mirrors (that increase the incident “face” of the total assembly by up to 1.5 times), the PV element facing down is exposed in its entirety to the incident (yet redirected) sun energy, this way taking advantage of more than 1.5 the surface of a single component panel.

Conclusions

The total power output of a dual faceted thin film solar panel assembly is presented herein. The output parameters emphasize the effect on solar panel’s irradiance when exposure area is increased. Authors emphasize the advantage that comes with the “vertical” expansion of the incident area of a panel vs. “expansion” on the horizontal. Similar study on such device using crystalline elements shows similar results.

Nomenclature

I – current, [A]
V- voltage, [V]
R – resistance, [Ω]
T – temperature [K]
k - constant [$1.38\text{x}10^{-23}$J/K]

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