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Engineering and Industry Series
Volume *Deregulated Electricity Market Issues in South Eastern Europe*

Experimental Characterization of a Single Axis Photovoltaic Tracking System

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Abstract

Nowadays, photovoltaic is one of the most prominent renewable energy source technologies. One of the most important aspects of maximizing the photovoltaic output is for the photovoltaic panel to face the sun at a right angle at all times such that maximum irradiation is incident on the solar cells. Due to the continuous movement of the sun, an automatic solar tracking system is necessary for tracking purposes. Ideally, a dual axis tracking system is necessary to track the sun in longitudinal and vertical directions; however the elevation angle to the sun in Cyprus is constant and known beforehand at an approximate elevation angle of 27^o to the South. Alternatively, one can use a much cheaper and effective single axis tracking system to track the sun effectively. The solar panel is allowed to move longitudinally from East to West from -165 to 165^o to sync with the sun. In order to conduct experimental measurements and verify them with analytical results, the I-V400 Photovoltaic Tester was utilized. The instrument was used to measure the incident power density of light and operating temperature of the photovoltaic panel using a light sensor and thermocouple respectively, as well as the current-voltage characteristics such as open-circuit voltage, short-circuit current, maximum power point operation and efficiency. The photovoltaic panel readings were taken under varying weather conditions in an attempt to compare with analytical results and determine the various parameters of the literature specific to the photovoltaic panel. A superior performance using the single axis tracking system was observed when compared to the fix PV panel case, producing 15.63% more average power.

Keywords

Photovoltaic, Thin Films, Experimental Methods, Current, Voltage, Efficiency, Short-Circuit Current, Open-Circuit Voltage, Actuator

1 Introduction

The increasing energy demand of the developing world and inevitably the diminishing of fossil fuel resources, as well as the pollution to the environment have made sustainable energy supply a planetary issue that has to be addressed literally at every sector of human life [1]. The increasing awareness of the ecological consequences of energy consumption and the need for clean energy for environmental protection, have made solar power as an ideal alternative source of energy.

Solar power from the sun is an abundant source of energy that has the ability to cover the Earth's needs for a year with less than one hour of illumination. PV's are a reliable source of energy with no moving parts and minimum maintenance and operating costs. Their operation is silent and do not pollute the environment. Also energy is produced where it is needed without necessary lines for its transfer [2]. These are the facts and silent features of photovoltaic which makes it ideal choice for renewable energy resources.

Experts have been exploring ways to improve efficiency and costs of construction of photovoltaic solar cells for more than 25 years. Major part of the research so

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DOI: 10.22618/TP.EI.20151.192024

far conducted deals with the improvement of the efficiency of solar cells such as in [3], [4] and [5]. Besides efficiency, the design of solar cells, interconnection patterns, physical installation of solar cells are factors which have also been investigated as in [6].

This paper focuses on a comparative experimental analysis between a photovoltaic panel orientated towards the sun at all times using a single axis tracking system and a stable PV panel, both inclined at an elevation angle of 27^o vertically. The single axis tracking system has the ability to track the sun's movement by moving the photovoltaic panel from East to West from an angle of -165 to 165^o, thereby having improved production of electricity.

Overall, this paper firstly presents some background knowledge of photovoltaic solar cells, secondly it analyzes the operation of the single axis solar tracking system, thirdly it analyses the measurements and finally conclusions are drawn.

2 Background on solar cells

The photovoltaic effect deals with the direct conversion of solar energy into electricity. This transformation is done using semiconductor p-n junctions that are exposed to solar sunlight. Each photon of radiation with energy equal to or greater than the energy bandgap of the semiconductor has the ability to be absorbed inside a material and release an electron and a hole. Thus, as long as solar radiation is readily available, an excess pair of carriers (free electrons and holes) will be created over and above the already existing concentration levels due to the doping of the semiconductors. The already existing intrinsic electric field will cause these light generated charge carriers to move through the load, causing current to flow. As a result, the photovoltaic solar cell device is a source of current and is maintained as long as the sunlight is irradiated on the surface of the solar cell [7].

The output voltage of a solar cell is approximately between 0.6-0.7 V, a voltage which is very low when compared with the operating voltages of most of the electronic devices. To increase the output voltage, various solar cells are interconnected in series and to increase the output current, many solar cell arrays are connected in parallel. This special interconnection arrangement of solar cells in series and parallel is used to generate the necessary power, as well as the desired voltage and current capability of the photovoltaic panel. Typical nominal output voltages of photovoltaic panels used extensively are 12, 24 and 48 V. The output power may vary among different manufacturers according to the different technologies used and other factors.

To get the maximum absorption of solar radiation from a solar cell, the photovoltaic elements are coated to reduce light reflection. A glass which is placed over the panel aims to protect solar cells from the ambient environment, but also has a rough surface in order to reduce glare and to absorb as much light as possible.

Solar PV modules and panels work best when their absorbing surface is perpendicular to the sun's incoming rays. The position of the sun in the sky can be traced using two angles, the azimuth and zenith angles [8].

Azimuth is the compass angle of the sun while it is moving through the sky from East to West over the course of the day. Generally, azimuth is calculated as an angle from true South. In general, it could be said that the azimuth angle which is essential for the correct solar panel orientation varies with the latitude and time of the year.

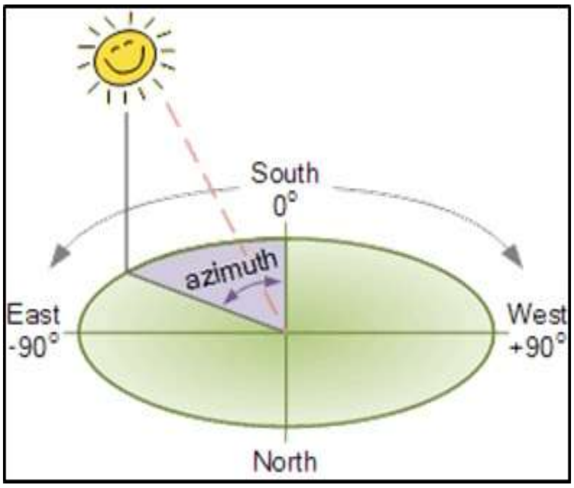

Fig. 1 Solar panel orientation - Azimuth angle [9]

Zenith is the angle of the sun looking up from ground level or the horizon. The zenith angle of the sun varies throughout the day in the form of an arc, with the sun reaching its maximum elevation (also called solar altitude) around mid-day. The sun's elevation is defined as 0^o at sunrise and sunset, and 90^o at mid-day, when the sun is directly above.

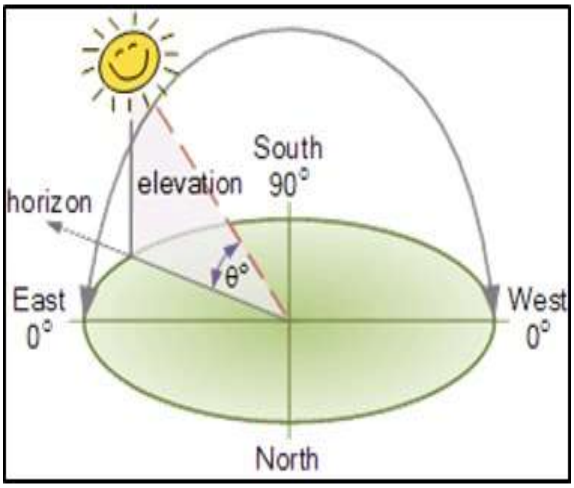

Fig. 2 Solar panel orientation - Zenith angle [9]

3 Single axis tracking system design

The most important objective of this study is to design a low cost solar tracking system. For this particular design, the following items were used: a) solar charge controller, b) 12 V battery and c) solar tracking system. The solar tracking system consisted of: a) solar tracking controller, b) solar tracking sensor and c) linear actuator. The photovoltaic panel was supported on a wooden hand-made structure. The base was designed to be at 27^{o} elevation angle, which is the angle for optimum power production for the whole year in Cyprus.

Fig. 3 Single axis tracking system

Fig. 4 Solar charge controller regulator

Fig. 5 Solar charge battery

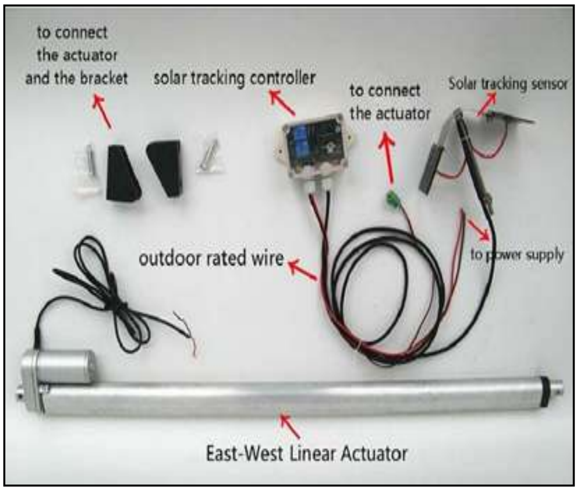

Fig. 6 Solar Tracking sensor, controller and actuator

The linear actuator was put in parallel to the surface of the photovoltaic panel, acting as a feedback binary controller to the sun’s irradiation. This allowed the PV panel to move from East to West such that radiation on both sides of the linear actuator is balanced, as shown in Fig. 3.

The light measuring binary sensor was connected with the solar controller, which provided electricity to the linear actuator, allowing for the PV panel to self-orientate itself. The energy needed for the movement of the PV panel was taken from the 12 V battery charged from the PV panel using the sun's irradiation.

4 Simulation results

In this section, experimental collected data are presented in graphical form. This data include relationships among different parameters related to the photovoltaic panel, such as efficiency, temperature, open-circuit voltage, short-circuit current, maximum power point voltage and irradiation intensity.

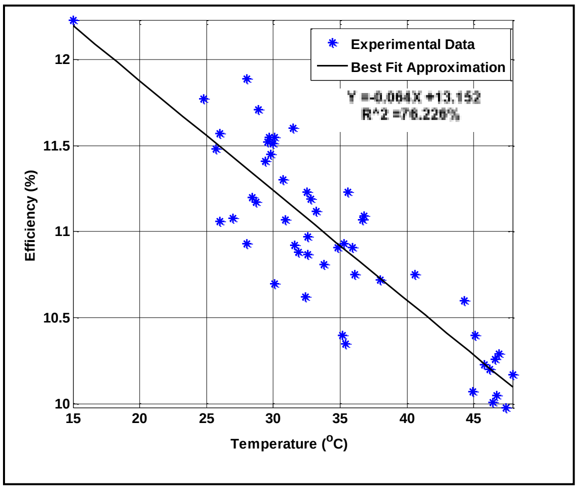

Fig. 7 Efficiency v/s operating temperature of panel

4.1 Photovoltaic efficiency versus temperature

It was observed that the efficiency of the PV panel experienced negative temperature coefficient, as expected. It can be seen in Fig. 7 that the efficiency of solar panel reduces by 0.064/°C. If one fits the data in a straight line using least square fitting, there is a 76.22% correlation between both parameters.

4.2 Photovoltaic voltage versus temperature

The two voltage values which can be analysed in relation with the operating temperature of the solar panel are the open circuit voltage V_{oc} and the maximum power point voltage V_{mpp}. The open circuit voltage is calculated when there is no current flow through the panel under no-load conditions and the maximum power voltage V_{mpp} when power through the panel is maximum. The correlation between the open-circuit voltage and maximum power point voltage and the temperature of the PV panel can be seen in Fig. 8 and Fig. 9, respectively.

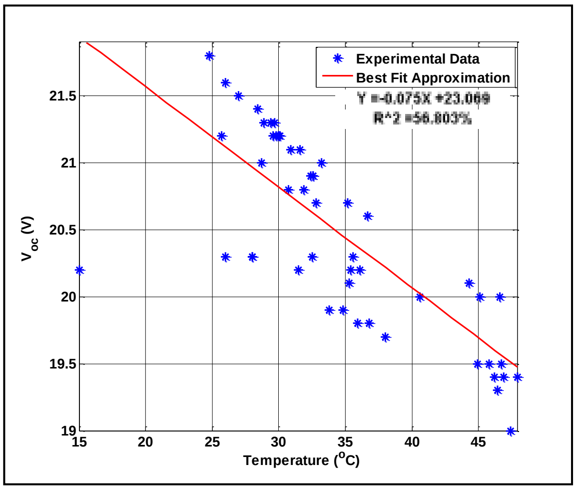

Fig. 8 V_{oc} versus temperature

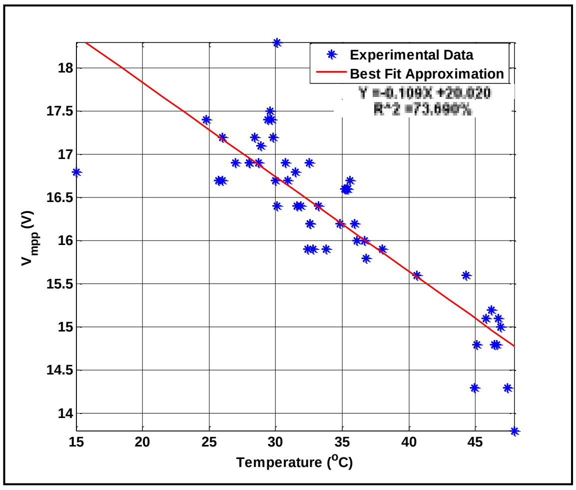

Fig. 9 V_{mpp} versus temperature

Observation clearly states that V_{mpp} is more dependent on operating temperature as compared to V_{oc}. It is obvious that the V_{mpp} decreases by 0.109 V/°C, whereas the V_{oc} decreases by 0.075 V/°C. The correlation coefficient for the open-circuit voltage is found to be 56.803%, whereas for the maximum power point voltage is 73.690%.

4.3 Current versus solar irradiation intensity

In this section, the short-circuit current and maximum power point current value are correlated with respect to the irradiation intensity. Fig. 10 and Fig. 11, show the relation of the solar irradiation with the short-circuit current and with the maximum power point current, respectively.

Fig. 10 and Fig. 11 reveal the fact that both currents have very strong dependence on solar irradiation. Both the maximum power point current I_{mpp} and the short-circuit current I_{sc} rise by 0.002 A per irradiation density unit. In both graphs, the correlation coefficients are very high, for I_{mpp} being 98.886% and for I_{sc} being 99.406%, which shows that the rate of rise of current is exclusively dependent upon solar irradiation intensity.

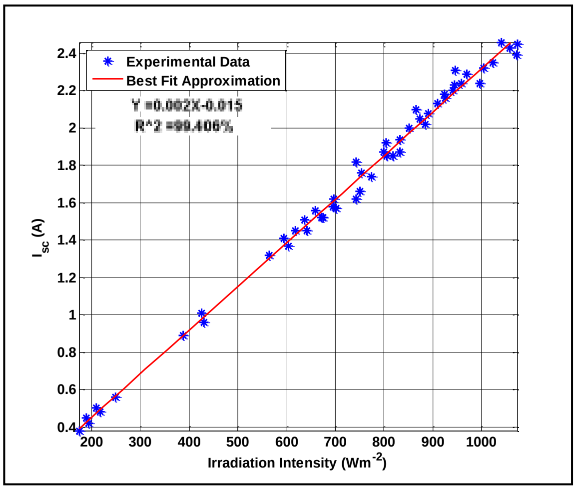

Fig. 10 I_{mpp} v/s Irradiation Intensity

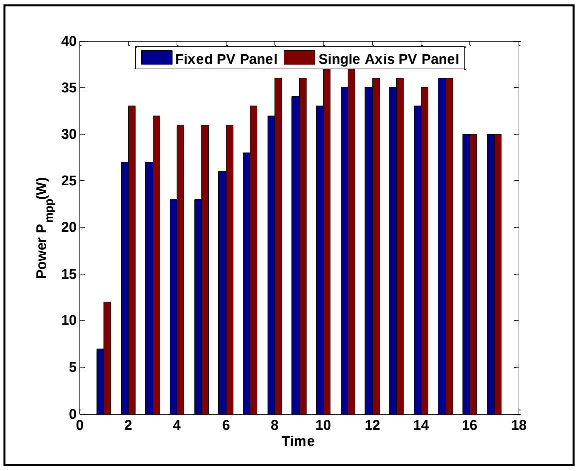

Fig. 13 Power P_{mpp} comparison

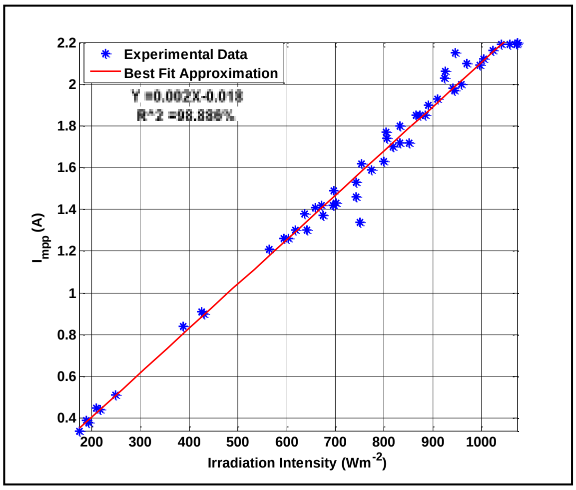

Fig. 11 I_{mpp} v/s Irradiation Intensity

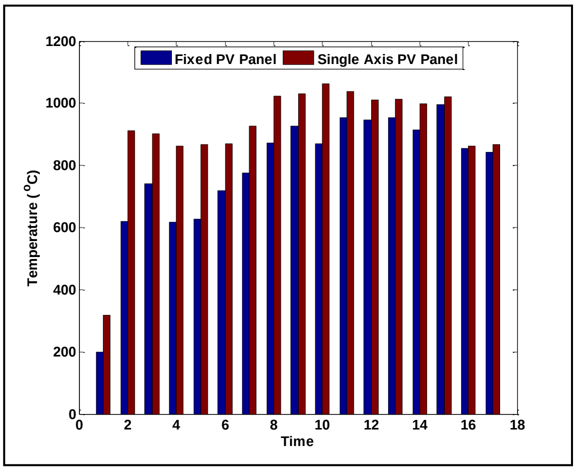

Fig. 14 Panel temperature comparison

4.4 Fixed panel versus single axis tracking system

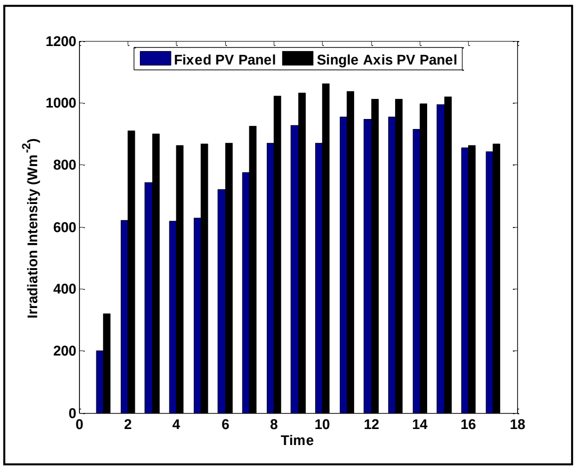

Fig. 12 Radiation intensity comparison

In this section, the performance of a fixed solar panel is compared with that of a single axis tracking system.

This comparison is made with respect to the captured solar irradiation, maximum power produced and temperature variations for both panels, as shown in Fig.12, Fig.13 and Fig.14, respectively for many instances in time during the day.

A comparison of the radiation measured in W/m^2 between fixed and single axis tracking system is presented in Fig. 12. The single axis tracking system panel has on average 17.48% more radiation received, when compared to the fixed panel case. Fig. 13 shows the comparison of maximum power and reveals that the single axis tracking system has 15.63% more production of energy as compared to the fixed solar panel case.

Finally, Fig. 14 shows the comparison of temperatures between fixed and single axis tracking system cases. It shows that there is a 10.55% increase in the case of the single axis tracking system because of the higher total irradiation that incidents on the PV panel. This increase in temperature causes a small decrease of V_{mpp} and V_{oc}, reducing slightly the energy production of the solar panel.

5 Conclusions

After performing experimental analysis and obtaining results which were presented in the previous sections, it can be concluded that the PV panel was affected positively by high irradiation and negatively by high temperatures. Furthermore, it was shown that the short circuit current and maximum power point current were highly affected by solar irradiation. Additionally, voltage was also highly influenced by temperature conditions, with the V_{mpp} influenced more than V_{oc}.

The single axis solar tracking system, which was designed in order to produce greater amount of energy by following the path of the sun was able to produce 15.63% higher power as compared to the fixed panel case.

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