Evaluation of a hybrid system to improve the electrical efficiency in photovoltaic panels

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Abstract. This project shows a photovoltaic hybrid system (PHS) that follows the sun using electronic and mechanic devices and reduces the solar panel's temperature with water in order to increase the energy obtained. The system was designed and implemented with a 1-axis solar tracker system and a water cooling system. PHS allows solar radiation beams to fall almost perpendicularly and decreases the temperature of the solar panel. Finally, its performance is compared against a traditional fixed photovoltaic system (FPS) oriented at 15° facing south. Experiments were made during only seven days in a year between December 1st and December 19th of 2017 in Guadalajara de Buga, Valle del Cauca, Colombia. Tests consisted of using the same electric loads at 20%, 40% and so on until 100% of the total power capacity of the solar panels. Results points out that electrical efficiency of the PHS increased 5.03% compared to the FPS on the same environmental conditions. Finally, PHS shows daily additional average power between 37% and 40% when it is loaded with electric loads at 80% and 100%.

1 Introduction

Big part, almost 79% of world energy production and consumption is derived from fossil fuels like oil, coal and gas; 19.3% is derived from renewable energy and a minor part with only 2.3% is derived from nuclear energy [1]. The problem with this consuming and generating scheme of energy is the negative effect on the earth climate and the contamination that it generates which affects vegetable, animal and human life. Thus, it is necessary to look for new laws and strategies to deploy the use of renewable energies.

A bunch of governments and people around the world have taken consciousness about this problem and they are redirecting its actions toward the use of renewable energies. On these days, exists different technologies to produces energy from natural resources as the sun, water, wind, decomposition and thermal heat. Among all the renewable technologies, the most popular is the photovoltaic solar energy which had a significant grow of 47% in 2016. Instead, wind and hydropower had a grow of 34% and 15.5% according to the information provided by [1].

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Despite this preference on photovoltaic solar energy there is a couple of issues that affects negatively its energy production: In the process of producing energy, solar panels are affected by the not perpendicularity incidence of solar radiation beams due to the relation movement of earth and sun, and the rise temperature effect gained through the exposition of solar radiation during the day.

Taking account, the aforementioned problems, a hybrid system is designed, implemented and characterized to follow the sun using a mechanical 1 axis solar tracker and integrated with a water cooling system to refrigerate the solar panel surface. The main goal is to know how much energy can produce our system against a traditional photovoltaic system. The figure 1 shows both systems.

Fig. 1. Location and installation of fixed and hybrid system.

2 Implementation of Hybrid System

The hybrid system aims to maximize the energy production, minimizing three phenomena that affect the uptake of energy: the non-perpendicular incidence of the solar radiation beams on the solar panel, for which a 1-axis solar tracker was constructed to follow the sun during the day; the negative influence of the temperature with respect to the power generated by the solar panel and the losses by reflection, and due to these last two factors a water cooling system was implemented, in order to decrease the operating temperature of the panel and also reduce the losses by reflection, this is due to the refractive index of water that is 1.3, intermediate medium between the air which has a refractive index of 1 and the panel glass with an index of approximately 1.5.

Thus, the hybrid system is integrated by three subsystems: the tracking system, the cooling system and the data acquisition system. See Figure 2.

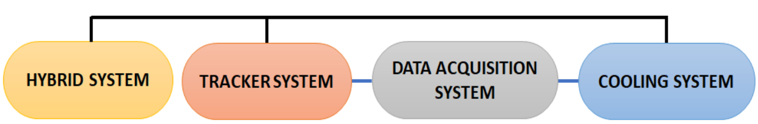

Fig. 2. Hybrid system is integrated by a solar tracker system, a water cooling system and a data acquisition system.

2.1 Tracker System

The tracking system implemented is one degree of freedom, it is responsible for moving the panel through the day to increase the incidence of solar radiation beams on it. To carry out the movement, the tracking system is composed of a mechanical system, which supports the solar panel, a DC electric motor, a DC power supply and finally the electronic system (power, sensors and control subsystems).

2.2 Cooling System

The cooling system is responsible for cooling the solar panel front surface by generating a film of water which was pumped by two DC water pumps. These pumps were placed in a clay container that stored the water. In addition, the system has a closed circuit of water circulation that allows water to circulate from the storage container, passes through the panel and finally returns to the container. The water recovery system was achieved by putting drains to each end-side of the panel.

2.3 Data Acquisition System

The physical variables measured for the traditional fixed system are the temperature in the rear center part of the panel, voltage and current consumed by the electric load. For hybrid system they are: temperature in the rear central part of the panel, water cooling temperature, water drain temperature, environment temperature, solar radiation, the voltage and current that is consumed by the electric load, voltage and current consumed by the DC motor and the angular position of the system.

3 Tests

In Colombia, due to the location next to Ecuador, the hours on which it is possible to have solar radiation are approximately from 6:00 AM to 18:00 PM. According with the information provided by UPME [6], the daily average range of solar radiation energy on December is from 4.0 to 4.5 kWh/m2. Our measured data says that the average amount of solar energy is 4.643 kWh/m2. In addition, in the same way as Ramkumar et.al [5], which carried out the experiment in five days and acquired data in the morning from 9:00 AM to 4:00 PM in the evening. Also, in [3] the measurements were performed during the month of February and recorded data from 9:00 AM to 4:00 PM. Therefore, due to the arguments mentioned before, the behavior of both systems were analyzed in seven days from 8 am. to 4 pm. GMT-5. The tests consisted in each day connecting an electric load of the same value to each system, whose objective was to analyze the both systems' performance measuring nominal power (Watts). Initially, an electric load demanded approximately 20% of the nominal power of each system that is 51W of 255W, the second day, an electric load of 40% demanded 102W of 255W and so on until reaching a load that demanded 100% of the nominal power of the system. All samples were carried out under the same environmental conditions and the work point of both solar panels were under the same electric load value. This experiment was done in order to analyze the behavior of both systems' generated power when the consumption, given the load, was close to the limit of both solar panels' capacity. This way, as the electric load demanded more power, it was expected that the hybrid system would be able to deliver more energy than the traditional fixed system. To analyze the performance, the power delivered by each system was sampled every 5 minutes and the data was sent via WiFi and stored in a spreadsheet on Google Drive.

4 Results

In this section the results are shown in terms of solar radiation measures, energy produced, electrical and thermal efficiency, fixed and hybrid system temperatures. There were 6,828 data collected in seven days of measurement, also, infrared pictures were taken that qualitatively shows the temperature behavior of both systems. Before showing the performance results, it is worth highlighting that the data acquired from the experiment contains different environmental conditions, from cloud days to sunny days, as well as the behavior of the shadows coming from cloud's journey. This kind of data let having a variety of days to support the experiment results under different weather conditions. The figures shown below support the description detailed before.

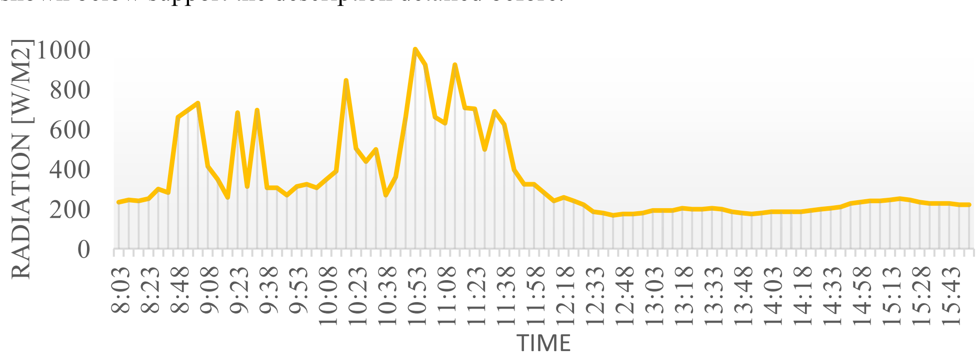

Fig. 3. Solar radiation behavior of December 1st of 2017.

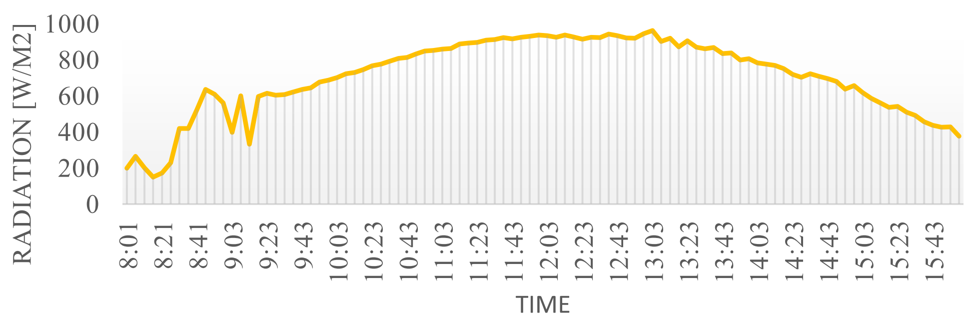

Fig. 4. Solar radiation behavior of December 19th of 2017.

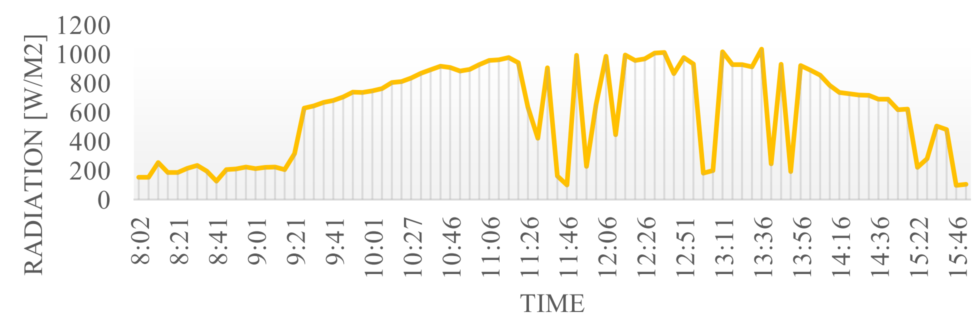

Fig. 5. Solar radiation behavior of December 16th of 2017.

Also, it should be mentioned that it was possible just to do a seven-day experiment, for the availability of the technical devices we had since they didn't belong to us and because of our economic resources that were too limited.

4.1 Electrical Results

Table 1 and Table 2 shows the data acquired about the average solar radiation, total energy produced and the average of electric efficiency for traditional fixed system and hybrid system during the day of experiment. Notice how energy produced by hybrid system is always greater than the fixed system (Table 1 and figure 6)

Table 1. Electric results of fixed system.

Load	Average Radiation $[W/m^2]$	Energy Fixed $[Wh/day]$	Energy Hybrid $[Wh/day]$	η Fixed	η Hybrid
20%	343.77	291.86	351.76	6.61%	8.10%
40%	597.33	688.83	849.85	9.88%	12.22%
60%	614.04	762.74	945.06	9.41%	11.38%
80%	628.34	931.13	1250.11	11.23%	15.47%
80%	628.34	1064.59	1455.29	11.93%	16.96%
100%	521.05	703.30	989.20	8.22%	11.92%
100%	661.91	1085.03	1467.28	12.55%	17.33%

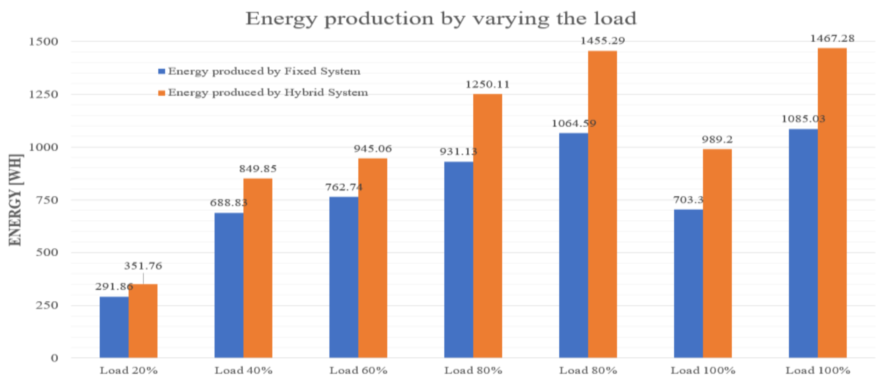

Fig. 6. Energy production of fixed and hybrid system by varying the load.

Analyzing the data about energy production in both systems, it is worth highlighting the power difference that the hybrid system could generated on the day, variable, which is called the additional percentage of power generated by the hybrid system over the fixed system. These numerical values are illustrated in Table 2.

Table 2. Additional percentage of power generated by the hybrid system over the fixed system.

Load	Average Radiation $[W/m^2]$	Additional Percentage of Power [%]
20%	343.77	22.70
40%	597.33	23.38
60%	614.04	23.90
80%	628.34	37.15
80%	628.34	40.48
100%	521.05	40.85
100%	661.91	39.52

From table 2, it is observed that best performances of the hybrid system occurred when the load is at 80% and 100% of the total energy capacity of solar panels. It is recalled that the measurements were made in equal environmental and operating conditions for both systems. Thus, figure 7 shows how are the production difference of the hybrid system during the day for all the tests. Here, best results occur at morning from 8:00 to 10:00, which can be explained for various reasons.

On those days close to winter solstice, a mismatch presented on the installation orientation together with "sun's movement" at the age the experiment was carried out and the connection of a high electric load favored the catchment of solar radiation beams during the morning for the hybrid system and thus its performance against the load was greater. As the hybrid system tracked the sun and as it had a high electric load that consumed more power, it could have more solar resources to deliver more energy than the fixed system. Instead, as fixed system does not track the sun, it is not well positioned from 8:00 to 10:00 to receive the solar radiation beams.

Finally, the water temperature of the cooling system at mornings was lower than at afternoons (the water acquired heat as the time passed), a condition that allowed to decrease the working temperature point of the hybrid system solar panel and hence have a better performance.

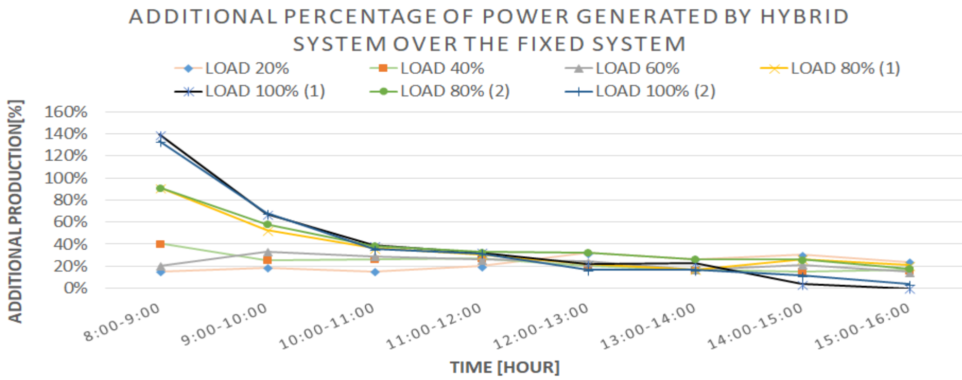

Fig. 7. Additional percentage of power generated by the hybrid system over the fixed system.

In addition, after 15:00, the figure 4 shows a decrement of additional production when the electric load connected to the hybrid system was 100% of the solar panel total capacity. This happened because both system was under rain conditions. For the rest of the days, the additional production was approximately 20%.

4.2 Thermal Results

Table 3 shows the average radiation for each experiment, the average of the ambient temperature, the temperature of the fixed system panel, the temperature of the hybrid system and its thermal efficiency.

Table 3. Thermal results of fixed and hybrid system.

Load	Radiation $[W/m^2]$	Environment Temperature [°C]	Hybrid Temperature[°C]	Fixed Temperature [°C]	ηth
20%	343.77	28.34	29.05	34.39	16.23%
40%	597.33	32.82	34.31	48.60	41.07%
60%	614.04	32.29	34.65	49.02	54.40%
80%	628.34	35.06	35.95	51.95	47.48%
80%	628.34	34.28	35.89	52.48	37.24%
100%	521.05	32.45	33.46	45.06	56.93%
100%	661.91	35.35	36.34	45.01	30.44%

By observing the temperature value of the fixed system panel and the hybrid system panel it is possible to see that the panel temperature of the hybrid system is much lower than that of the fixed system and tends to be the ambient temperature. Regarding the relation of the thermal efficiency and the variation of the load, there is not a distinguished pattern, so the thermal efficiency depends, in this work, on the weather conditions.

Now, the influence of the temperature distribution in the panel of the fixed system and the hybrid system in figure 8 will be analyzed qualitatively, where figure 8.a shows a higher temperature distribution than the one of the hybrid system in 8.b, this last one shows the effect of water cooling. Finally, figure 8.c shows a thermal scale of the temperatures. Note: these pictures were taken with the FLIRONE camera with the recommendations specified in [2].

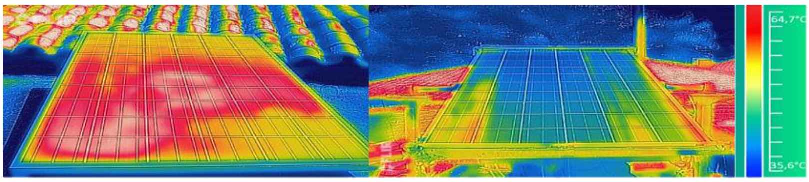

Fig. 8a. Fixed system **Fig. 8b.** Hybrid system **Fig. 8c.** Thermal scale

Fig. 8. Thermographic images of both systems and thermal scale with maximum and minimum values.

5 CONCLUSIONS

- The hybrid system discussed increased the energy production in 40% compare to the fixed system, working at 80% to 100% of load capacity.
- When a solar panel is directly connected to an electrical load of lower power consumption than the panel can deliver, it needs less radiation to satisfy the energy demand of the load.
- The electrical efficiency of the hybrid system over the fixed system could be up to 5.03%.
- Fixed mount photovoltaic installations oriented towards the south diminish their capture of solar radiation from the spring equinox to the autumn equinox in locations close to the equator, that is, from March to September, since this installation would not be to exposed to the direct radiation of the sun thanks to the apparent movement of this.

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