Comparison of the effect of temperature parameter on the functionality of tracking and fixed photovoltaic systems: A case study in Tehran, Iran

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Abstract. Production of energy by renewable energy including photovoltaic systems is always dependent on the environmental and geographical parameters based on which these system are installed. Temperature is one of the most important environmental parameters that affects the performance of photovoltaic systems. The effect of this parameter on the functionality of fixed and tracking photovoltaic systems is not the same. Since it is exposed to the sun from sunrise to sunset, the tracking photovoltaic system has a higher temperature on the surface of the panels than the fixed photovoltaic systems. The result of the experiments in this study showed that the temperature-induced efficiency decline rates for the fixed and tracking photovoltaic systems were more than 7.98% and 10.02%, respectively. According to calculations, the temperature-induced efficiency drop in tracking photovoltaic systems was about 25.55% higher than that in fixed photovoltaic systems. Observations showed that the temperature difference was on full display at sunrise and sunset, while this difference was minimized around noon.

1. Introduction

Environmental pollutions and limited extent of fossil fuels have prompted human societies to switch to clean and renewable energies to produce energy [1,2]. Fossil fuels are still the main source of energy production [3]. However, using renewable energies has been increasing in recent decades [4], as it is predicted that 16% of the required electricity of the world will be generated by renewable energies by 2035 [5]. Renewable energies, unlike fossil fuels, are available in many parts of the world and they can be employed to produce energy, even in remote areas [6].

Among renewable energies, the sun is the dominant source of energy that can easily be converted to other types of energy such as thermal, electrical, and chemical energies [7]. Photovoltaic systems are one of the mechanisms that can be used for producing electrical energy using sunlight [8]. Using solar energy for energy production is increasingly growing [9]. Electricity production using photovoltaic systems is highly dependent on the environmental and geographical situations of the site being used. Sunlight intensity, temperature, humidity, dust, and wind are some of the influencing environmental factors [10].

Temperature is one of the most important envi-

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ronmental factors influencing the efficiency of photo-voltaic systems [11]. It causes a reduction in the voltage of the photovoltaic system, which, in turn, leads to a reduction in the power generated by the system [12]. Typically, upon a 1°C increase in temperature, 0.45% of the efficiency of the system is reduced [13]. Another important environmental factor is dust effect. An increase in the dust amount in air and on panel surfaces reduces the sunlight reaching the solar cells, thus reducing the efficiency [14,15].

In addition to all of the advantages of photo-voltaic systems for energy production, low efficiency and capacity factor are one of the main problems in these systems. To this end, one possible solution is using tracking systems. In tracking systems, panels are always facing the sun. This causes an increase in system production. Many research pieces have investigated and compared the energy produced by these two systems [16–21]. A comparison between fixed and tracking photovoltaic systems in different geographical areas may produce different results [22–28]. The rate of increase in the yield of tracking systems in hot and cold geographic regions varies. For example, according to a study specific to Germany, the difference in the output power of fixed and tracking systems is 39%, while it is 8% in Egypt [26].

Environmental parameters, sometimes, have different effects on fixed and tracking photovoltaic systems. Some portion of the dust may touch and remain on tracking systems due to its permanent movement during the day. Besides, tracking systems are always facing the sun directly. Consequently, the surface temperature of these panels goes higher than that of fixed systems [13,29]. However, the main question is how much the temperature increase on the surface of tracking panels is. Is it significant enough to exert a tangible influence on energy production of the tracking systems? Or is it too inconsiderable to be neglected and ignored?

In this study, the difference in the temperature of the surfaces of fixed and tracking photovoltaic panels will be investigated and compared. This research has already been investigated in brief by a number of studies, qualitatively. However, in this study, the investigations are quantitative so as to evaluate and determine the effectiveness of temperature parameters in the functionality of the systems. This is performed by the PVSyst 6.4.3 software, at first, and the calculations are done. Then, the results obtained from the simulations are verified by conducting an experiment.

2. Materials and methods

This section describes the existing materials in the laboratory and how to use them in testing. The simulation method performed here will be elaborated, as well. The software used as well as the assumptions intended for this simulation will be examined.

2.1. System description

This experiment was carried out in the Technical and Engineering Campus of Shahid Beheshti University, east of Tehran, with latitude 35.7426 and longitude 51.5788. The fixed system consisted of 57 panels (255 W) that were connected to the end of three inverters (5 kW). The panels were installed on the rooftop of one of the university's buildings to the south at an angle of 30 degrees. The power generated in the system is eventually injected into the power grid (Figure 1).

The tracking system is a single-axis type installed towards the south at an angle of 30 degrees and follows the sunrise and sunset. The control system is configurable and follows the sunlight using the program compiled on its controller. The system consists of nine 255 W panels. The specifications of the panels are given in Table 1. The panel's output is connected to

Figure 1. Fixed photovoltaic system in Shahid Beheshti University (SBU).

Table 1. Photovoltaic (PV) module technical specifications [37].

PV module	Specifications
Model	Conergy PE 255
Type	Monocrystalline Silicon
Number of cell	60
Nominal Power at STC (PSTC)	255
Module efficiency	15.59%
Maximum power current (Impp)	8.42 A
Maximum power voltage (Vmpp)	30.29 V
Short circuit current (Isc)	8.98 A
Open circuit voltage (Voc)	37.82 V
Power temperature coefficient	0.43 %/°C

an inverter of 2.5 kW and the generated electricity is eventually injected into the power grid (Figure 2).

The surface temperature of the panels is measured every 5 minutes and recorded. To increase the reliability coefficient, the temperature of two different panels was measured simultaneously and averaged. Temperature was measured using a TM-925 thermometer.

Sunny Webbox was employed for data logging of existing systems (version-M2). With this tool at hand, information about the fixed and tracking systems is recorded every 5 minutes. Weather data such as temperature, wind speed, and irradiance are also recorded with the implementation of sensors available at Sunny Webbox.

PVSyst is designed to be used by architects, engineers, and researches. It features a help menu that explains the used models and methods. This tool presents results in the form of a full report, specific graphs, and tables. Also, data can be employed for use by other software [30].

2.1.1. System modeling
In this simulation, for ease of system design, each system was considered 10 kW. Each of these systems consisted of forty solar panels, individually producing 250 W, and two 5 kW inverters. To increase the simulation accuracy of the software, the panels and inverters similar to the ones in the laboratory were used.

3. Result and discussion

This section calculates the loss of temperature-induced efficiency for the fixed and tracking systems by the software. Then, this efficiency decline can be calculated through experimentation and comparison of the results obtained from the simulation.
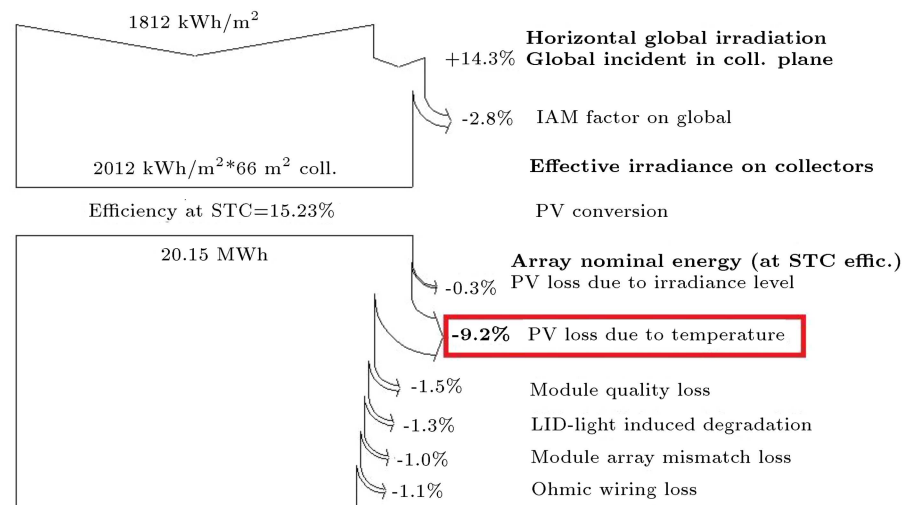
3.1. Simulation
The results of the simulation show that the loss of temperature-induced efficiency for the fixed and tracking systems is 9.2% and 11.1%, respectively (Figures 3 and 4). According to the obtained numbers, the temperature-induced efficiency drop in the tracking photovoltaic system is 20.65% higher than that in the fixed photovoltaic system. These calculations show that the photovoltaic tracking system is much more susceptible to temperature damage than the fixed photovoltaic system. In the next section, the results will be validated by field experiments.

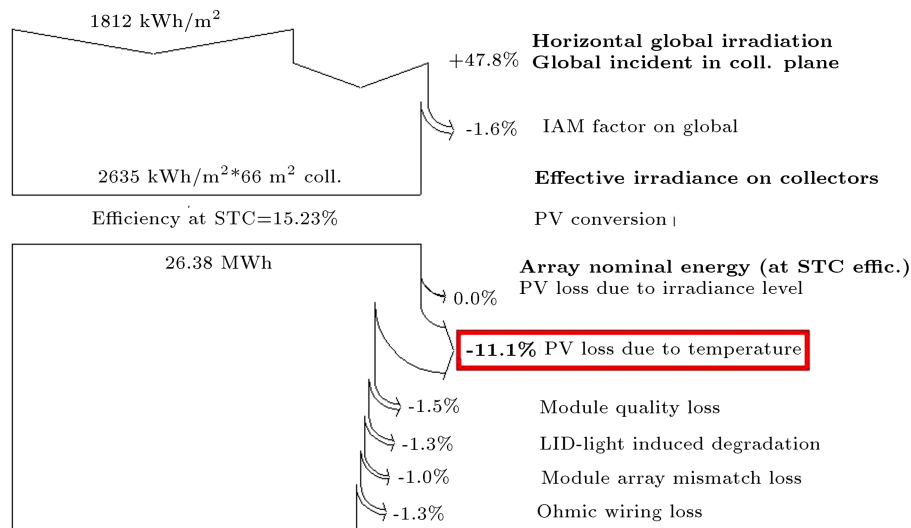### 3.2. Experimental analysis
This experiment was carried out on May 16th, 2019. The temperature of the air as well as fixed and tracking photovoltaic systems are shown in Figure 5. As shown in Figure 5, the temperature of the fixed system panels is close to air temperature during the morning and evening. The reason for this is the maximum possible angle between panels and sunlight beams. Thus, during these hours, the lowest energy is received by the panels from the Sun. The energy produced by the panels is
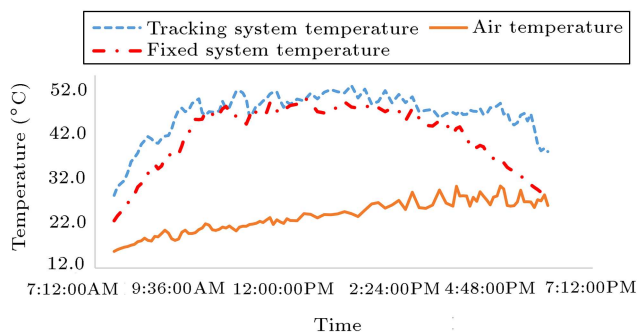

Figure 2. Tracking photovoltaic system in Shahid Beheshti University (SBU).

1812 kWh/m^2

Horizontal global irradiation
Global incident in coll. plane
+14.3%

-2.8%   IAM factor on global

2012 kWh/m^2*66 m^2 coll.

Effective irradiance on collectors

Efficiency at STC=15.23%   PV conversion

20.15 MWh

Array nominal energy (at STC effic.)
PV loss due to irradiance level
-0.3%

-9.2%   PV loss due to temperature

-1.5%   Module quality loss

-1.3%   LID-light induced degradation

-1.0%   Module array mismatch loss

-1.1%   Ohmic wiring loss

Figure 3. Decrease in efficiency due to temperature in the fixed photovoltaic system.

1812 kWh/m^2

Horizontal global irradiation
Global incident in coll. plane
+47.8%

-1.6%   IAM factor on global

2635 kWh/m^2*66 m^2 coll.

Effective irradiance on collectors

Efficiency at STC=15.23%   PV conversion

26.38 MWh

Array nominal energy (at STC effic.)
PV loss due to irradiance level
0.0%

-11.1% PV loss due to temperature

-1.5%   Module quality loss

-1.3%   LID-light induced degradation

-1.0%   Module array mismatch loss

-1.3%   Ohmic wiring loss

Figure 4. Decrease in efficiency due to temperature in the tracking photovoltaic system.


Figure 5. Temperature of the air as well as fixed and tracking photovoltaic systems.

also minimal at this time. As a result, the temperature of the fixed system panels is very low at these hours and is close to the air temperature. However, at the same time, the tracking system panels are facing the sun directly. This has led to the production of these panels during sunrise and sunset. Therefore, the surface temperature of the panels is higher than the air temperature at this time.

The air temperature is reduced from the temperature of the fixed and tracking system panels in Figure 6 to provide a better comparison between the fixed and tracking systems.

Each chart is also fitted with a 5-degree chart to check out, more accurately, the movement of temperatures throughout the day (Eq. (1) for the fixed system and Eq. (2) for the tracking system). As can be seen in Figure 6, the temperature of the fixed and tracking panels is very close to each other at noon, and the further it moves from the noon to the sunrise and sunset, the wider the temperature difference will be. Generally, at the test hours, the average temperature of the tracking and fixed system panels was 45.02°C
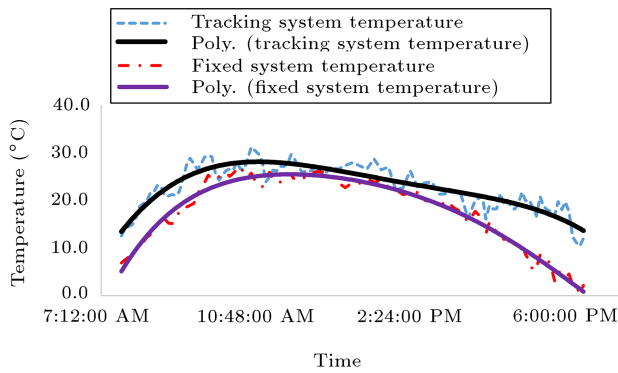
Figure 6. The temperature of the fixed and tracking photovoltaic systems with lower ambient temperature.
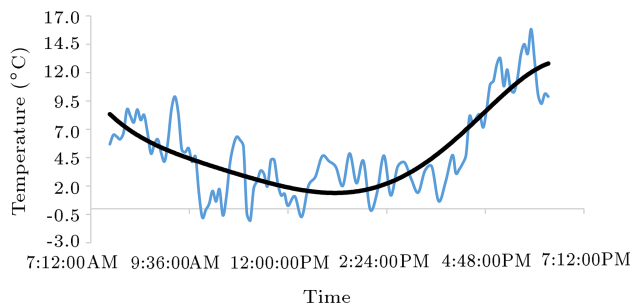
Figure 7. The temperature of the tracking system, with the fixed system temperature being lower.

Figure 8. Intensity of sun's Irradiance.

Figure 9. Wind speed during the test day.

and 40.94°C, respectively. According to the results, the average temperature of tracking system panels on this day was 12.2% higher than that of the fixed system panels. The average air temperature was 23.25°C on this day.
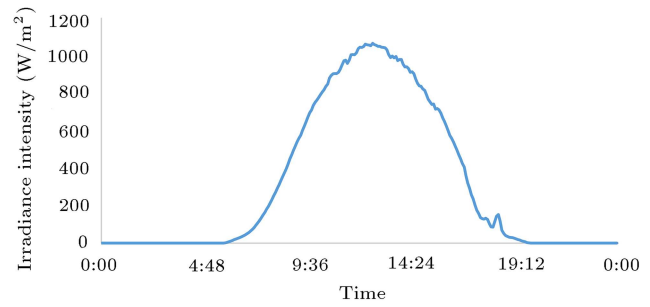
$$y = -1530.4x^5 - 172.82x^4 + 5761.6x^3 - 6658.5x^2$$

$$- 2870.5x - 404.98, \tag{1}$$

$$y = 11102x^5 - 33221x^4 + 39416x^3 - 23487x^2$$
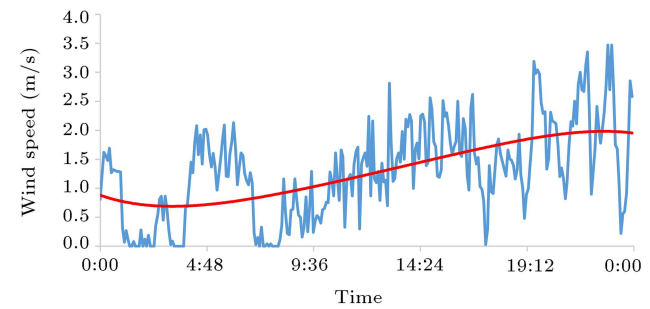
$$+ 7053.6x - 827.23. \tag{2}$$

In Eqs. (1) and (2), x and y denote time and temperature, respectively.

As shown in Figure 7, the temperature of the fixed panels is lowered by the temperature tracking panels. The diagram shows the temperature difference between the tracking and fixed panels (Eq. (3)). Figure 7 clearly shows that there is the highest temperature difference between the panels in the morning and evening, and as it approaches the noon hours, the angles of the panels approach each other. This allows the surface temperatures of the panels to approach each other and minimize the temperature difference between them.

$$y = -12633x^5 + 33048x^4 - 33654x^3 + 16829x^2$$

$$- 4183.1x + 422.25, \tag{3}$$

where x and y represent time and temperature, respectively.

Due to the importance of other environmental parameters such as radiation and wind and their influence on the temperature parameter, these environmental parameters were measured in this study, as shown in Figures 8 and 9. In Figure 9, the wind speed diagram is highly fluctuating and, so, the curves are fitted to the following equations (Eq. (4)) to better visualize the wind behavior on this day.

$$y = -9.42x^5 + 24.72x^4 - 27.74x^3 + 16.74x^2$$

$$- 3.22x + 0.88, \tag{4}$$

where x and y represent time and wind speed, respectively.

In the experiments performed in this study, the temperature of the back surface of the panels was measured. To determine the rate of temperature drop on the panels, it is necessary to calculate the surface temperature of the photovoltaic cells. After determining the temperature of the back surface of the panels, the surface temperature of the photovoltaic cells is obtained using Eq. (5) [13]:

$$T_c = T_m + \Delta T \times (G/G_{STC}). \tag{5}$$

In this case, T_c and T_m are the photovoltaic cell temperature and the surface temperature behind the panel, respectively. ΔT is the fixed number equal to 3 [31]. G is the intensity of ambient radiation on the test day, and G_{STC} is the standard radiation intensity

(1000 W/m^2). According to Eq. (5), the surface temperature of the panels in fixed and tracking systems is $43.56°$C and $48.31°$C, respectively. Accordingly, the surface temperature of photovoltaic cells in the tracking systems is 10.91% higher than that of the fixed systems.

Given the surface temperature of the cells, the efficiency of each system can be calculated. According to the catalog of available panels, due to the structural features of the panels used, upon increasing temperature by $1°$C, the power of the panels decreases by 0.43% (power temperature coefficient) (Table 1). Therefore, the power drop due to the temperature in the panels is calculated using Eq. (6):

$$P_{\text{Loss}} = (T_C - T_{STC}) \times 0.43, \qquad (6)$$

where P_{Loss} is the power drop due to the temperature in the panels, which is obtained as a percentage and T_{STC} is the temperature under standard conditions ($25°$C). Therefore, 0.43 is also power temperature coefficient.

According to Eq. (6), the loss of temperature-induced efficiency in the fixed and tracking systems is 7.98% and 10.02%, respectively. Accordingly, the tracking systems are 25.55% more vulnerable to temperature than fixed systems. Figure 10 shows the results of the conducted experiment and simulation.

According to the results obtained from the simulation and experiments, the surface temperature of the panels in the tracking systems is higher than that of the panels in the fixed systems. This indicates that the tracking systems are highly affected by the temperature parameter. This means that if the panels in the tracking systems can be cooled, the efficiency of the system will increase significantly. There are different ways to cool down the panels. One of these solutions is using photovoltaic thermal panels. These panels function by reducing the heat on the surface of the panels and extracting the heat obtained [32–36]. Using these panels in photovoltaic systems can yield a very positive effect. Moreover, upon lowering the temperature of the panels, the overall efficiency of the system increases and there is a great deal of thermal energy. According to the results obtained in this section, the use of these panels is much more efficient in the tracking systems because the temperature has a more negative effect on the tracking systems and the efficiency of the system increases with decreasing temperature. On the other hand, tracking systems generate more heat and photovoltaic-thermal panels can generate more thermal energy from these systems. As a result, the use of these panels in tracking systems results in greater electrical and thermal efficiency.

4. Conclusion

The effect of such an important parameter as temperature on the fixed and tracking photovoltaic systems may vary. Tracking systems are characterized by higher temperatures because they are directly placed opposite to the sun from the sunrise to sunset. In this paper, an attempt was made to quantitatively calculate this increase in temperature in tracking systems compared to fixed systems. The quantitative calculation is important because it indicates whether the negative impact of temperature on the tracking system is low enough to be ignored, or that this value is significant and cannot be ignored.

The results of the simulation show that in a place like Tehran, Iran where the experiment was carried out, the negative impact of temperature on the tracking system is about 20.65% higher than the fixed system. This study witnessed 9.2% and 11.1% rates of temperature-induced efficiency drop in fixed and tracking systems, respectively. The results of the experiment approximately confirmed these findings. According to the simulation results, the fixed and tracking systems experienced 7.98% and 10.02% reductions in temperature-induced efficiency, respectively. According to the obtained numbers, the temperature-induced efficiency drop in the tracking photovoltaic system was 25.55% higher than that in the fixed photovoltaic system. Observations showed that the largest temperature difference between the systems was at sunrise and sunset when the tracking system was directly facing the sun and the fixed system had the highest angle with sunlight. As it gets closer to noon time, the difference decreased and the temperatures of the two systems became closer together. At noon, the two systems had a nearly identical angle with both of them facing the sun. The difference in power drop due to the temperature above 20% between fixed and tracking systems indicates that in examining and comparing the types of photovoltaic systems, the vulnerability of the systems to temperature should be examined. This means that although the tracking system is superior to the fixed system with a higher energy production, it is subject to a number of disadvantages. This makes the operating systems more vulnerable to temperature in very hot
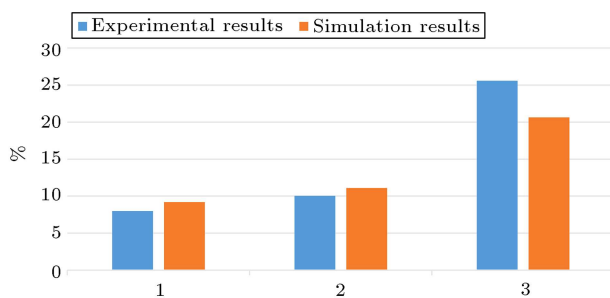
Figure 10. Comparison of experimental and simulation data.

climates. The drop in temperature efficiency is so high that using these systems will no longer be an advantage.

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Biographies

Mahdi Mohammad Mirzaei Darian (1991) is a graduate of Mechanical and Energy Engineering from Shahid Beheshti University. He has studied the blades of gas turbines and applied non-destructive tests to them in the Bachelor's thesis. His field of interest is renewable energy, especially solar energy. He works in the field of installation, maintenance, research and development on photovoltaic systems as well as research on increasing efficiency and manufacturing solar inverters.

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