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

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Abstract

The production of energy by renewable energy, including photovoltaic systems, is always dependent on the environmental and geographical parameters at which the system is installed. Temperature is one of the most important environmental parameters affecting the performance of photovoltaic systems. The effect of this parameter on the fixed and tracking photovoltaic system is not the same. The tracking photovoltaic system, because it is exposed to the sun from sunrise to sunset, has a higher temperature at the surface of the panels than the fixed photovoltaic systems. The result obtained from the experiments in this study shows that the temperature-induced efficiency drop in the fixed and tracking photovoltaic systems is more than 7.98% and 10.02%, respectively. According to calculations, the temperature-induced efficiency drop in tracking photovoltaic systems is about 25.55% higher than that of fixed photovoltaic systems. Observations show that this temperature difference is most extent at sunrise and sunset, and as we approach noon this difference is reduced and minimized.

Keywords: Temperature; Renewable energy; photovoltaic system; Efficiency; Fixed and tracking.
1 Introduction

Environmental pollutions and the finitude of fossil fuels have led 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 is 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 produce energy, even in remote areas [6].

Among renewable energies, the sun is a source of energy that can easily be converted to other types of energy such as thermal, electrical and chemical energy [7]. Photovoltaic systems are one of the mechanisms which are used for producing electrical energy by 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 amount, temperature, humidity, dust, and wind are some of the influencing environmental factors [10].

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

Besides all of the advantages of photovoltaic systems for energy production, low efficiency and capacity factor are one of the main problems in these systems. One of the solutions that may help in the issue improvement is using tracking systems. In tracking systems, panels are always facing the sun. This causes an increase in system production. In many types of research, the energy produced by these two systems is investigated and compared [16]–[21]. Comparison of fixed and tracking photovoltaic systems in different geographical areas is different [22]–[28]. The rate of increase in production by tracking systems in hot and cold geographic regions is very different. For example, according to a study in Germany, the difference in output power between fixed and tracking system is 39%, while in Egypt it is 8% [26].

Environmental parameters, sometimes, have different effects on fixed and tracking photovoltaic systems. Tracking systems, due to their permanent movement during the day, part of the dust is depleted on them. On the other hand, tracking systems are always facing the sun directly. This causes the surface temperature of these panels to get higher than fixed systems [13], [29]. But, the main question is that how much the temperature increase in the surface of tracking panels is. Is it that much that has a tangible influence on energy production by the tracking systems, or this temperature increase is very few and can be ignored.

In this study, the temperature difference on the surface of fixed and tracking photovoltaic panels will be investigated and compared to each other. This work has already been investigated in brief studies, qualitatively. In this study, the investigations are quantitative, to obtain the effectiveness of temperature parameters on systems, and evaluate its effectiveness. This is performed by the PV Syst 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 for testing. It will also explain the simulation method performed. The software used as well as the assumptions intended for this simulation will be examined.

2.1 System Description

This experiment is performed on the technical and engineering campus of Shahid Beheshti University, east of Tehran, with latitude 35.7426 and longitude 51.5788. The fixed system consists of 57 panels (255W) that are connected to the end of three inverters (5kW). The panels have been 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 that installed towards the south, at an angle of 30 degrees and follows the sunrise and sunset. The control system of this system is programmable and it follows the sunlight regarding the program which is compiled on its controller. The system consists of nine panels of 255 W. The Specifications of the panels are given in Table 1. The panel's output is connected to 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.

Data logging of exciting systems is by SUNNY WEBBOX (version-M2). With this tool, information about the fixed and tracking system 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 detailed the Help menu that explains the models and methods that are used. This tool presents results in the form of a full report, specific graphs, and tables. Also, data can be exported for use in other software [30].

System Modelling

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

3 Result and Discussion

In this section, the loss of temperature-induced efficiency in the fixed and tracking systems are calculated by the software. Then this efficiency drop is calculated by experimenting and compared with the results obtained from the simulation.

3.1 Simulation

The results of the simulation show that the loss of temperature-induced efficiency in the fixed and tracking system is 9.2% and 11.1%, respectively (Figure 3, Figure 4). According to the obtained numbers, the temperature-induced efficiency drop in the tracking photovoltaic system is 20.65% higher than that of the fixed photovoltaic system. These calculations show that the photovoltaic tracking system is 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 done on May 16th, 2019. The temperature of the air, 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, in these hours, the lowest energy is received by the panels from the Sun. The energy produced by the panels is also minimal at this time. As a result, the temperature of the fixed system panels is very low at these clocks and is close to the air temperature. But 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 system.

Each chart is also fitted with a 5-degree chart to see more accurately the movement of temperatures throughout the day (equation 1 for the fixed system and equation 2 for the tracking system). As can be seen in Figure 6, the temperature of the fixed and tracking panels are very close to each other at noon, and the further it moves from noon to the sunrise and sunset, this temperature difference increases. Generally, in the test hours, the average temperature of the tracking system panels was 45.02°C and for the fixed system panels was 40.94°C. According to the results, the average temperature of tracking system panels on this day is 12.2% higher than the fixed system panels. The average air temperature was 23.25 °C on this day.
\[ y = -1530.4x^5 - 172.82x^4 + 5761.6x^3 - 6658.5x^2 - 2870.5x - 404.98 \]  
(1)

\[ y = 11102x^5 - 33221x^4 + 39416x^3 - 23487x^2 + 7053.6x - 827.23 \]  
(2)

In equations 1 and 2, \( x \) is time and \( y \) is temperature.

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 (equation 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.

\[ y = -12633x^5 + 33048x^4 - 33654x^3 + 16829x^2 - 4183.1x + 422.25 \]  
(3)

In equation 3, \( x \) represents time and \( y \) represents temperature.

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

\[ y = -9.42x^5 + 24.72x^4 - 27.74x^3 + 16.74x^2 - 3.22x + 0.88 \]  
(4)

In equation 4, \( x \) represents time and \( y \) represents wind speed.

In the experiments performed in this study, the temperature of the back surface of the panels was measured. To obtain the temperature drop in the panels, it is necessary to calculate the surface temperature of the photovoltaic cells. By having the temperature of the back surface of the panels, the surface temperature of the photovoltaic cells is obtained from Equation 5 [13].

\[ T_c = T_m + \Delta T \times \left( \frac{G}{G_{STC}} \right) \]  
(5)

In this case, \( T_c \) and \( T_m \) are the photovoltaic cell temperature and the surface temperature behind the panel, respectively. \( \Delta T \) is a 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/m²). According to Equation 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.

By having 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, with 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 from Equation 6.

\[ P_{Loss} = (T_c - T_{STC}) \times 0.43 \]  
(6)

In this equation, \( P_{Loss} \) is the power drop due to the temperature in the panels, which is obtained as a percentage. \( T_{STC} \) is the temperature under standard conditions (25°C). 0.43 is also Power temperature coefficient. According to Equation 6, the loss of temperature-induced efficiency in the fixed and tracking system is 7.98% and 10.02%, respectively. Accordingly, tracking systems are 25.55% more vulnerable to temperature than fixed systems.
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 more affected by the temperature parameter. This means that if the panels in the tracking systems can be cooled, the efficiency of the system will be significantly increased. There are different ways to cool the panels. One of these solutions is the use of photovoltaic thermal panels. These panels are such that they reduce the heat at the surface of the panels and extract the heat obtained [32]–[36]. Using these panels in photovoltaic systems can have a very positive effect. On the one hand, by lowering the temperature of the panels, the overall efficiency of the system increases and on the other hand, there is a great deal of thermal energy. According to the results obtained in this section, the use of these panels is 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 increased electrical and thermal efficiency.

4 Conclusion

The influence of an important parameter such as temperature on the fixed and tracking photovoltaic systems is not the same. Tracking systems have higher temperatures because they are directly opposite the sun from sunrise to sunset. In this paper, it is attempted 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 where the experiment was carried out, the negative impact of temperature on the tracking system is about 20.65% higher than the fixed system. In this study 9.2% and 11.1% decrease in temperature-induced efficiency drop in fixed and tracking systems, respectively. The results of the experiment approximately confirm these data. According to the simulation results, the fixed and tracking systems, show 7.98% and 10.02% reduction in temperature-induced efficiency drop, respectively. According to the obtained numbers, the temperature-induced efficiency drop in the tracking photovoltaic system is 25.55% higher than that of the fixed photovoltaic system. Observations show that the largest temperature difference between the systems is at sunrise and sunset when the tracking system is directly facing the sun and the fixed system has the highest angle with the sun's rays. As it gets closer to noontime, the difference decreases and the temperatures of the two systems get closer together. At noon the two systems have a nearly identical angle, and both 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 in addition to the advantages that the tracking system has over the fixed system, including the increase in energy produced, it also has such disadvantages. This makes the operating systems more vulnerable to temperature in very hot climates. The drop in temperature efficiency is so great that using these systems will no longer be an advantage.

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Figure 10. Comparison of experimental and simulation data.

(1-Fixed system, 2-Tracking system, 3- Final results)
Table 1. 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)       | 8.42A                  |
| Maximum power voltage (Vmpp)       | 30.29V                 |
| Short circuit current (Iscc)        | 8.98A                  |
| Open circuit voltage (Voc)          | 37.82V                 |
| Power temperature coefficient      | 0.43%/° C              |

Biography

Mahdi Mohammad Mirzaei Darian (1991) is a graduate of Mechanical and Energy Engineering from Shahid Beheshti University. He has studied on the blades of gas turbines and performs non-destructive tests on them, in the bachelor's thesis. Interested in 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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