

Experimental performance comparison of a 2-axis sun tracking system with fixed system under the climatic conditions of Düzce, Turkey

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Abstract: In this study, an experimental performance comparison of a 2-axis tracking system with a fixed panel in a solar renewable energy system is conducted. The paper mainly focuses on a cost–benefit analysis of fixed and tracking modules. For this aim, an experimental setup was built and periodical measurements were then obtained from the setup. To provide a better comparison, the panels were exposed to the same conditions during the measurements. By considering the real-time experimental results, the paper provides a quantitative analysis of the feasibility of tracking panels for domestic applications as well as an analysis of payback period if a tracking system is used for a home-building application instead of using a conventional fixed module. The study is restricted to the geographical region of Düzce, Turkey.

Key words: Photovoltaics, sun tracking systems, renewable energy, solar energy

1. Introduction

Finding clean sources of energy is one of the main challenges that governments face. Interest in renewable energy sources is due to the benefits they offer; they are not as limited as the exhaustible fossil fuels and they are environmentally friendly. Nonrenewable energy sources rely on consumption of fossil fuels and are considered as the principle cause of pollution and global warming. Among many alternatives for renewable sources, solar power units provide a viable solution to the problem of delivering clean sources of energy. Solar energy can be converted into electrical energy by means of photovoltaic (PV) systems. Early applications of PV panels were mainly focused on their use in the space industry [1–3], but since then many specific application areas have emerged, such as rural electrification [4], production of hydrogen [5], industrial electrification [6], and, finally, home-building electrification [7]. Today PV systems have proven a useful tool for harvesting electrical energy from the sun in domestic applications [8].

In general, there are two options for the placement of PV panel modules: first, the solar modules are fixed to the country latitude angle, and second, the modules are supported by a sun-tracking system to obtain the largest possible amount of solar energy from the sun at any operation time. The former is cheaper, but apparently converts less energy from the sun. The latter increases the first investment cost, but the obtained energy can also be increased by about 20%–40%, depending on several factors such as country location and seasonal variations [9]. Life cycle assessment is another important aspect and a useful life cycle analysis was presented in [10]. For fixed modules, determination of the optimal tilt angle has a predominant effect on system

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efficiency [11–13]. For the modules with a tracker, determination of the optimum tracking mechanism directly affects system performance [14–17]. It is also apparent that a fixed system has a lower operating cost and requires less maintenance effort. Then the question is whether it is worthwhile to build a sun-tracking system instead of utilizing fixed modules. Rustemli et al. compared the performances of a fixed module and sun-tracking module in Van, Turkey, in [18]. Another useful comparison was provided in [19], which presents the experimental performance results of a fixed module and a tracking module located in Denizli, Turkey. Al-Najjar performed similar work in Baghdad, Iraq [20]. Several other comparisons were provided in [21,22]. In this paper we try to explore the answer to this question experimentally by comparing the performances of a 2-axis sun-tracking system and a fixed system when both are off-grid. The study is restricted to the geographical region of Düzce, Turkey. The rest of the paper is organized as follows: Section 2 introduces the experimental setup, Section 3 defines the analysis problem and explains the method, and Section 4 presents the experimental results. The last section presents the concluding remarks.

2. Experimental setup

An off-grid PV system was built for experiments. The maximum active power produced by the system is 2640 W. The produced electrical energy is stored in gel batteries (24 V, 800 Ah). The batteries are charged through a total of 4 maximum power point trackers (MPPTs), three with a current rating of 30 A and one with a current rating of 40 A. The solar energy is converted into electrical energy by using 12 PV panels (8 fixed and 4 moving). The specifications of the panels are given in Table 1. By using the same panels whose specifications

Table 1. Specifications of the PV panels.

Cell type	Polycrystalline
Dimensions	1638 × 982 × 40 mm
Weight	20 kg
Nominal maximum power at STC (P_{max})	220 W
Optimum operating voltage (V_{mp})	29.3 V
Optimum operating current (I_{mp})	7.52 A
Open circuit voltage (V_{oc})	36.6 V
Short circuit current (I_{sc})	8.09 A



Figure 1. Experimental setup.

are given in Table 1, a tracking mechanism that controls the 4 moving panels was also built. Figure 1 shows the entire system. Two separate solar meters were placed at proper locations of the fixed and moving panels to determine solar energy potential. Figure 2 shows the solar meters located on the panels. All the measurements given in the following sections were calculated for only one panel for both the fixed module and the tracking module.



Figure 2. The solar meters located on the fixed and tracking modules.

For the comparison of the performances of the fixed and tracking modules, measurements were taken from the input terminals of the batteries. Such a measurement preference eliminates the consideration of the losses in the batteries shown in Figure 3. MPPTs and inverters are all shown in Figure 4.

The tracking system is driven by a permanent magnet direct current (PMDC) motor through a linear actuator, as shown in Figure 5. The tilt angle of the tracking system is fixed to 30° . The linear actuator converts the rotational motion into linear motion and then actuates the 6-m^2 metallic surface on which the panels are mounted. The tracking system consumes 2.74 Wh energy per day to move the mechanism via a sensorless position control scheme.



Figure 3. Batteries.



Figure 4. MPPTs and inverter.



Figure 5. Tracking system.

3. Experimental results

By using the solar meter introduced in the preceding section, the potentials of solar energy for both fixed and tracking modules were measured during a common time period. Figure 6 shows the radiation intensity for fixed and tracking modules. These measurements were taken during the daytime (from 8 AM to 5 PM). The figure shows the amount of active power that the modules can provide versus time. Thus, the unit of the vertical axis is W/m^2 . Since the measurements were taken at Düzce, Turkey, the fixed panels' latitude angle was assigned as 30° , its optimum value for all seasons. It is clear from the figure that for a fixed panel the radiation intensity reaches its maximum, $1096 \text{ W}/\text{m}^2$, at noon, and tends to decrease during the remaining part of day, especially in the morning and evening. The tracking module, on the other hand, harvests more energy from the sun during the entire day, as expected. To provide a quantitative answer to the question of payback period, some voltage, current, and power measurements from the output terminals of the panels were taken. The results of these measurements and a cost-benefit analysis based on the measurements are presented in the following text.

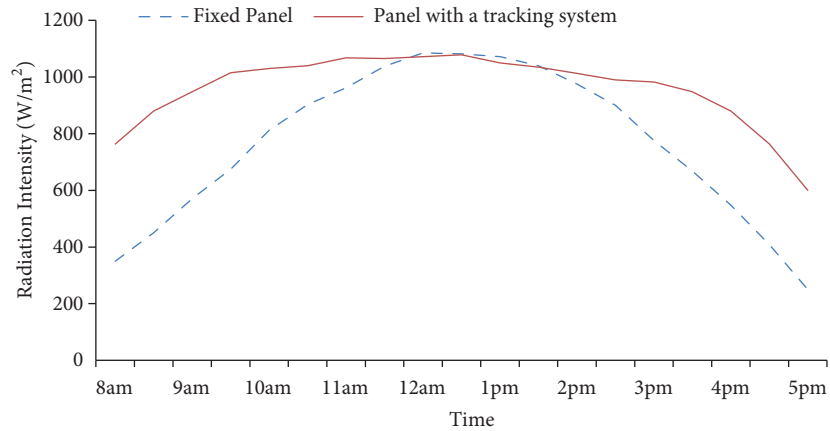


Figure 6. Radiation intensity acting on fixed and tracking modules.

Table 2 shows the voltage, current, and power measurements taken from the fixed panel and Table 3 shows the values of the same quantities for the tracking module during daytime (8 AM to 5 PM). As expected, the tracking module collects more solar energy and thus supplies more electrical energy to the end user. For a graphical representation of the performances of the two modules, Figure 7 shows the time variations of the power supplied by the two types of panels. By considering these measurements, it can be clearly said that for the same mechanical dimensions, the tracking module provides 200 Wh/(day × panel) more energy. This critical calculation will be utilized in the following cost–benefit analysis.

Table 2. Electrical measurements taken from the fixed panel during daytime.

Time	Current (A)	Voltage (V)	Power (W)
8 AM	2.06	24.60	50.68
9 AM	2.25	24.90	56.03
10 AM	2.80	25.10	70.28
11 AM	3.86	25.20	95.76
12 AM	3.90	25.30	98.67
1 PM	3.81	25.60	97.28
2 PM	3.70	25.80	95.46
3 PM	3.50	25.90	90.65
4 PM	2.65	25.90	68.64
5 PM	1.81	25.90	46.62

Table 3. Electrical measurements taken from the panel with a tracking mechanism during daytime.

Time	Current (A)	Voltage (V)	Power (W)
8 AM	3.57	24.60	87.94
9 AM	3.87	24.90	96.48
10 AM	3.92	25.40	99.69
11 AM	4.05	25.20	102.06
12 AM	4.35	25.30	110.05
1 PM	3.92	25.60	100.48
2 PM	3.67	25.80	94.81
3 PM	3.50	25.90	90.65
4 PM	3.35	26.03	87.20
5 PM	3.12	26.00	81.25

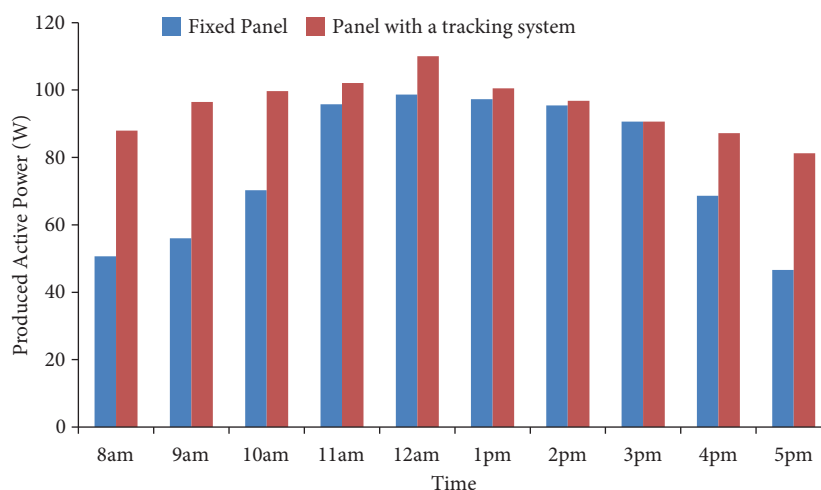


Figure 7. Graphical comparison of the active power generated by the fixed panel and the panel with a tracking system.

For a practical comparison, the energy requirement of a standard residential building should be estimated. Table 4 presents such an estimation. According to Table 4, the daily energy requirement is around 10,000 Wh. The presented comparison is based on the following assumptions:

Table 4. Estimation of daily energy requirements of a standard home residency.

Device	Operation time (h)	Rated power (W)	Number of the device	Daily energy consumption (Wh)
Refrigerator	8	200	1	1600
TV	6	50	1	300
Computer	4	50	1	200
Iron	0.25	1600	1	400
Oven	0.5	1000	1	500
Lamp	6	25	6	900
Dishwasher	0.5	1000	1	500
Washing machine	0.25	1000	1	250
Air conditioning	6	1000	1	6000
Other	-	-	-	1250
Total				11,900

- There is a linear correlation between the number of panels and the extra energy provided by the tracking modules compared to the fixed modules.
- The electrical energy requirements of a standard residency can be supplied by 10 panels with the specifications given in Table 1.

The following are also noteworthy:

- All calculations are made for an off-grid system.
- Daily energy requirements for a standard residency are presented in Table 4.
- All measurements were obtained in March under clear sky conditions. Measurements are not valid for foggy and cloudy conditions.

- Validation of the results is restricted to the geography of Düzce, Turkey. However, the method and results can be roughly adapted to other geographical regions, which is beyond the scope of this study.

It was found above that a panel with a tracking mechanism ensures 200 Wh/(day × panel). This necessarily means that it was experimentally proven that the tracking module ensured 35% more harvested energy compared to the fixed module. The calculation given in Table 4 dictates the use of 10 panels, which means that the additional energy provided by the tracking module is 2 kWh/day. By considering the cost of the experimental setup introduced in Section 2, the difference between the total cost of the fixed and tracking modules, both with 10 panels, is 1000 USD. In the city where the measurements were taken, the market price of electrical energy is 0.1 USD/kWh. Therefore, it can be said that if the tracking module is used, the time to payback is about 15 years. However, an important aspect of payback period calculation is the energy consumed by the tracking mechanism. The tracking mechanism is supplied by a separate small-size PV panel and does not consume the energy harvested by master panels. This surely affects the first investment cost of the system. By considering its cost, the tracking mechanism increases the payback period to 16 years. Due to the fact that the life span of a solar panel is 25 years, utilizing the tracking module for standard home application is not so feasible. Instead, 1000 USD can be spent for purchasing at least 4 extra (fixed) panels. Nevertheless, it is clear that the tracking module could be feasible for large power applications.

4. Conclusion

An experimental performance comparison of a 2-axis tracking system with a fixed panel in a solar renewable energy system was performed in Düzce, Turkey. The comparison provides a quantitative analysis to calculate the time required to payback if a tracking module is used instead of fixed module. It was found that, under the same conditions, the tracking module harvests 35% more energy from the sun compared to the fixed module, and the tracking system amortizes itself in 16 years. After that time, the system starts to ensure savings for the end user. For the same rated power, Rustemli et al. found that the tracking module harvests 29.46% more energy from the sun compared to the fixed module in Van, Turkey, in [18]. Al-Najjar found this value as 29.60% in Baghdad, Iraq. Since we calculated this value as 35% under the climatic conditions of Düzce, Turkey, it can be said that tracking modules are not feasible for small power applications, although they can be feasible for large power applications in Düzce.

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References

- [1] Goetzberger A, Hoffman VU. Photovoltaic Solar Energy Generation. Berlin, Germany: Springer-Verlag, 2005.
- [2] Messenger RA, Ventre J. Photovoltaic System Engineering. 2nd ed. Boca Raton, FL, USA: CRC Press, 2005.
- [3] Patel MR. Wind and Solar Power Systems. Boca Raton, FL, USA: CRC Press, 1999.
- [4] Stutenbaumer U, Negash T, Abdi A. Performance of small scale photovoltaic systems and their potential for rural electrification in Ethiopia. *Renew Energ* 1999; 18: 191-204.
- [5] Tributsch H. Photovoltaic hydrogen generation. *Int J Hydrogen Energ* 2008; 33: 5911-5930.

- [6] Aparnathi R, Dwivedi VV. Maximum power point tracking in PV system with industry applications. *International Journal of Power Electronics and Drive System* 2013; 3: 417-423.
- [7] Singh SN, Singh AK. Optimal design of a cost effective solar home power system – an alternate solution to DG for grid-deprived rural India. *International Journal of Research and Reviews in Applied Sciences* 2010; 2: 60-66.
- [8] Swart A, Schoeman R, Pienaar C. Cost-effective energy monitoring of domestic off-grid PV systems. *Energy and Power Engineering* 2013; 5: 182-188.
- [9] Khalil AA, El-Singaby M. Position control of sun tracking system. In: *IEEE 2003 Midwest Symposium on Circuits and Systems*; 27–30 December 2013; Cairo, Egypt. New York, NY, USA: IEEE. pp. 1134-1137.
- [10] Bayod-Rújula AA, Lorente-Lafuente AM, Cirez-Oto F. Environmental assessment of grid-connected photovoltaic plants with 2-axis tracking versus fixed modules systems. *Energy* 2011; 36: 3148-3158.
- [11] Nijegodorov N, Devan KRS, Jain PK, Carlsson S. Atmospheric transmittance models and an analytical method to predict the optimum slope of an absorber plate variously oriented at any latitude. *Renew Energ* 1994; 4: 529-543.
- [12] Gunerhan H, Hepbasli A. Determination of the optimum tilt angle of solar collectors for building applications. *Build Environ* 2007; 79: 249-260.
- [13] Yakup MABHM, Malik AQ. Optimum tilt angle and orientation for solar collector in Brunei Darussalam. *Renew Energ* 2001; 24: 223-234.
- [14] Sharan AM, Prateek M. Automation of minimum torque based accurate solar tracking systems using microprocessors. *J Indian I Sci* 2006; 86: 415-437.
- [15] Baz A, Sabry A, Mobarak A, Morcos S. On the tracking error of self-contained solar tracking system. *J Sol Energ-T ASME* 1984; 106: 416-422.
- [16] Huynh PT, Cho BH. Design and analysis of a regulated peak-power tracking system. *IEEE T Aero Elec Sys* 1999; 35: 84-92.
- [17] Hiyama T, Kouzuma S, Imakubo T. Identification of optimal operating point of PV modules using neural network for real time maximum power tracking control. *IEEE T Energy Conver* 1995; 10: 360-367.
- [18] Rustemli S, Dincadam F, Demirtas M. Performance comparison of the sun tracking system and fixed system in the application of heating and lightning. *Arab J Sci Eng* 2010; 35: 171-183.
- [19] Kivrak S, Gunduzalp M, Dincer F. Theoretical and experimental performance investigation of a two-axis solar tracker under the climatic condition of Denizli, Turkey. *Prz Elektrotechniczn* 2012; 2: 332-336.
- [20] Al-Najjar HMT. Experimental evaluation of the performance of one-axis daily tracking and fixed PV module in Baghdad, Iraq. *J Eng* 2013; 19: 1145-1157.
- [21] Serhan M, El-Chaar L. Two axes sun tracking system: comparison with a fixed system. In: *EA4EPQ 2010 International Conference on Renewable Energies and Power Quality*; 23–25 March 2010; Granada, Spain. Vigo, Spain: EA4EPQ. pp. 1-7.
- [22] Maatallah T, El Alimi S, Nassrallah SB. Performance modeling and investigation of fixed single and dual-axis tracking photovoltaic panel in Monastir city, Tunisia. *Renew Sust Energ Rev* 2011; 15: 4053-4066.