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Performance comparison of a double-axis sun tracking versus fixed PV system

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Abstract

In the present study, performance results of two double axis sun tracking photovoltaic (PV) systems are analyzed after one year of operation. Two identical 7.9 kWp PV systems with the same modules and inverters were installed at Mugla University campus in October 2009. Measured data of the PV systems are compared with the simulated data. The performance measurements of the PV systems were carried out first when the PV systems were in a fixed position and then the PV systems were controlled while tracking the sun in two axis (on azimuth and solar altitude angles) and the necessary measurements were performed. Annual PV electricity yield is calculated as 11.53 MW h with 1459 kW h/kWp energy rating for 28 fixed tilt angle for each system. It is calculated that 30.79% more PV electricity is obtained in the double axis sun-tracking system when compared to the latitude tilt fixed system. The annual PV electricity fed to grid is 15.07 MW h with 1908 kW h/kWp for the double axis sun-tracking PV system between April-2010 and March-2011. The difference between the simulated and measured energy values are less than 5%. The results also allow the comparison of different solutions and the calculation of the electricity output.

Keywords: Double axis tracking system; Photovoltaic; PV performance

1. Introduction

The sun is one of the most important Earth's natural resources. Solar energy is clean, renewable and abundant in most part of our world and can be converted into electrical energy by means of photovoltaic (PV) systems (Bayod-Rújula Ángel et al., 2011; Cruz-Peragón et al., 2011). The amount of power produced by a photovoltaic system depends upon the amount of irradiation to which it is exposed. As the sun's position changes throughout the day, the photovoltaic system must be adjusted so that it is always aimed precisely at the sun and, as a result, produces the maximum possible power (Koussa et al., 2011a,b; Al-Mohamad 2004; Abdallah and Nijmeh 2004). Sun tracking systems can be used to maximize energy production since they keep the PV modules perpendicular to the incoming solar radiation. As the sun's position changes throughout the day, the PV modules are adjusted by the sun tracking systems so that they can always be pointed precisely towards the sun. There are some classifications of the sun tracking system based on movement capability and control system. Regarding movement capability, sun tracking systems are designed to track the sun on a single axis (according to the azimuth angle) or to track the sun on both axis (according to the azimuth and solar altitude angles). Regarding to control system they can be divided into two: astronomically controlled systems and sensor controlled systems (Lee et al., 2009). At present, the PV industry thinks in terms of price per kWp, being this figure

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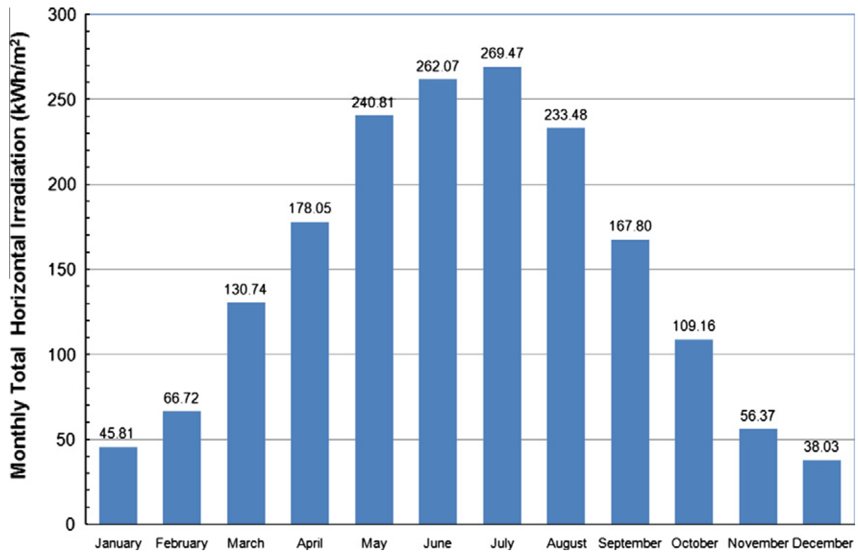

Fig. 1. Monthly calculated horizontal irradiation for Mugla between 2004 and 2010.

Table 1
AS 95HPC PV module specifications under STC (Sunset, 2011a).

AS HPC 100	
Rated power (P_{mpp})	95 W
Rated current (I_{mpp})	5.35 A
Rated voltage (V_{mpp})	17.7 V
Short circuit current (I_{sc})	5.75 A
Open circuit voltage (V_{oc})	21.5 V
Temp. coefficient (P_{mpp})	−0.38%
Max. system voltage (V)	500
Area (m^2)	0.54912
Weight (kg)	6.7

Table 2
SUN3Grid 5000 inverter specifications (Sunset, 2011b).

SUN3Grid 5000	
Input voltage	340–600 V_{DC}
Max. input voltage	800 V_{DC}
Input current	14.5 A_{DC}
Nominal output power	4400 W
Max. output power	4800 W
Output voltage	190–254 V_{AC}
Nominal output current	19.1 A_{AC}
Max output current	20.9 A_{AC}
Frequency	50 ± 1% Hz
Efficiency	96.3%

presented as the decisive criteria for the success of a PV project. Currently, the cost of installation of a tracking system per kWp of installed power is higher than the cost of conventional fixed systems; and due to the prices reduction in the PV industry, especially in the modules, the economical advantage of the surplus yields that could be obtained with tracking systems is now questionable (Oner et al., 2009). To analyze the benefits of using sun-tracking systems, it is just necessary to look through the existing studies (Mousazadeh et al., 2009; Gay et al., 1982), which show that a gain of 30–50% in the annual radiation can be achieved in comparison with the same installation if this had fixed modules instead. An environmental or energy point of view in order to offset the current tendency of the investors to avoid them, as the previously clear economic advantage is now non-existent. These reflections are based on the fact that the more energy is produced by renewable sources, as photovoltaic, the less the use of conventional energy sources, which have a higher impact and are scarce (Bayod-Rújula et al., 2011). Usually, the construction cost of a PV system mounted on a roof will be about 1–2$/Wp (Huang et al. 2011). The cost of the each tracker including the ground construction is about 16.500$ which is about 2$/Wp in 2009. The real cost of the PV electricity can be calculated by including the PV system cost with the cost of the tracker and maintenance. But the goal of this paper is the energetic comparison of two types of systems so the electricity cost is not analyzed in detail and performance analysis of two types of installations (with and without solar tracking) with identical PV systems is presented. The results also allow the comparison of different solutions and the calculation of the Energy outputs.

2. Irradiation data and PV systems

Mugla is located in south west of Turkey (latitude: 37.13+N, longitude: 28.22+E, altitude: 646 m). Solar radiation measurements of Mugla province have been carried out by Mugla University Clean Energy R&D Centre. An average daily solar radiation is found to be over 9.5 h during December and January and over 14 h during June and July. Corresponding average daily solar energy per square meter is calculated to be just above 50 kW h for December and January and well over 200 kW h for June and July (Oguz 1999). Total average horizontal solar irradiation is

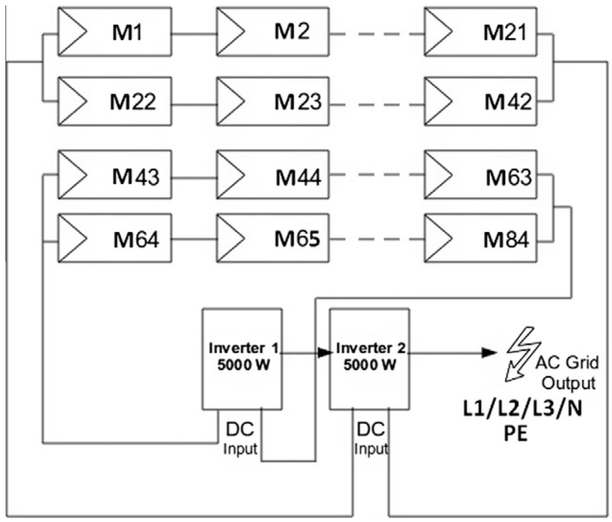

Fig. 2. PV system wiring on a tracker.

calculated as 1582 kW h/m^2 and 1685 kW h/m^2 between 1998–2000 and 2004–2010, respectively (Fig. 1). It is seen that maximum irradiation for per area is collected in June and July on horizontal plane over 260 kW h/m^2 monthly total measured value.

The produced energy by a photovoltaic system over a given period can be estimated from historical values of the incident radiation at the site. The source data for the performance simulation is a set of daily values of global horizontal irradiation. The measurements are taken on the roof of a building at Mugla University Campus which is only 300 m far away from the PV plant. In the optimum array design, the 21 of 95 W Sunset AS 95HPC back contact single crystalline silicon solar modules are electrically connected in series and 2 parallel groups are connected to obtain a voltage of 451.5 V at open circuit and 11.5 A current at short circuit which corresponds 371.7 V and 10.7A with producing DC power of 3990W$_p$ (Table 1) at maximum power point under standard test condition (STC: 25 °C cell temperature and 1000 W/m^2 incident radiation) and plugged in a 5000 W SUN3Grid inverter (Table 2).Totally 84 Sunset AS 95HPC back contact single crystalline silicon PV modules are used in each tracking PV system to obtain 7.9 kWp installed power (Fig. 2).

As the incident radiation on a PV array varies during the day it is not possible to obtain the rated values from the PV modules and also from the PV array. It is the first installation of back contact mono crystalline silicon PV modules in Turkey. One AS 95HPC PV module is under test in Mugla University PV outdoor test site to monitor the outdoor performance. The measured current–voltage curves and operating temperatures for different irradiation levels in 26th of August 2010 for AS 95HPC back contact single crystalline silicon solar module is shown in Fig. 3. Power voltage curves for the tested module for different irradiation levels and measured operating temperatures are also given in Fig. 4. Cell efficiency of the used module is 21.7% and module efficiency is about 18% where the maximum single crystalline Si cell efficiency is reported as 22.9% for a small aperture area when the system was installed (Green et al., 2009).

Night power assumption of each inverter is 0.3 W and maximum input voltage is 600 V. PV modules are mounted on two Pesos SF-40SD double axis sun trackers (pesos) in Fig. 5. Each tracker has a 40 m^2 mounting area and tracks the sun once with 8 min interval from sunrise to sunset during a day. Power consumption of each tracker was recorded as 100 W in 230 V/50 Hz while tracking and 0.5 W in rest mode (except night). For comparing the performance of different operating PV systems, one plane set to 28 fix tilt angle which is calculated to be the optimum tilt for Mugla (Eke 2000) while the other operates in double axis tracking mode.

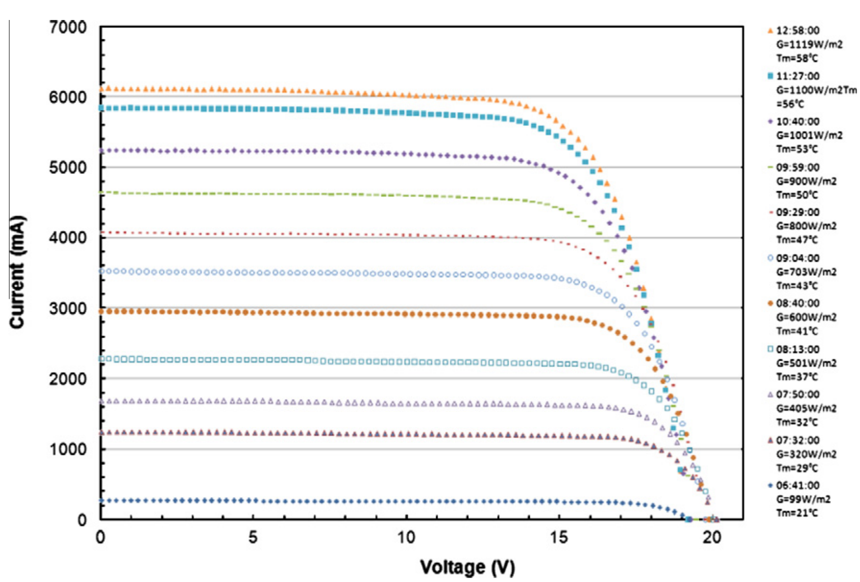

Fig. 3. Current–voltage curves of AS HPC95 PV Module for different irradiation levels in 26/08/2010.

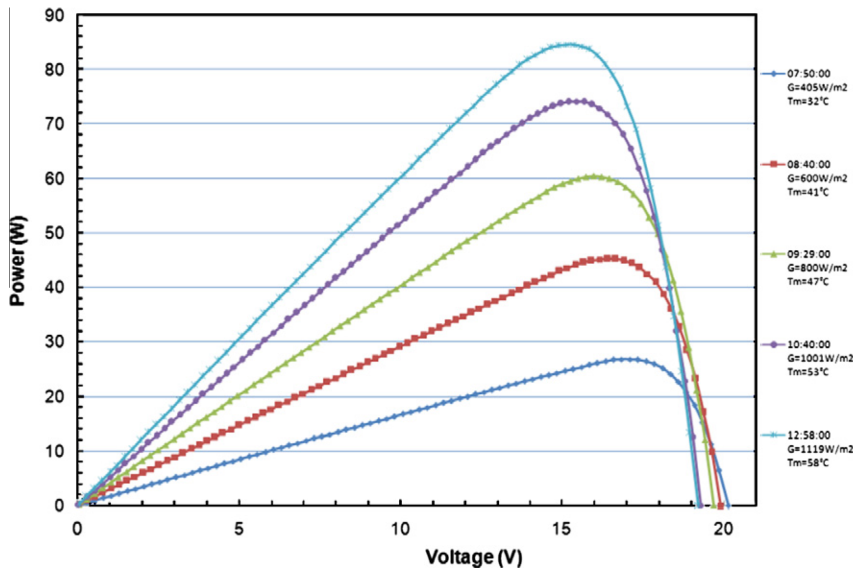

Fig. 4. Power–voltage curves of AS HPC95 PV Module.

Fig. 5. Double axis sun tracking PV systems at Mugla University campus (7.9 kWp each).

Fig. 6. Displays of PV systems.

Power output of the inverters, produced energy from startup and CO_2 savings are shown to the public in a display in Fig. 6.

Table 3
Operation of double axis tracking and fixed PV system.

	Double axis tracking		Fixed	
	August 26, 2010	January 18, 2011	August 26, 2010	January 18, 2011
Operation hours	12.45	12.45	9.30	9.30
Maksimum power (W)	6476	6942	6451	6298
Daily electricity yield (kW h)	71	48	52	40
Maksimum operating temperature (°C)	58.5	58.5	35.6	35.6
Average operating temperature (°C)	50	26	44	22

3. Simulation

For designing 7.9 kW_p PV systems on the demo site in Mugla University Main Campus a modeling software (PVSYST V5.05) is used (PVSYST, 2009). This software describes PV systems performance and losses under given conditions. The measured irradiation values and ambient temperature data is used for the weather data. Modules, inverters and the other design parameters are selected proper to the actual parts of the installed PV systems. The simulation for the 28 fixed tilt angle array showed that the calculated yearly electricity will be about 11.94 MW h with 0.772 performance ratio (PR) and 1512 kW h/kWp energy rating. The yearly electricity fed to grid will be about 15.98 MW h with 0.787 PR and 2023 kW h/kWp. According to the simulations it is calculated that 33.8% more electricity will be obtained in the double-axis sun-tracking system compared to the fixed system (Eke et al., 2010).

4. Performance results of PV systems

This study compiled, by a data-logging system, 10 min average radiation on both planes, operating temperature

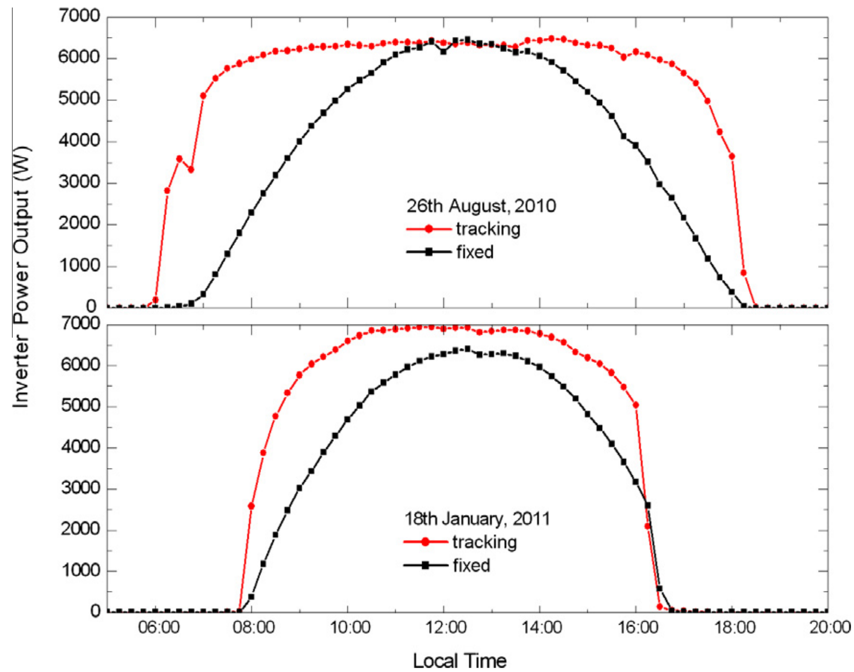

Fig. 7. PV systems operation in representative days.

of a PV module for each system, electricity values (current, voltage and power) on both sides (input and output) of the inverters in PV systems (Sunset 2011c). With this information, daily, monthly and annual average radiation, temperature and electricity were calculated for PV systems so as to determine the gain of using tracking systems.

Every part of the PV systems is identical so comparison of the obtained results is quite favorable. Two clear sky days representing a hot summer day (26th of August 2010) and a cold winter day (18th of January 2011) is selected. The results for the different operated PV systems for two selected days can be seen in Table 3.

Daily power output and PV module temperature variation of PV systems for representative clear days in summer and winter are shown on Fig. 7 and Fig. 8. According to these figures the systems reaches their maximum power about 12.30 and operates round 80–87% of their installed power. Maximum operating temperature of the PV module is measured as 58.5 °C in August and 35.6 °C in January. Because of the high collected irradiation on the PV module plane, average operating temperature of the PV modules on double axis tracking PV system is 24 °C over the operating temperature of the PV modules on 28 tilt fixed PV system. Daily yield of PV systems are measured as 71 kW h and 52 kW h for tracking and fixed PV systems respectively in 26th of August 2010 and 48 kW h and 40 kW h in 18th January 2011. Electricity gain for the double axis tracking vs. fixed tilt PV system is calculated as 36.5% in 26th of August 2010 and 20% in 18th of January 2011 as expected between the differences in operating durations.

As indicated in section 2, two inverters are used for each PV systems. Power conversion efficiencies of inverters for

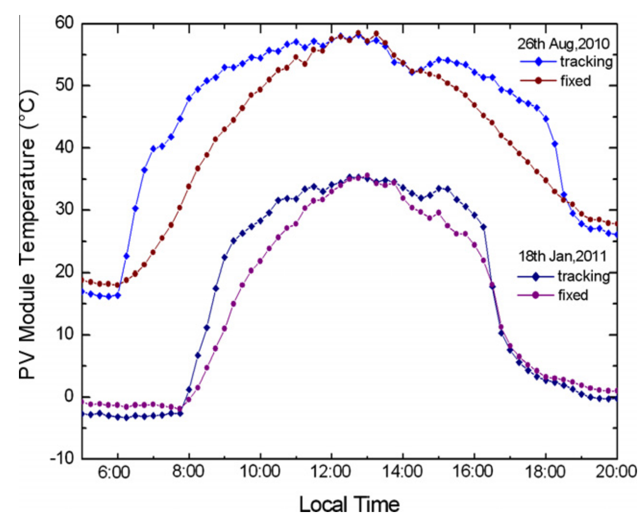

Fig. 8. Temperature variation of PV modules for representative days.

both PV systems are similar and vary about 94%. Measured efficiencies vs. output power for inverters used in PV systems are shown in Fig. 9 for summer and winter from sunrise to sunset. Although the PV system works on 10% of its rated power for low irradiation levels inverter efficiency is over 92%.

The electrical energy generated by the PV systems, has initially been calculated using the Software package PVSYST. Real data have been measured and compared with the simulated results. Monthly total electricity comparisons are shown in Fig. 10. Higher values are estimated (4.4% for the double axis tracking and 2.2% for the fixed PV system). The difference between the estimated values and measured values are lower than 5% and it is reasonable

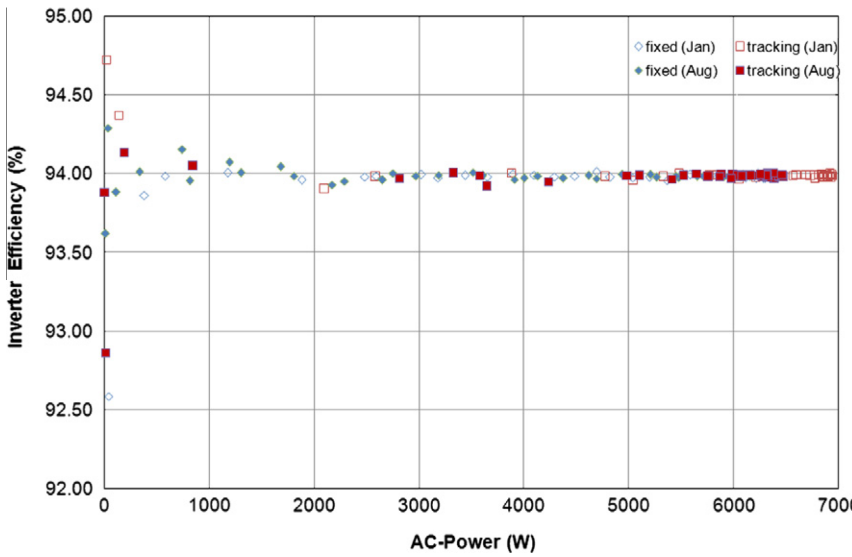

Fig. 9. Measured inverter efficiencies.

with respect to the difference in the irradiation data used in simulations to calculate the PV systems performance.

Daily produced electricity from the PV systems in summer (August 2010) and in winter (January 2011) are shown in Fig. 11. Maximum generated daily electricity from the double axis tracking system is recorded as 71 kW h in 26th of August 2010. In summer months there is only few closed days so daily produced electricity is calculated over 50 kW h/day for May to September. But in winter, the number of clear sky days are low so daily electricity is calculated as 16 kW h/day in Jan-2011 and 12 kW h/day in Dec-2010.

The measurements give a value of 15076 kW h/year electricity generated by the double axis tracking PV system. In contrast, the electricity production of the fixed PV system is measured as 11526 kW h/year. The performances of PV arrays are usually compared by the annual energy production normalized by peak power (kW h/kWp) (Ransome 2008; Kousa et al., 2011; Kenny et al., 2006; Kelly and Gibson 2009)Energy rating value for both planes (fixed and double axis tracking) are also calculated and compared. It is found that 1459 kW h/kWp for 28 °C fixed tilt angle and 1908 kW h/kWp for the double axis tracking system. Monthly energy gain and total yield of the PV systems are given in Table 4. Maximum energy gain is calculated as 42% in June 2010 and minimum energy gain is calculated as 17% in January 2011. Daily normalized energy is calculated as 6.95 kW h/kWp and 4.88 kW h/kWp for the

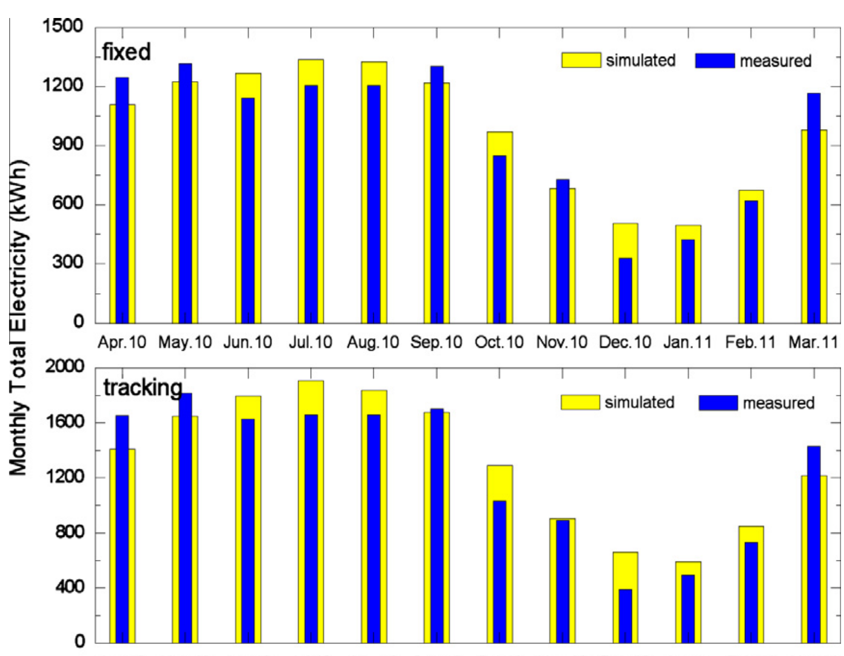

Fig. 10. Simulated and measured energy differences for fixed and tracking PV systems.

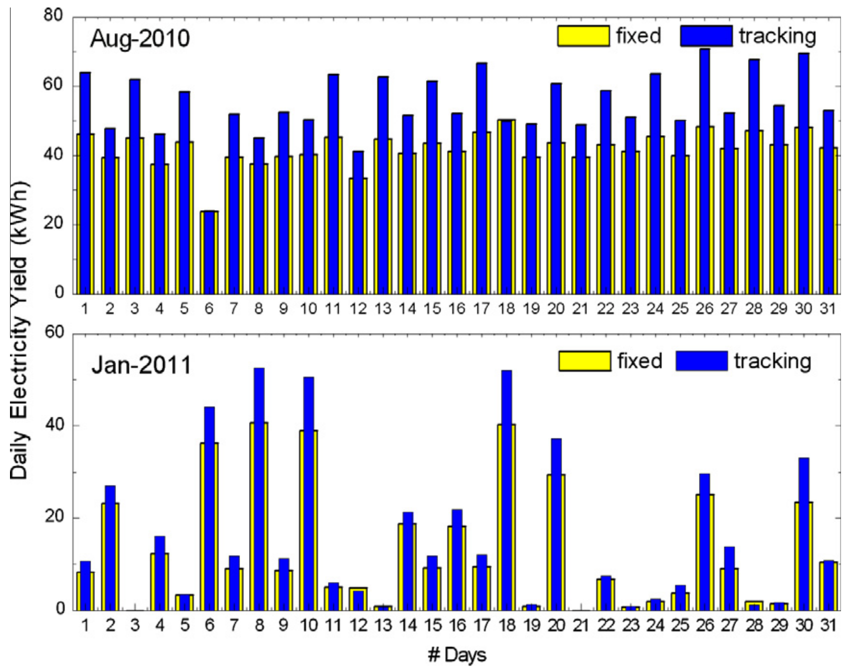

Fig. 11. Daily Electricity yield of PV systems for representative months of summer and winter.

Table 4
Monthly yield and energy gain of the double axis tracking PV system.

Month	Fixed (kW h/month)	Double axis tracking (kW h/month)	Gain (%)
April-10	157.65	209.32	32.78
May-10	166.80	229.90	37.83
June-10	144.80	206.26	42.45
July-10	152.67	209.92	37.50
August-10	152.67	209.92	37.50
September-10	165.16	215.63	30.55
October-10	107.61	131.12	21.85
November-10	92.48	113.10	22.31
December-10	41.45	49.40	19.19
January-11	53.49	62.56	16.97
Feburary-11	78.29	92.50	18.14
March-11	147.75	181.11	22.57

double axis tracking and fixed PV systems respectively for June 2010. Energy gain ratio is related to the operating hours of the PV system and the plane of irradiation. Monthly mean daily horizontal irradiation is measured as 7.58 kW h/m^2 and the operating hours is recorded as 13.30 h for the PV systems in June 2010. Beside this, monthly mean daily horizontal irradiation is measured as 1.50 kW h/m^2 and the operating hours is recorded as 9.30 h for the PV systems in January 2011. Yearly energy gain between the different operating systems is 30.79% for Mugla climatic conditions.

5. Conclusion

In this study photovoltaic double axis sun-tracking system is briefly described and annual performances of double axis tracking and fixed latitude tilt identical PV systems are summarized. The electricity yield is 11.53 MW h for fixed tilt PV system and 15.98 MW h for the PV system on the double axis sun tracker. It is calculated that 30.79% more electricity is obtained in the double-axis sun-tracking system when compared to the latitude tilt fixed PV system. The yearly total energy rating value for PV systems on the double axis tracking system with AS95HPC back contact mono crystalline silicon PV modules is calculated as 1908 kW h/kWp. Higher values are estimated (4.4% for the double axis tracking and 2.2% for the fixed PV system). The difference between the estimated values and measured values are lower than 5%. A selected AS 95HPC PV module is tested under real conditions in August 2010 and the PV module power is calculated as 83.12 W for 72 °C operating temperature. The measured and calculated power value of the PV module at this operating temperature fits well.

This installation gives the advantage of testing back contact mono crystalline silicon PV modules and the performance of large scale tracking PV system for Mugla climate in Turkey.

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