SOLAR ENGINEERING 2002

Proceedings of the International Solar Energy Conference
ASME Solar Energy Division

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SOLAR-PV WATER PUMPING WITH FIXED AND PASSIVE TRACKING PANELS

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ABSTRACT

A solar-PV (photovoltaic) water pumping study for pumping water for livestock was conducted over a 4-year period to determine the difference between using a passive one-axis tracking system compared to a fixed panel system. The passive tracking system provided 19% more power than the fixed panel system during the spring and summer, but only 15% more water was pumped. The power increase was restricted to 19% because of wind blowing the panels from the optimum position and the solar radiation being dispersed on partly cloudy and cloudy days. The reason the increase in the water pumped for passive tracking was lower than the increase in power was due to the controller restricting the power going to the pump. During the winter and fall, the amount of time it took for the panels to point from west to east (early morning wakeup) reduced the performance of the passive tracking system. The water pumped by either the fixed or the passive tracking system was essentially the same during late fall and winter.

1. INTRODUCTION

Solar passive tracking systems have been used for over 2 decades. The purpose of the solar tracker is to increase the solar power of the panels by keeping them pointed at the sun. The passive tracking system in our study tracked the sun from east to west on a single axis using gravitational forces as the result of the exchange of Freon[a] (due to sun's heating) between two cylinders located on the east and the west ends of the solar panel array. A very good description of the Zomeworks[a] passive solar tracking system (the one used in our study) can be found at the following website: www.zomeworks.com/solar/trackrack/trackwork.html.

Using solar-PV panels with DC motor/pump to pump water from shallow (less than 60 meters) underground wells has been quite common in areas with a good solar resource. This paper quantifies the various efficiencies (panel, pump, system) of the passive tracking and fixed panel systems. This paper also presents the amount and percentage change in power and water volume for a passive tracking system compared to a fixed panel system in Bushland, TX, over a 4-year period.

A theoretical performance calculation of one-axis and two-axis tracking systems was compared to a fixed tilted solar array [1]. The difference between the theoretical and the measured performance of these tracking and fixed systems had an average root mean square error of about 7.5 %. The author in [2] compares tracking (motor driven) panels to a fixed panel system and showed a 21% improvement in power during spring, summer, and fall for tracking. This same study showed little improvement or actual degradation in power in winter for tracking. The effect of temperature, early morning wakeup, and wind on the Zomeworks passive tracker were investigated over a 9-month period with a resistive electrical loading [3]. The effect of temperature (higher temperature causes a decrease in solar panel efficiency) according to this author caused less than a 2% degradation for passive tracking (faces sun more so gets hotter) compared to fixed. This study also found the early morning wakeup energy loss of the passive tracking panels compared to the fixed panel system was much worse in the winter than in the summer. This previous study on the Zomeworks tracker determined that the passive tracker panels would be affected by winds greater than 7.5 m/s from the southwest with a panel angle tilt of 45°. A paper has already been published on the first year of performance of the passive tracking and fixed panel system at Bushland, TX, [4].

2. EXPERIMENTAL SETUP

In Jan. 1996 a study was begun at the USDA-ARS Conservation and Production Research Laboratory in Bushland, TX to analyze the benefit of using a passive tracking system for pumping water for livestock. Zomeworks one-axis passive trackers were installed on two different polycrystalline silicon panel systems containing two modules. Each panel was rated at 50 Watts and the panels were connected in series. Each set of panels was connected to a Solarjack[a] controller (PCA 10-30 on tracking and PCA 10-28H on fixed) which restricted the DC power to 50 Watts going to the Solarjack SDS D-228 diaphragm pump. The controller also optimized the voltage and current going to the pump for a solar irradiance below 700 W/m^2.

Previous research [5] showed that the lifetime of a submersible DC solar pump was greatly decreased at a 50 meter pumping depth; therefore, a 30-meter pumping depth was chosen for this study. The pumping depth of 30 m was simulated during the entire study on each system using a back pressure regulating valve and a pressure tank. The flow rate was measured on each system with a turbine meter equipped with an electronic output. Other measurements on both the fixed and passive tracking systems included:

1. water pressure – psig (kP)
2. irradiance – W/m^2
3. Voltage – V (between controller and pump)
4. Current – A (between controller and pump)

All data were sampled every 1 sec and the averaging interval was 1 min. Data were recorded onto a data logger and the 1 min averages where stored for further processing.

3. RESULTS

3.1 Measured Efficiencies of Tracking & Fixed Systems

The pumps on the tracking and fixed panel systems had different flow rates; therefore, the measured flow rates were averaged for the tracking and fixed systems (Fig. 1). The flow rate was gradually decreasing over this 4-year period, but considering the fact that the pumps were working all the time when there was sunshine during this period, the loss in performance was minimal. For the first 1.5 years of the study, the voltage and current between the controller and the diaphragm pump were measured. This enabled us to calculate panel and pump efficiencies. Fig. 2 presents the panel efficiency measured without restriction until the controller restricts the power going to the pump at approximately 50 W. The panel efficiencies of the fixed and tracking systems were very similar (within about 0.5%).

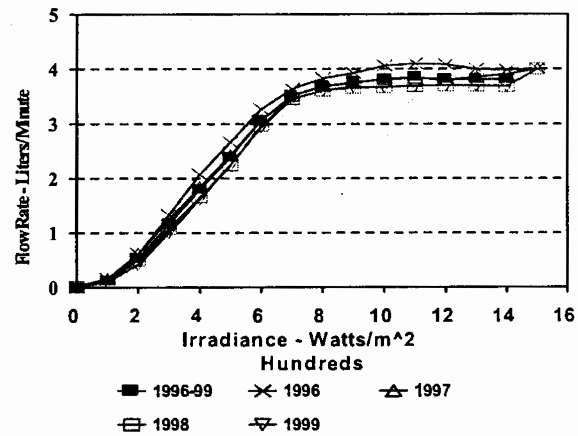

Fig. 1: Avg. measured flow rate of tracking & fixed panel systems (30m head, Bushland,TX,1996-99).

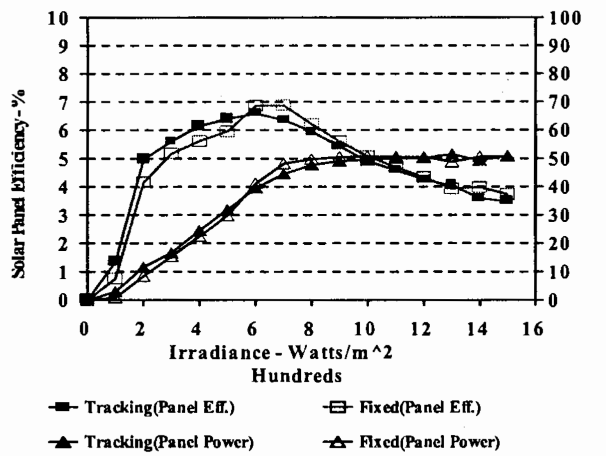

Fig. 2: Solar panel efficiency and power in 1996 of solar panel systems (Bushland, TX).

The peak measured panel efficiency was about 7% but was reduced when the controller restricted the power delivered to the pump. The peak measured voltage was about 30 V and the peak current was 1.7 A. The pump efficiencies of the tracking and fixed systems are presented in Fig. 3. The pump efficiency of both pumps usually ranged between 35 and 40%. The average system efficiency for each year is presented in Fig. 4. The slow decrease in flow rate is reflected in lower system efficiencies in the later years.

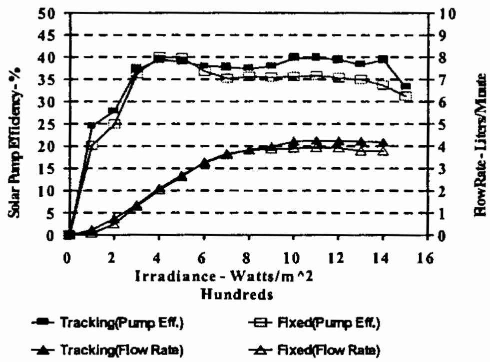

Fig. 3: Solar pump efficiency and flow rate in 1996 of Solarjack pumps (30m head, Bushland, TX).

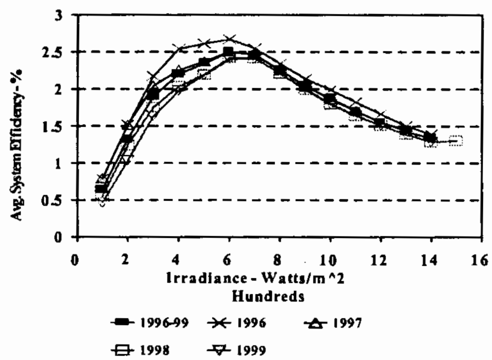

Fig. 4: Avg. System Efficiency of tracking & fixed panel systems (30m head, Bushland,TX,1996-99)

3.2 <u>Solar Panel Tilt Angle Setting</u>

A previous study at Bushland [6] considered three potential solar panel angle settings:

(1) the optimum panel angle set daily for Bushland, TX, (12 °N to 58 °N)

(2) the panel angle set to the latitude of Bushland, TX, (35 °N)

(3) changing the panel angle twice per year during the equinoxes – fall and winter (45°) and spring and summer (25°)

A simple cosine relationship was used to estimate the loss in solar energy due to the panel angle setting not being optimum. The equation used to calculate the energy loss was:

energy loss = {1 - COS[ABS(Opt. Ang.-Panel Ang.)]}

The approximate maximum decrease in solar energy from optimum when using one panel angle (35°) was 9% and when using two panel angles (25° and 45°) was 3%. Since there was only a maximum loss in energy of 3% for the changing the panel angle twice per year compared to 9% for leaving the panel angle the same all year long, we changed the panel angle in this study for both fixed and tracking panels twice per year at the equinoxes from 1996 to 1999.

3.3 <u>Effect of Early Morning Wakeup on Passive Tracking System</u>

The loss in energy of the passive solar tracking system in winter and summer is presented in Fig. 5 and 6. In winter it can take an hour or more for the panels to turn from pointing to the west to pointing to the east. It may take longer than an hour if there are thin clouds blocking the sun early in the morning which disperses the sun's radiation needed to warm the Freon – heating of the Freon is integral to the function of the passive tracking system. For this particular winter day (Fig. 5) the panel took about 45 min to go from pointing west to pointing east. There was only about a 2% loss in water pumped compared to the fixed setting. However, if the panels had been pointing east at

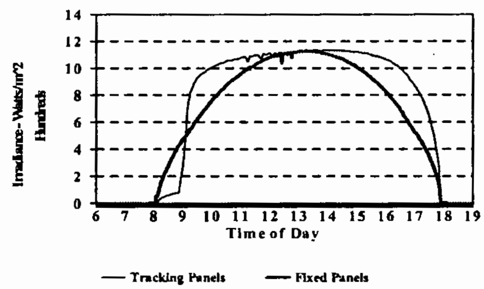

Fig. 5: Effect of sunrise on passive tracker in the Wintertime (Jan. 8, 1996, Bushland, TX).

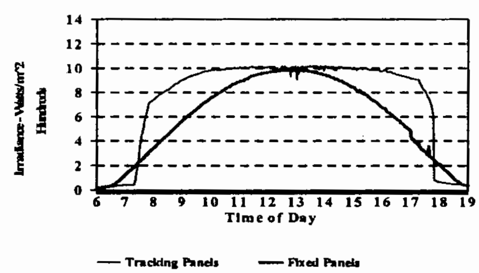

Fig. 6: Effect of sunrise on passive tracker in the Summertime (Jun. 21, 1996, Bushland, TX).

8:00 a.m. then there would have been a 10% increase in water pumped when comparing tracking pointing west to tracking pointing east at 8:00 a.m. For the summer case (Fig 6) the percentage change in water pumped is much smaller because the irradiance intensity required to heat the Freon is much less. The finding that early morning wakeup cause a significant decrease in performance of passive tracking panels during winter but not during summer was also found in [2,3].

3.4 Effect of Wind on Passive Tracking System

The effect that wind has on a passive tracking system is presented in Fig. 7 and 8. Fig. 7 shows how the passive tracking system performed on a calm day (wind speed < 5 m/s). Fig. 8 shows how the passive tracking system typically behaved when it was windy (wind speed > 8 m/s) with a southwest wind direction. The wind had little effect on the passive tracking system until the wind speed reached 8 m/s and was blowing from the west. The wind would then flip the panels to a full east (early morning) position, then the heated Freon would move the panels back to the normal position. The panels would oscillate between these two positions. In late afternoon after the panels faced perpendicular to the wind, the panels were facing the sun in the west. These effects of wind on passive tracking have

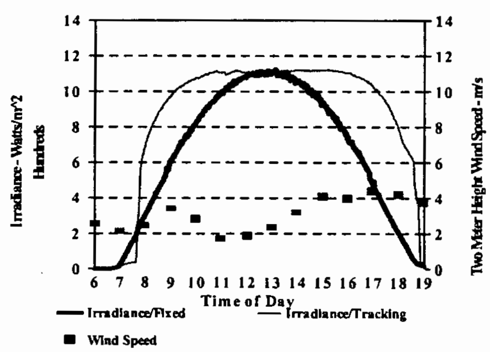

Fig. 7: Fixed and passive tracking panels on a calm day (Bushland, TX, Mar. 31, 1996).

also been observed in [3]. There is a high wind passive tracking system (at an extra cost of $200) developed by Zomeworks which was not tested – it basically uses two shock absorbers instead of just one.

3.5 Sun Energy and Water Pumped

The bottom line for whether the passive solar tracking system is cost effective depends on how much more solar energy can be collected and ultimately how much more water can be pumped. The amount of sun energy collected by both the fixed and passive tracking systems in Bushland, TX, for the period 1996-1999 maximized in the spring but remained fairly constant during the rest of the year (Fig 9). The amount of additional energy collected by the tracking system was lowest in the late fall and winter months (i.e. close to winter solstice). However, the amount of additional energy collected by the passive tracking system in the hot summer months was substantial. Fig. 10 presents the percentage increase in daily solar power which averaged about 19% for the spring and summer months. This compares favorably to the 21% increase in solar tracking (motor driven) to fixed panels in another location – Widderstall, Germany [2].

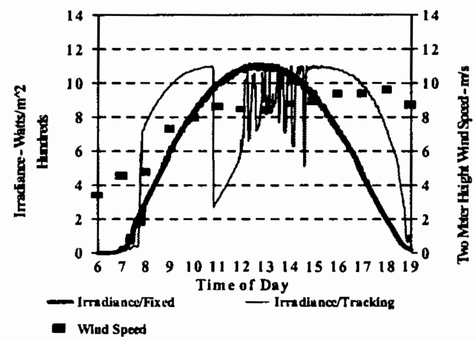

Fig. 8: fixed and passive tracking panels windy day (Bushland, TX, Apr.1, 1996)

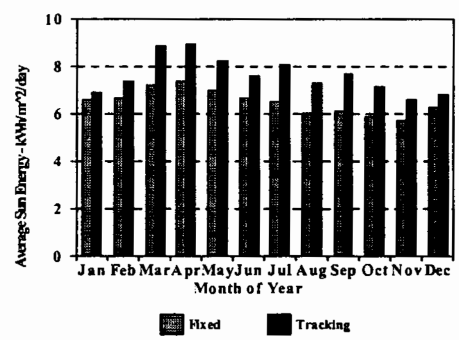

Fig. 9: Comparison of solar energy collected by fixe fixed and passive tracking panels (Solarjack pumpumps, 30m head, Bushland,TX,1996-99).

Fig. 11 shows the average monthly water pumped at Bushland, TX, for both fixed and passive tracking panels. In the months of January and December, the passive tracking panels pumped about the same amount of water as the fixed panels. This result differs from the amount of energy collected because the controller restricted the amount of power going to the pump for an irradiance above 700 W/m^2. About 15% more water was pumped during the spring and summer months (Fig. 12).

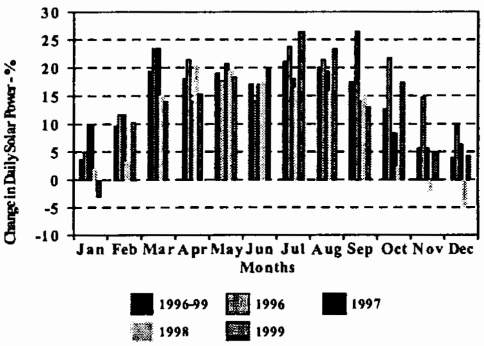

Fig. 10: Change in solar power collected due to using passive tracking instead of fixed panels (Bushland, TX, 1996-99)

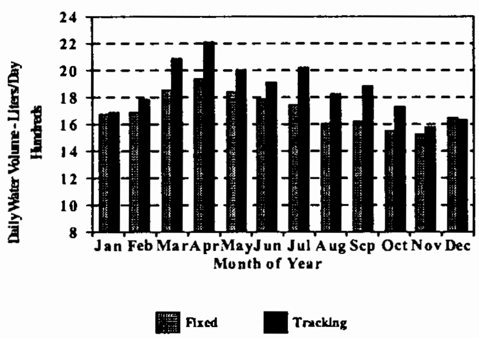

Fig. 11: Comparison of daily water volume for fixed and passive tracking panels (Solarjack,30m head, Bushland,TX,1996-99).

3.5 Cattle Water Requirements

The amount of water needed by cattle can vary greatly (35L to 50L per day) depending on the size of the cattle, time of year, and whether they are on range or in a feedlot. Range cattle consume more water than feedlot cattle [7]. Assuming a cow needs 35L/day in the winter and 50L/day in summer, the number of cattle watered by this system can easily be obtained. Additional water is needed in summer not only because livestock need more water due to the higher temperatures, but because most livestock water is pumped into stock tanks and evaporation is much higher in summer than winter. This passive tracking system should provide water for 46 cattle in winter and 40 in summer at a 30 m head for a solar resource similar to Bushland, TX. Since the passive tracking system works better in the hotter summer than the cooler late fall and winter, the passive tracking system should help meet the cattle water requirements better than the fixed panel system.

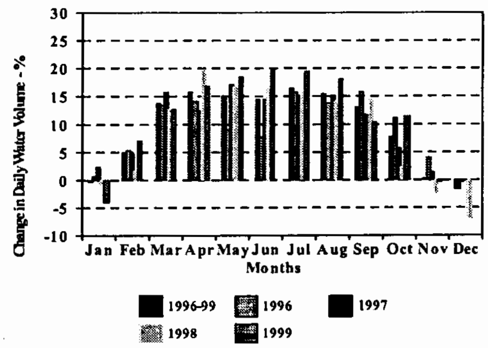

Fig. 12: Change in daily water volume due to using passive tracking panels instead of fixed panels (Solarjack pumps,30m head, Bushland,TX,1996-99).

4. CONCLUSIONS

Data were collected at Bushland, TX, over a four-year period on a fixed panel system and a passive tracking system, and the passive tracking system pumped about 15% more water during the spring and summer than the fixed panel system. The passive tracking solar system could have pumped more water if:

1. the site wasn't as windy
2. the controller didn't restrict the power going to the pump for irradiance levels above 700 W/m^2
3. there were less partly cloudy and cloudy days.

A device to point the panels in the east, so no loss of power in the early morning would help in the winter, but would probably not help significantly in the summer when the water is needed the most. A passive tracking system for a 30 m well using a Solarjack D-228 diaphragm pump with a solar panel rating of 100 W will water about 40 cows compared to 35 cows for the fixed panel system. There have been no breakdowns on either solar panel system for 6 years – no problems with solar modules, Zomeworks tracking system, the Solarjack controllers, or the Solarjack pumps.

We cannot estimate how many more cows a motor driven tracking system could water than the passive tracking system since this type tracker was not tested in our study. However, reference [8] determined the monthly daily average tracking (motor driven) and fixed panel insolation for Amarillo, TX, based on horizontal irradiance data collected at the airport. A comparison of this data compared to the data we collected at Bushland, TX, (30 km away) would make us estimate that the motor driven tracker would collect about 34% more solar energy during the spring and summer than the fixed panels (this is about 80%

more than the amount the passive tracking system collected). Of course, the reliability of the system will be decreased with a motor driven tracker due to the possible breakdown of the motor.

It is difficult to determine whether the passive tracker would be economical for ranchers or farmers. Each user will have to make a determination whether the additional water in the spring and summer would make it cost effective. For two solar panels the cost difference between having a passive tracking or a regular fixed panel system is between $300 and $400. The total system cost of the fixed panel solar system is about $2000. Purchasing more panels would not produce more water because this pump has a maximum pumping rate of 4 L/min. If more water is needed, a different pump would be required.

5. ACKNOWLEDGMENTS

We would like to thank Chad Jones and Jeremy White, USDA-ARS student employees, and Shitao Ling, WTAMU-AEI (West Texas A&M Univ. – Alternative Energy Institute) employee for maintaining the equipment and instrumentation on the solar systems and processing the data needed for this paper. Special recognition goes to Sara Ledbetter for spending days checking and correlating the irradiance on data that was collected on both the fixed and passive tracking systems.

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