Design, Fabrication and Preliminary Testing of a Two-Axes Solar Tracking System

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ABSTRACT

A two-axes equator based tracking mechanism with computer control for solar photovoltaic modules has been designed, fabricated and tested. The performance of the system is quite satisfactory; the tracking error is quite small. Tracking leads to an increase in the output of the PV modules typically by about 30 %. The operation of the tracker is found to consume a very small fraction of the output power.

1. INTRODUCTION

Tracking is desirable for orienting a solar device towards the sun thereby collecting maximum solar energy and improving efficiency. In case of photovoltaic applications, tracking has been found to be much more advantageous. It has been estimated that tracking of cells yield 20 % to 60 % more power for conventional cells. Experiments conducted by Mosher et al. [1] show that the output of a tracker solar cell is 31 % greater than that of an identical conventional stationary solar cell on a clear day while operating at near maximum power loading. Thus sun tracking for cell is preferable to stationary mounted cell as long as the operation of the tracker can be ensured to consume a very small fraction of the output.

Generally, there are two types of tracking modes such as one-axis (either horizontal, vertical or latitude axis) tracking and two-axes (azimuth - altitude or hour angle - declination) tracking. But by means of suitable control electronics, it is possible to design tracking system using a large variety of rotational axes or linear motions. Recently Davies [2] has proposed a new concept that uses, in addition to the familiar equatorial axis, a second axis perpendicular to the ecliptic plane. The two axes are parallel to those of spin and orbital motion of the earth. There are three general categories of sun trackers namely passive type, programmable type and electro-optically controlled type [3]. Any tracking system essentially consists of a sensor and a controller. Various kinds of sensors have been reported in literature [4,5]. Different types of controls have been suggested and implemented by various workers [6,7]. Some of the practical problems have been [3]:

1. Poor performance in partly cloudy or hazy weather by systems for not getting tracking mechanism activated due to unavailability of sufficient sun's ray.
2. Time consuming initial alignment and frequent readjustment of some sensors.
3. Overriding of limit switches causing damages.

Various mechanisms exists for automatic solar tracking, but some of them are either very complex, bulky or need some form of manual adjustment [6]. Under this background, a project has been undertaken to design, fabricate and test a two-axes solar tracking system, controlled completely by a computer, for two photovoltaic modules. This paper reports the results of such investigation.

2. TRACKING MECHANISM

A two-axes tracking system has been designed and fabricated. The basic principle underlying the choice of the tracking mode refers to the consideration of the consumption of power by the tracker. Unlike azimuth altitude angle tracking mode where both axes could be required to be rotated by about 180° over a day, two-axes tracking based on equatorial system consumes less power. This is because in the later case, the rotation of the polar axis would be around 180° while that about the declination axis would be a fraction of a degree over a day.

Schematic sketch of the tracking mechanism is shown in Fig. 1. It consists of a frame rigidly attached to the declination shaft. The shaft is made to rotate at a speed equal to the rate of change of declination angle with time. Consequently, its motion cancels out the effect of earth's revolution

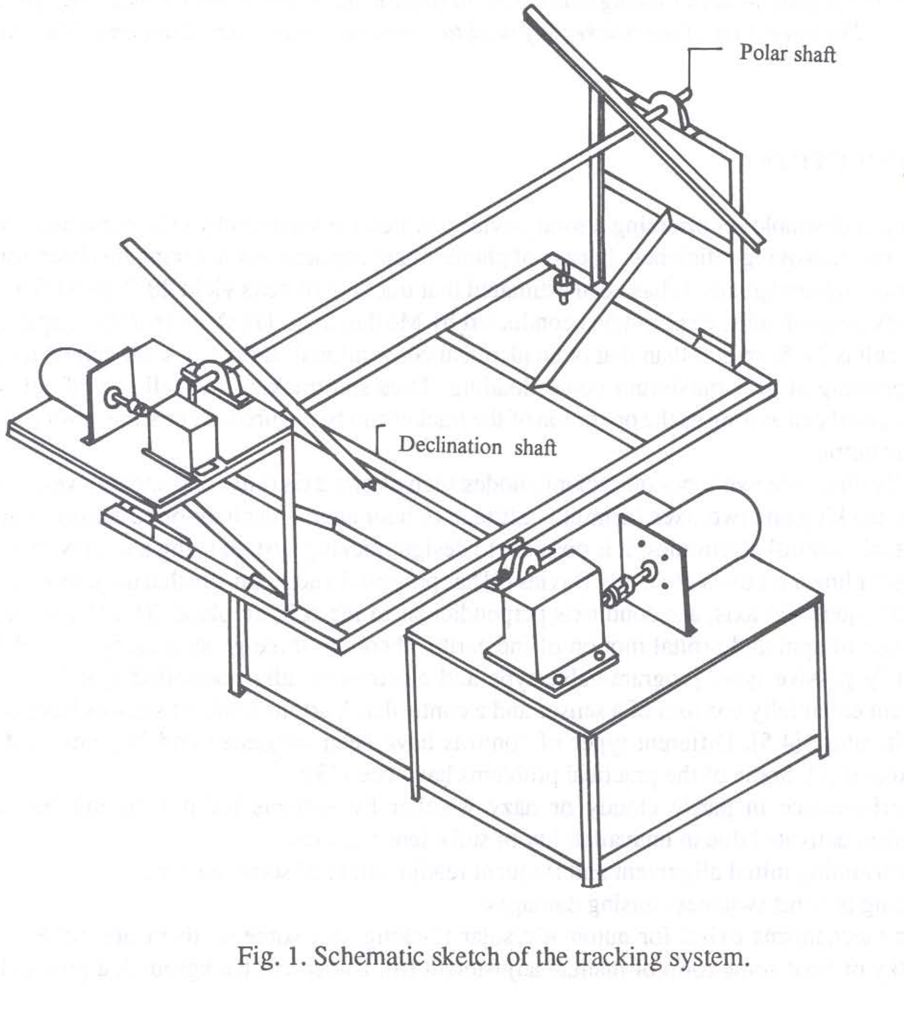

Fig. 1. Schematic sketch of the tracking system.

around the sun. Suitable supports are mounted on this rotating frame to hold polar shaft so that the rotation around the declination shaft tilts the polar shaft. The polar shaft in turn is rotated at a constant speed of 15° per hour so that it cancels out the effect of the earth's diurnal motion. Thus PV modules resting on a rigid frame attached to the polar shaft is always perpendicular to sun rays. The design of the structural components of the tracking system has been done taking into account the self weight, wind forces and load imposed due to tracking motion.

Drives of both the axes consist of permanent magnet DC stepper motor (its detent torque avoids rotation due to wind load and self weight of the modules) with reduction gear box . The gear boxes are primarily meant for increasing the torque rather than for imposing tracking resolution. Hence a 1.8° stepper motor is used instead of micro-stepper motor which is expensive. Unidirectional gear box such as worm and worm gear are used to prevent false rotation due to random wind motion. The power needed to drive the tracker has been found to be very small.

3. PC BASED CONTROLLER

A controller of the tracking system generates actuating signals for drivers to correct misalignment between sun's ray and the surface normal. In the present case, a personal computer based controller is used since the same machine can acquire and process the data from PV modules. The computer used is on IBM compatible 486 DX-2 machine. However, the same controller can work without any modification in any IBM compatible PC. The controller and its associated software performs the following operations:

1. Two 4-phase stepper motors are simultaneously controlled.
2. Status of 5 on/off type sensors (high wind cut-off, extreme left and right positions for both the frames) is monitored.
3. It has the position of acquiring data (up to 8 channels) and pass them one by one through one channel of an existing data acquisition system.

Fig. 2 shows a block diagram of the controller. The controller circuit can be divided into two parts - controlling logic and power circuit. The former is a specially designed I/O card, having parallel input and output PIO chip and is inserted through 62 pin expansion slot available on the mother board of a PC-AT. All the control signals, address bus and data bus are buffered using octal buffers/traceivers. The PIO can be selected using appropriate address through the decoding and chip select logic. One of the 8-bit port of the PIO is configured as output port in Bit set/reset mode. Each output signal is optoisolated and passed to the power circuit to the drive stepper motors. Another port of the PIO is configured as an input port that reads status of the limit switches and wind sensor through optoisolators. 3-bits of the third port are given to analog multiplexer which passes input parameter (voltage/current feedback of the PV cells) one by one to the data acquisition system. The power circuit consists of a 12 V, 5A power supply and darlington pair transistors [8].

The controlling action is determined by software which does the followings :

1. If the panel is in reference position (perfectly horizontal in our case), tracking is started till the angle of incidence at that particular time becomes zero.
2. The rotation of the motor is only from sunrise to sunset.
3. It remembers the last position at the end of the day and use it the next day.
4. It takes care of the switching sequence of the stepper motors.
5. It stops the rotation if limiting position is reached.

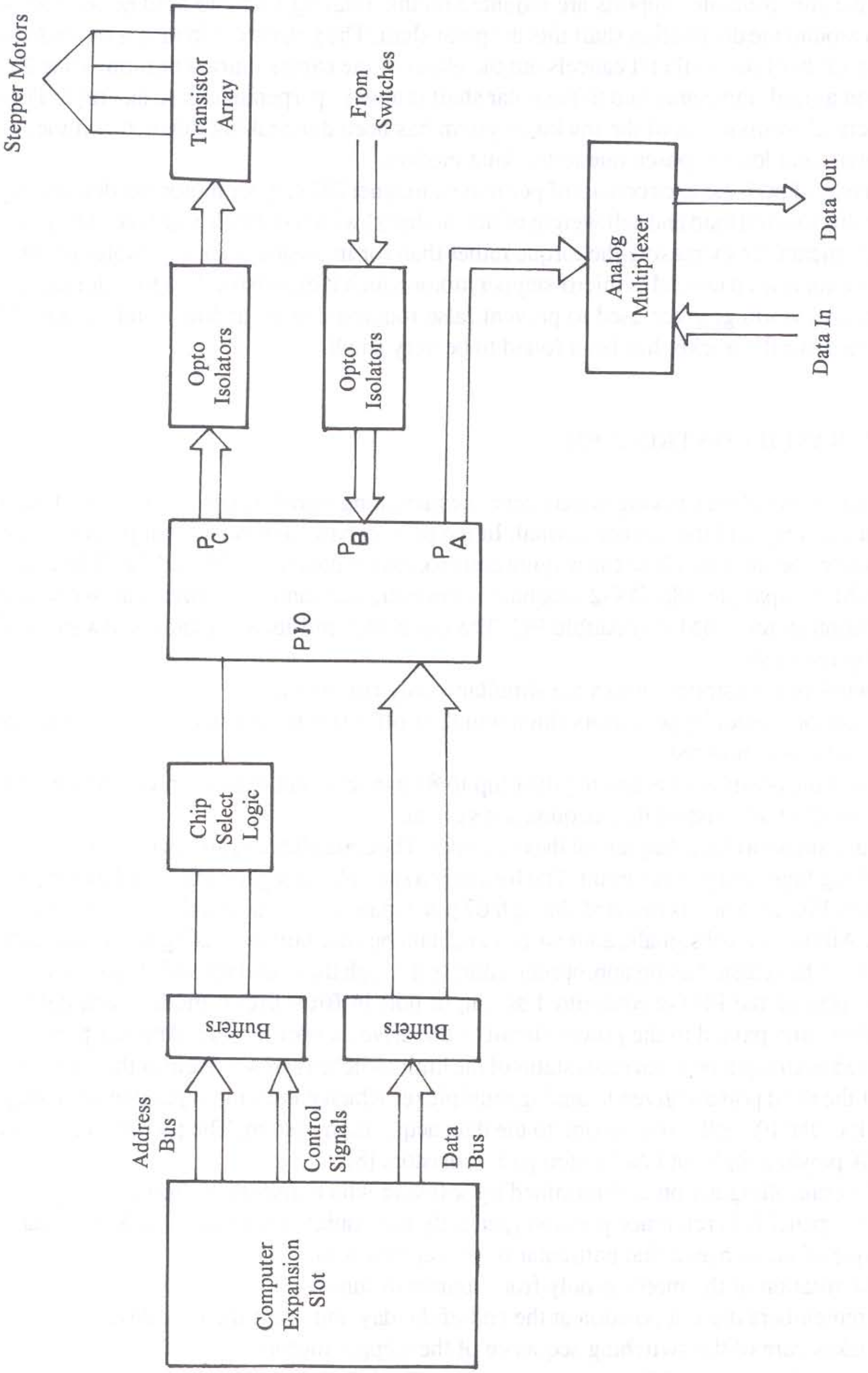

Fig. 2. Block diagram of controller.

4. RESULTS AND DISCUSSIONS

The tracking system has been installed by orienting it to the due equator and shafts are rotated either manually or through computer program to bring the PV modules to perfectly horizontal position. This is the reference position for the program and from this position tracking operation starts.

The performance of the tracking system has been tested for several days. A perfect two-axes tracking should lead to zero angle of incidence at all times; hence deviation from this is a measure of inaccuracy. A shadow method is used to find out the inaccuracy. A pin is fixed normally to the plane of the PV module; its shadow on the graph paper fixed in the plane measures the tracking error (Fig. 3). It can be seen that the x-axis and y-axis projections lead respectively to estimation of errors in tracking for polar and declination shafts.

Table 1. Tracking error.

Local Time (h)	0845	0915	0945	1015	1130	1200	1300	1330	1400	1430	1600	1630
Error (degree)	1.0	1.3	1.6	1.7	2.2	2.8	2.9	4.0	4.2	5.0	6.7	7.2

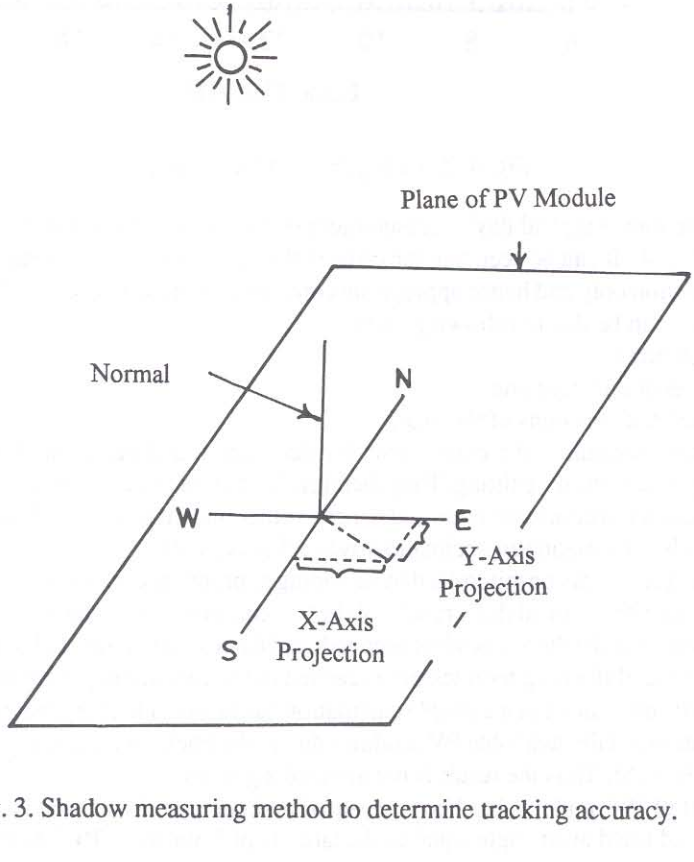

Fig. 3. Shadow measuring method to determine tracking accuracy.

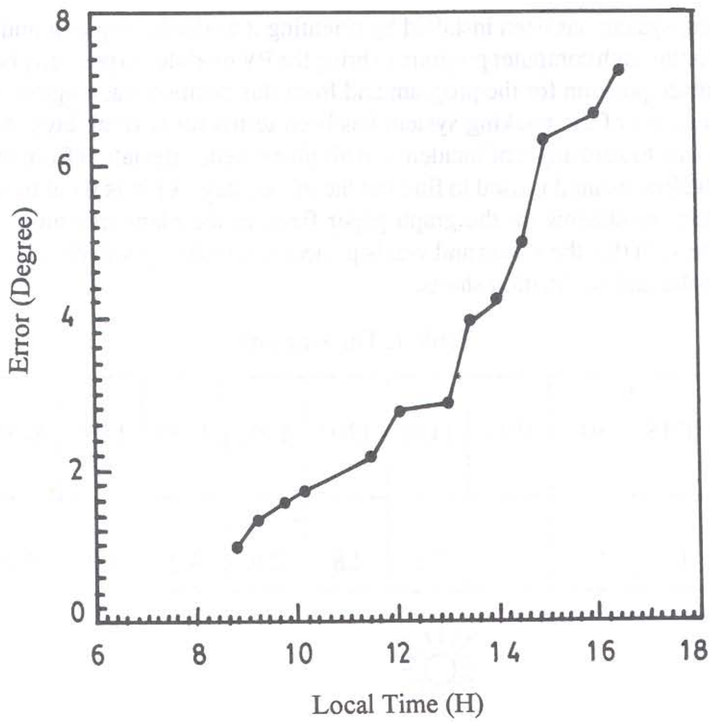

Fig. 4. Tracking error (typical values).

Table 1 presents a typical day's measurement of inaccuracy; the result have also been shown graphically in Fig. 4 . It can be seen that the error in the shaft rotation is increasing, over a period of time, in one direction only and hence appropriate correction can easily be made. The probable reason of the inaccuracy can be due to following facts:

a) Fabrication error.
b) Backlash (gear and coupling).
c) Unequal teeth dimensions of the gear.
d) Approximate formulae (the expressions for declination and equation of time correction are essentially based on curve fitting. They therefore lead to some deviation. Further, the expression for declination is true at solar noon and hence at other time, it is likely to lead to incorrect values even though the variation in declination over a day is small).

The tracking errors can be minimized by including appropriate correction factors in the software. This has been done and a typical day's results of the tracking errors after the corrections are presented in Table 2. It shows that the inaccuracy has been reduced from a maximum of about 7° to about 3°. This can further be reduced if a long term testing is carried out to identify appropriate correction factors. It may however be mentioned that a simple calculation has been made to estimate the reduction in the output of the commercially available PV modules due to the tracking inaccuracy of 3°; the reduction is only about 1.6 % [8]. Thus the result is not affected significantly.

The output of PV modules has been measured and compared with that of stationary modules facing equator and tilted at an angle equal to the latitude of Bombay (19°). The results are presented

Table 2. Tracking error with correction factors.

Local Time (h)	0745	0815	0930	1020	1100	1230	1310	1400	1430	1500	1600	1630
Error (degree)	1.0	1.3	1.5	1.4	1.7	1.4	1.4	2.0	2.1	2.5	2.9	2.9

Table 3. Output of PV modules.

December 30, 1995			December 31, 1995 (Partly Cloudy)		
Local Time (h)	Tracking Module (W)	Stationary Module (W)	Local Time (h)	Tracking Module (W)	Stationary Module (W)
0815	9.4	7.6	0920	15.5	11.7
0930	17.1	12.1	0930	12.6	10.0
1020	24.7	15.2	1010	18.4	13.4
1100	23.3	17.3	1045	23.0	15.8
1230	25.3	19.6	1100	21.7	15.6
1315	25.2	19.3	1130	19.6	15.2
1335	24.4	17.2	1235	23.6	16.6
1400	24.4	16.9	1255	23.6	16.5
1430	21.3	13.3	1400	22.2	14.4
1500	21.3	11.6			
1600	21.8	11.8			
1650	13.8	7.5			

in Table 3 and graphically in Figs. 5 and 6. It is seen that the tracking increases the output by about 30 % as expected. With maximum power point tracker the increase will be higher.

5. CONCLUSIONS

1. A two-axes equatorial based tracking mechanism with computer control has been designed, fabricated and tested. The performance of the system is found to be quite satisfactory, the maximum deviation being about 3° over a day. Theoretically this much of deviation does not lead to any significant effect.
2. Tracking yields an increase of the output of the PV module by about 30 %.
3. The power needed to drive PV modules is found to be very small.

6. REFERENCES

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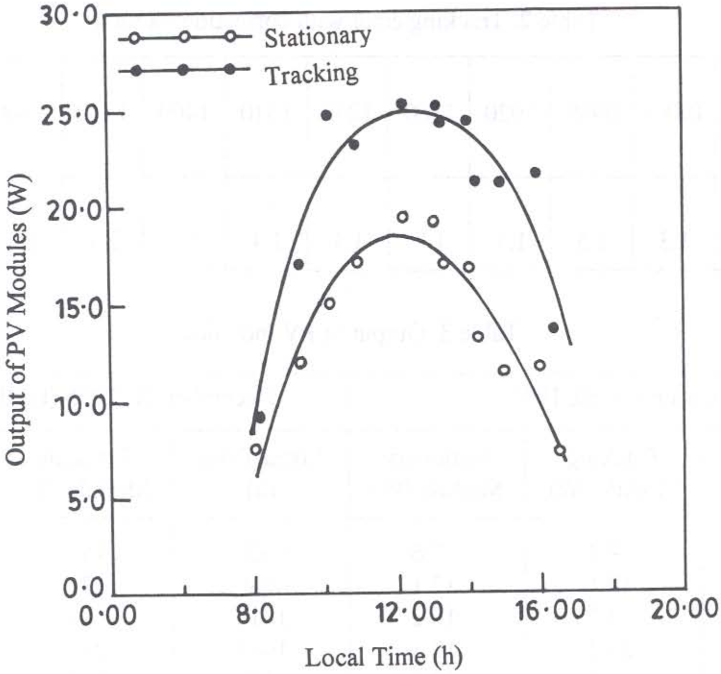

Fig. 5. Comparison of output of PV modules (December 30, 1995).

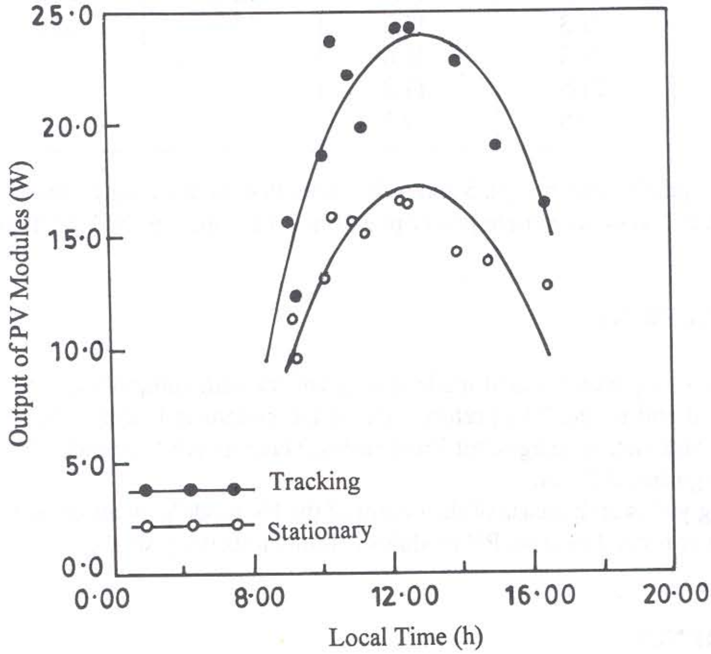

Fig. 6. Comparison of output of PV modules (December 31, 1995).

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