Solar Tracking for Maximum and Economic Energy Harvesting

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***Abstract*— This paper deals with the development of fully automated environment sensitive solar tracking system to maximize solar energy harvesting economically and efficiently. It is controlled by micro-controller with necessary interface. Limit switches are used to bring back the panel to morning position after each day without human interference. Hardware implementation aims at friction free system. Worm gear mechanism is used to tolerate any environmental forces including wind or any backlash forces.**

Keyword-Limit switches, micro-controller, solar energy, worm gear mechanism

I. INTRODUCTION

Recent developments in solar energy focus on maximizing system efficiency. Solar tracking is used to improve the efficiency. The energy derived from the solar cells, is highly non-linear in nature, it varies randomly depending on environmental conditions like temperature, intensity of radiation and partial shading effects. Nonlinear VI characteristics of Photovoltaic cells [1], and changing climatic conditions increase the need for an efficient sun tracking system technology [2], [3]. Various methods are developed for efficient and cost effective tracking systems with the objectives of friction free, sensitive and efficient sun tracking system. Maximum energy harvesting is not achieved with photo-voltaic cells installed in fixed panel throughout a day. Automatic tracking system tracks the sun such that the panel is aligned normal to sun at all instants of a day.

Several methods of sun tracking systems have been surveyed and evaluated to keep the PV cells perpendicular to the sunlight. An ideal tracker would allow the PV cells to accurately point toward the sun, compensating for both changes in the altitude angle of the sun (throughout the day), latitudinal offset of the sun (during seasonal changes) and changes in azimuth angle. Tracking with reference to latitudinal offset increases the system cost. Single axis system tracking the altitude angle is considered. Two main types of sun trackers exist: passive (mechanical) and active (electrical) trackers [4]. One class of the passive solar trackers is the fixed solar panel. It is placed horizontally on the fixed ground and face upwards to the sky. But most of the passive solar trackers are based on manual adjustment of the panel [5]. Major active trackers are based on microprocessor / computer controlled date and time / auxiliary bifacial solar cell / combination of these three systems. Angular steps required for motor is calculated by two widely used methods.

1. Location and azimuth elevation range [6]-[10].
2. Illumination detected by sensors like photo-resistor [11], [12] light-dependent resistor (LDR) [10]-[13].

Recent developments are based on neural network computing. This paper focuses on profitable way of tracking by considering the output power of solar panel. Tracker is activated only if enough power is derived from solar cells, thereby power consumed by driver and other electronic circuits is saved. Mousazadeh [4] calculated theoretically the amount of power gained by tracking to an ideal 57% difference. Practically it varies due to varying weather conditions, frictional losses and power losses while tracking. Abdallah and Nijmeh, designed an electro-mechanical, two-axes, open-loop sun-tracking system using programmable logic controller to control the motion [14], [16]. Barakat et al. designed a two-axes, closed loop sun tracking system with complicated electronic control circuits. It is found that the energy available with two-axes tracker is higher by 20% [15]. Neville presented a theoretical comparative study of the energy available to two-axes tracker, east–west tracker and fixed surface.

It was found that the energy available to the ideal tracker is higher by 5–10% and 50% than east–west tracker and fixed surface, respectively [17]. Real time clock based tracker is always enabled without considering the illumination. This leads to considerable power consumption in the motor and driver circuits. It is not necessary to activate the tracker during cloudy environment, where overall light intensity is low and almost equal in all places. If the system is based on intensity level comparison, it will find a mean position which may cause oscillations. To overcome these drawbacks, this paper proposes a controller considering the output power. Controller initiates tracking, only if sufficient solar power is derived. The complete system is a mechatronic system consists of mechanical parts like gear wheels, stand and frame, Electronic parts includes PIC microcontroller with necessary interfaces to control DC geared motor and switches. It tracks the movement of sun by comparing the intensity of light falling on two photovoltaic cells .This design can be altered by using LDR also. The key features of the system are: Economical hardware design, Sensitive for economical harvesting, Minimum power consumption, Minimum error, Backlash tolerable to environmental forces, Portable and Easy installation.

II. Functional Blocks of Solar Tracking System

Major functional blocks of tracking system are shown in figure 1. Two photo-voltaic (PV) cells are used to detect the illumination in east and west direction. Outputs of PV cells are compared and given to PIC micro-controller PIC16F877A for tracking purpose. Power derived from solar panel is calculated by voltage, current sensor outputs. It is used to initiate tracking algorithm for economic and maximum power harvesting. During rainy / cloudy days, power output is very low and tracker is not activated to save power consumption of electronic circuits. Initially panel is tilted towards east direction and touches east limit switch. At the end of the day, panel is tilted towards west direction and touches west limit switch. When output power is reduced, the panel is brought back to east side to initiate tracking for next day.

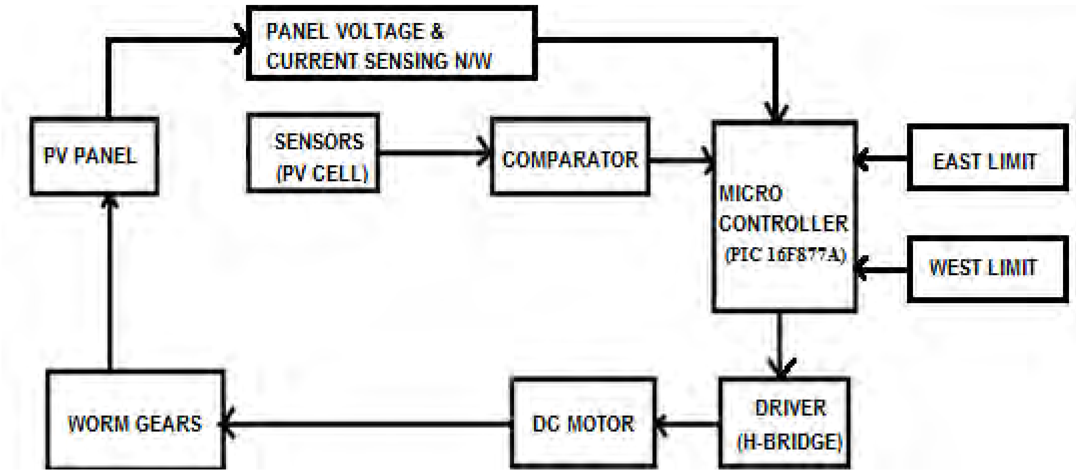
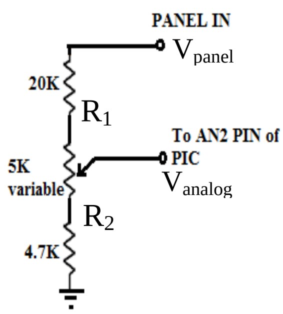


Fig.1 Block diagram of automatic solar tracking system

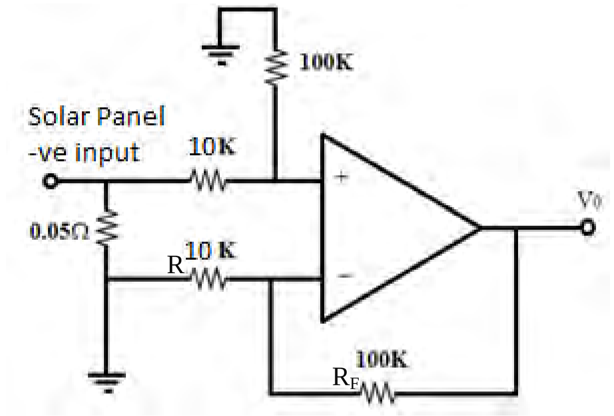
Two photovoltaic cells arranged in the form of triangle as shown in figure 2 is used for sensing the position of sun. The device detects the movement of sun by comparing the intensity of light falling on two sensors. The intensity variations are determined by voltage variations in the sensors [18].



$$R_1 = 20K\Omega + 4K\Omega = 24K\Omega,$$
$$R_2 = 4.7K\Omega + 1K\Omega = 5.7K\Omega$$
$$V_{ana\log} = \frac{(R_2 \times V_{panel})}{(R_1 + R_2)}$$
$$V_{ana\log(\max)} = \frac{(5.7 \times 21)}{(24 + 5.7)}$$

Fig. 2 Arrangement of PV cells for tracking Fig. 3 Potential divider voltage sensing circuit

Solar power is calculated by voltage / current sensing circuits. Voltage sensing is achieved with potential divider voltage sensor. Panel output voltage ranges from 17V to 21V and it is converted into 5V signal to connect with PIC microcontroller. Voltage divider circuit shown in fig.3 is used for voltage sensing. It uses two fixed resistances and a potentiometer (for fine tuning). Analog voltage sensed from solar panel is connected to input 'AN2' of micro-controller. It varies from 3.26V to 4.03 V in the presence of illumination and it is less than 3.26V in the absence of light i.e. during dim light or night hours.



$$V_0 = \left(\frac{1 + R_F}{R}\right) V_{in}$$

$$V_{0(\max)} = \frac{\left(\frac{1+100}{10}\right)}{(0.05 \times 6)} = 3.3V$$

Fig. 4 Differential Amplifier Current Sensing

Differential amplifier low side current sensing is used for sensing solar current that has maximum short circuit current of 6A. Maximum output of current sensing is 3.3V and it is connected with input 'AN3' of micro-controller. Output power of solar panel is calculated and displayed in liquid crystal display.

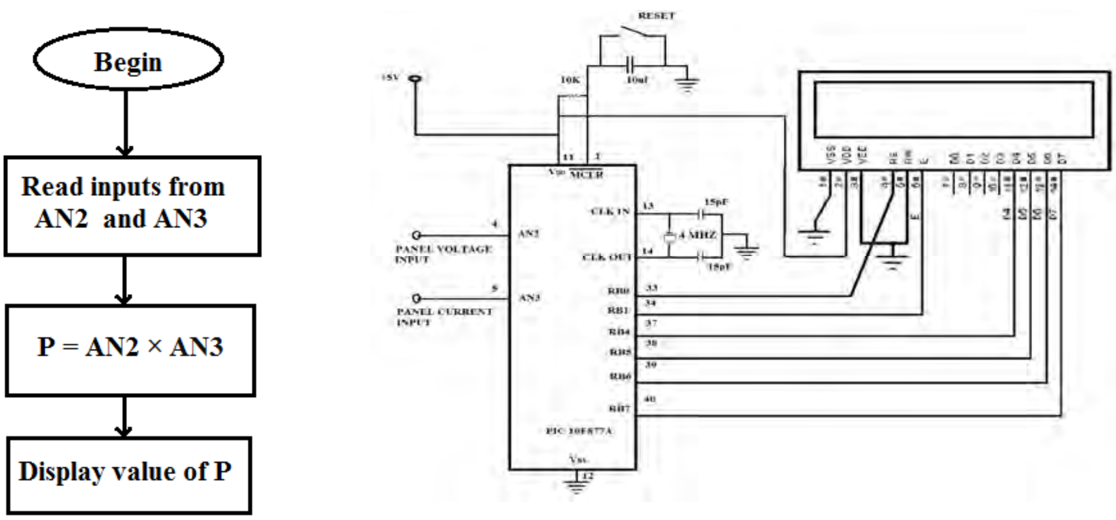


Fig. 5. Flow chart and Circuit for Power calculation

III. THE CONTROL SCHEME

The controller performs the tasks according to the power received from solar panel. Two levels of threshold are used. First threshold is used to activate tracking, indicates availability of sufficient solar power. Second threshold is used to switch off the peripherals during non-availability of solar power for longer period, similar to cloudy / rainy day. Solar panel is tilted towards east direction for next day tracking. Analog inputs accepted by the PIC (considering PIC 16F877A) is converted into 10 bit digital data. First limit is chosen as 400 to enable tracking and second limit is chosen as 150. With solar power greater than first threshold limit activates the tracker. Device aligns itself perpendicular to the radiation by comparing the intensity of light falling on two sensors. Photovoltaic cells are used in this single-axis tracking system for deciding the panel position. The cells are configured as east and west plane sensors for moving the single axis motion of the panel. The sensors are connected to the centre shaft of the panel for tracing the position of solar panel. These sensors are placed in the form of triangle to make it sensitive to ambient light, as shown in fig.2. Solar power less than second limit switch off the peripherals and solar panel is tilted towards east direction. Controller implementation using PIC16F877A with peripherals are shown in figure 6. Flow chart representation of control algorithm is shown in figure 7.

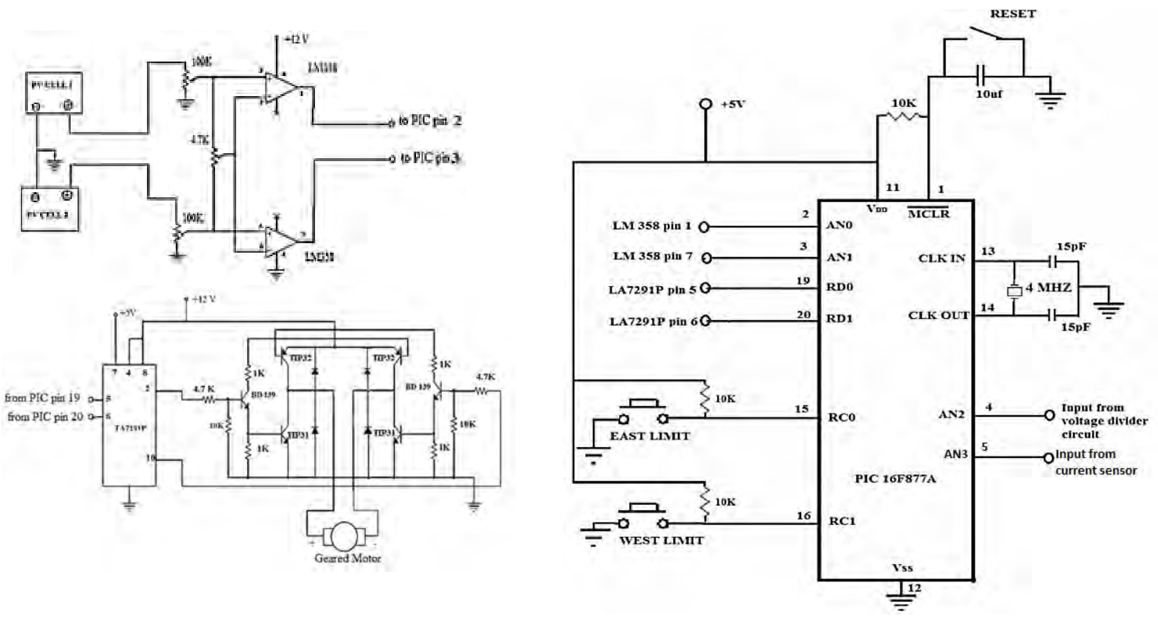


Fig. 6 Controller with peripherals

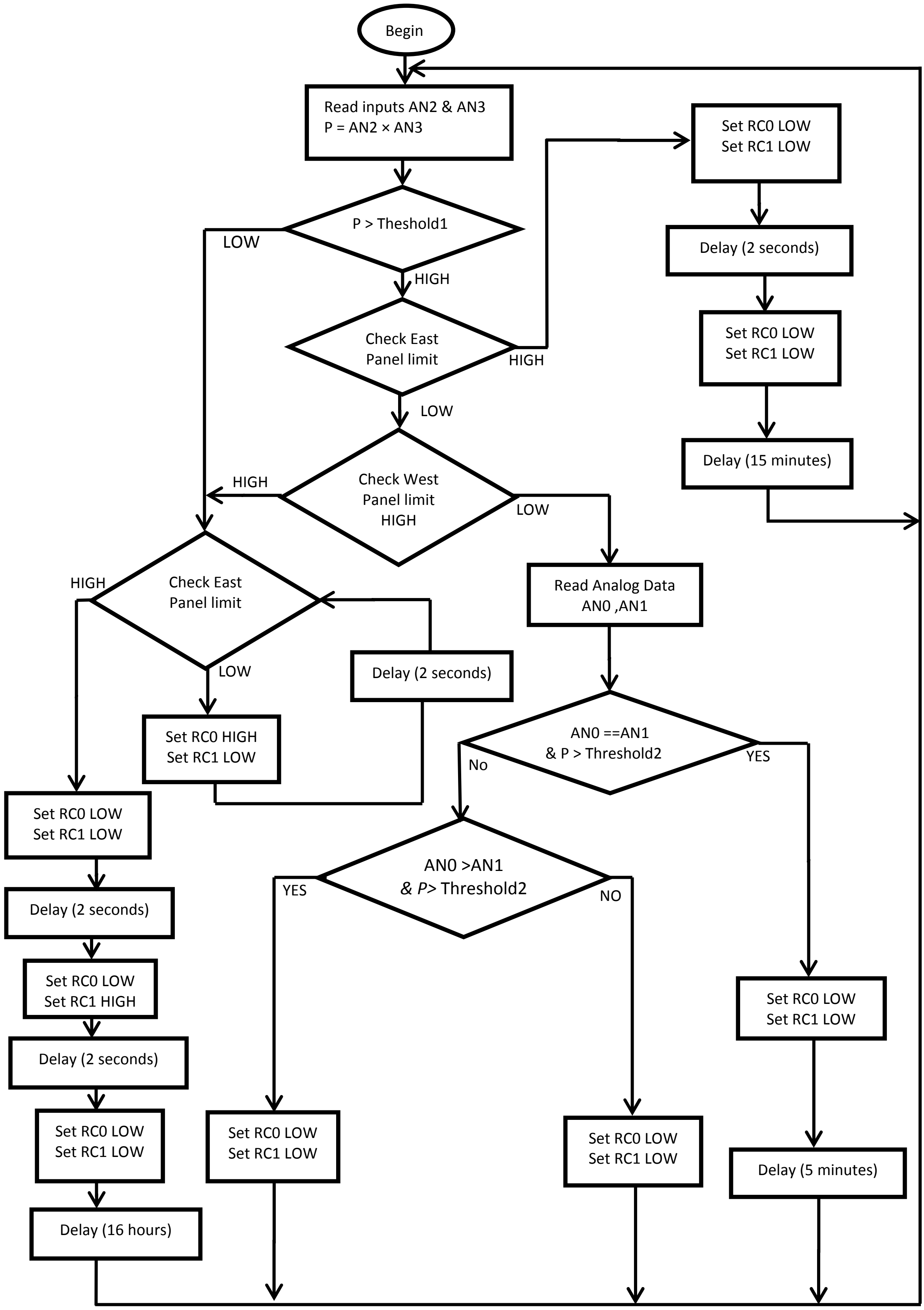


Fig. 7 Flow chart representation of Control algorithm

PV cells should be balanced before installation to avoid unexpected errors due to manufacturing errors. They are balanced using two 100K variable resistors as shown in figure 6. TA7291P IC is used for driving DC geared motor as shown in figure 6 [18]. The system is made periodically active for a specific interval after each alignment with sufficient during day time. It eliminates wastage of power due to continuous activation. Periodic tracking and mean position detection eliminates chances of oscillations in the DC motor. Program is developed to achieve all these features and it is shown with suitable conditions in the flow chart. System reaching RC0-RC1 equal to 0-0 condition leads to uniform wait delay of 5-8 minutes for next tracking activation.

PIC 16F877A 8 bit micro-controller, controls the tracking system through peripheral devices. PV cell comparator outputs are connected to RA0 and RA1 of micro-controller. External clock is applied with 4MHz crystal. Outputs RD0 and RD1 are connected to motor driver IC, TA7291P. Assembly of controller and peripheral circuits is shown in figure 8.

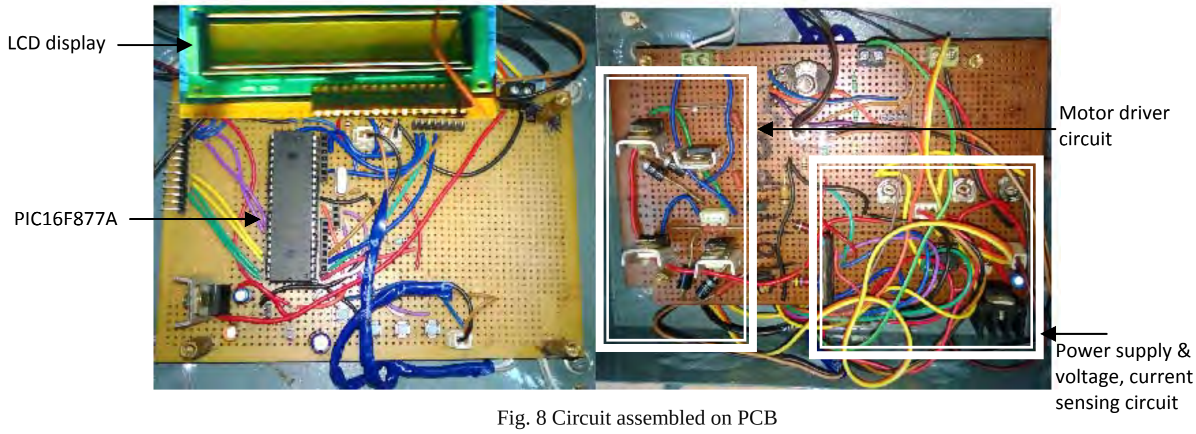


Fig. 8 Circuit assembled on PCB

Mechanical System

This auto-tracking system is controlled with 12V, 10N-m DC gear box motor. The speed of the motor (60rpm) is reduced to 0.5rpm (3 degree) for efficient tracking. Mechanical parts include supporting frame, ball bearings at two end of the shaft in which a 100W solar panel is fixed to gear wheels [18]. Mechanism of worm gear system against backlash forces is shown in figure 9.

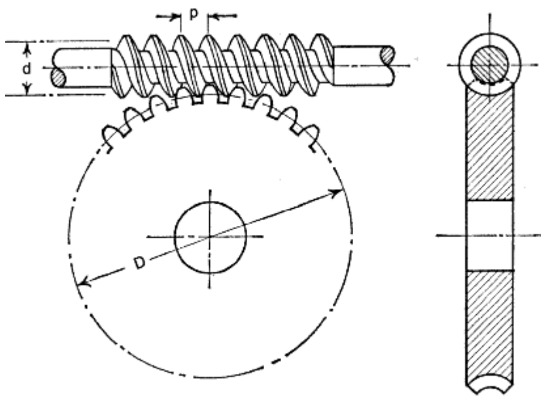


Fig. 9 Worm gear system locking.

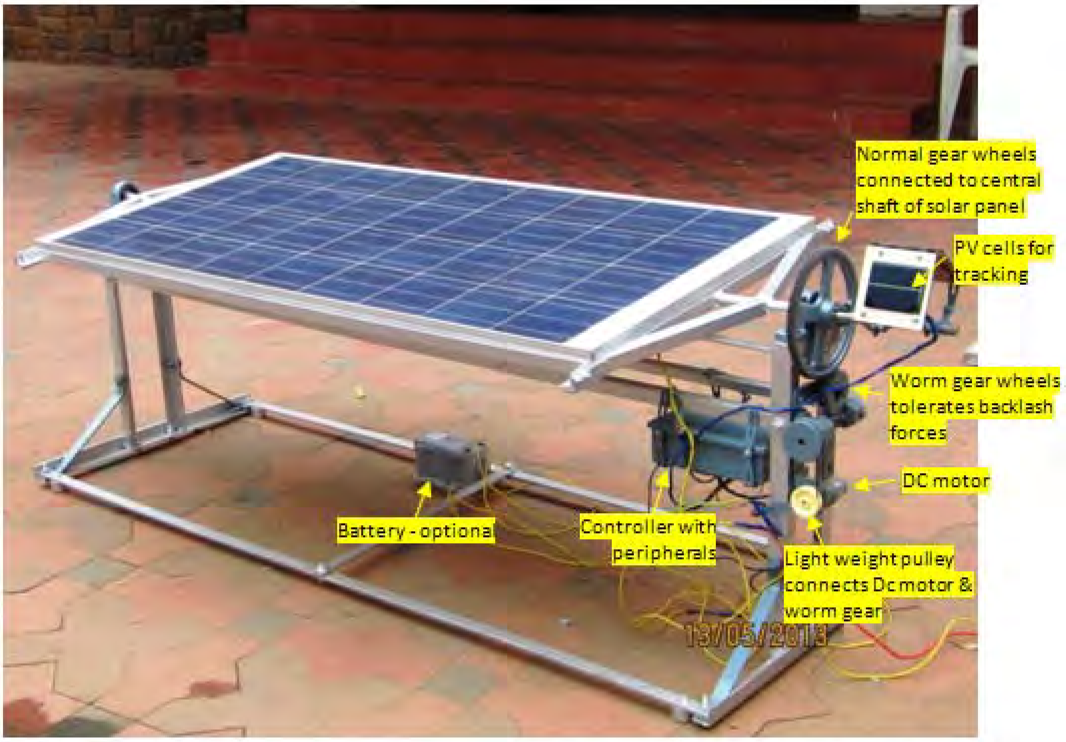


Fig. 10. Frame assembled with gear wheels and motor

Mechanical system with gear wheels assembled on a frame as shown in fig. 10. For maximum efficiency, friction must be minimum for the interlink gear wheels, which is fixed to the frame using 10mm ball bearings. The worm gear is fixed to frame using 10mm ball bearing block. Solar panel is fixed on two ends of the shaft fixed with 20mm ball bearing blocks. To minimize the maintenance of the system, sealed bearings are used otherwise periodic lubrication is required for proper working of the system. Controller power consumption is derived from battery or from the solar panel directly. This system is used to charge 12V, 100Ah battery.

IV. RESULTS

The tracker is stepped in small increments. It jumps to next position approximately 7 seconds. It forms “stable zone” that is 0.04° off of the sun’s position. When the tracker is within this stable zone, the system is at equilibrium and the tracker does not move. When the sun moves outside the safe zone, it sees the error and responds by turning the motor on in that direction. It stays at equilibrium until the sun moves out of safe zone and the cycle repeats.

TABLE I
Status of Motor in a day

Initial time	Final time	Sensor 1 Final Voltage	Sensor 2 Final Voltage	Error in degrees approx.	Motor status
8.00am	8.00.8 am	1.72V	1.74V	2	On (clockwise)
9.01am	9.00.9am	1.80V	1.84V	2	On (clockwise)
10.40am	10.40.8am	1.90V	1.94V	2	On (clockwise)
11.12am	11.12.8am	2.22V	2.24V	2	On (clockwise)
12.05pm	12.08.8pm	2.22V	2.24V	2	On (clockwise)
1.40pm	1.40.8pm	2.09V	2.11V	2	On (clockwise)
3.10pm	3.10.8pm	1.98V	2.00V	2	On (clockwise)
4.00pm	4.00.8pm	1.92V	1.94V	2	On (clockwise)
4.40 pm	4.40.8pm	1.76V	1.78V	2	On (clockwise)
5.16 pm	5.19pm				On (anticlockwise)
5.19 pm	7.46am				Off

In this design, overall area and power output from the panel is an important factor for economic implementation. This can be evaluated by comparing PV systems of different capacity. Power consumption of comparator and controller circuit is constant but power consumption of drive circuit and Motor varies. Also, net frictional losses are less for large scale installation compared with small scale installations. These factors play a major role in the design of profitable tracker. Increase in power consumption for different systems is shown in table II.

TABLE III
Increase in power output for different PV systems

PV capacity	Power Consumption		Losses due to Friction	Increase in power output	
	Electronic circuit	Motor and driver circuit		Without losses	With losses
50Wp System	1W	5W	1.5W	22.5	15W
100Wp System	1W	10W	2W	45W	32W
500Wp System	1W	50W	5W	225W	169W

V. Conclusion

The objective of the proposed paper is to implement single-axis sun tracking system effectively. Hardware of the system is designed with maximum friction free motion parts enabling increased overall efficiency than existing systems. It is tested by tracking 100Wp photo-voltaic solar panel. Use of worm gears enables protection against backlash forces and it is suitable for practical applications. Control algorithms are implemented in PIC16F877A micro-controller with inbuilt ADC. It eliminates the requirement of external ADC and makes the electronic part much simpler. It is built with commercially available components of less cost. This paper provides a cost effective and efficient solution for solar tracking.

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