DUAL AXIS SOLAR TRACKING SYSTEM USING MAGNIFYING LENS SHEET

Dr.K.Chitra[1], M. Arun kumar[2], G.R. Suriya[3], S.N.Rubini[4]

[1]*Assistant Professor (Senior Grade), EEE Department, Bannari Amman Institute of Technology (India)*

[2,3.4] *Final Year Students, EEE Department, Bannari Amman Institute of Technology (India)*

ABSTRACT

The main goal of this paper is to develop and implement a prototype of two- axis solar tracking system based on a PIC microcontroller to produce electricity. The magnifying lens sheet is used to capture the sun's energy. The Fresnel lens is focused to get extremely high temperature. This two axis auto-tracking system has also been constructed using PIC 16F877A microcontroller. The assembly programming language is used to interface the PIC with two-axis solar tracking system. The temperature at the focus of the Fresnel lens is measured with temperature probes. The Thermocouple sensor is used to convert the focused heat into electricity. This auto-tracking system is controlled with two 12V, 6W DC motors and a driver circuit. The four light sensors (LDR) are used to track the sun and to start the operation (Day/Night operation). Time Delays are used for stepping the motor and reaching the original position of the magnifying lens sheet. The two-axis solar tracking system is constructed with both hardware and software implementations.

Keywords - Solar Energy, Solar tracking, Lenz sheet, Dual axis, Immobile and Mobile

I. INTRODUCTION

The recent decades have seen the increase in demand for reliable and clean form of electricity derived from renewable energy sources. One such example is solar power. The challenge remains to maximize the capture of the rays from the sun for conversion into electricity. This paper presents fabrication and installation of a solar magnifying lens sheet mount with a dualaxis solar tracking controller. This is done, so that rays from the sun fall perpendicularly unto the solar magnifying lens to maximize the capture of the rays by pointing the lens towards the sun and following its path across the sky. Thus electricity and efficiency is increased. Electrical energy is derived by converting energy from the rays of the sun into electrical current in the thermocouple sensor. The main challenge is to maximize the capture of the rays of the sun upon the solar lens, which in turn maximizes the output of electricity. A practical way of achieving this is by positioning the magnifying lens such that the rays of the sun fall perpendicularly on the solar magnifying lens by tracking the movement of the sun. This can be achieved by means of using a solar magnifying lens mount which tracks the movement of the sun throughout the day. Energy conversion is most efficient when the rays fall perpendicularly onto the solar lens. Thus, the work is divided into three main parts namely the mounting system, the tracking controller system and the electrical power system.

Not all countries possess all the commodities that are available to humanity. These so called underprivileged countries lack amenities such as; abundant food, clean water, medicine, wealth, education, and a healthy environment. The World Bank and other institutions believe that the lack of access to clean and efficient energy services is a factor involved in underprivileged countries from gaining more resources associated with higher living quality, such as wealth. There are a few new forms of advanced energy, but electricity has been proven to be one of the cleanliest and most efficient forms.

One possible solution to unreliable or nonexistent central electricity distribution systems is to have distributed generation system (DG). A distributed generation system is characterized by the fact that the electricity is produced locally rather than externally. DG is often used in underprivileged countries; however, usually in the form of small generators that run on different types of fossil fuels. The most common DG options include; solar, wind, and thermal.

II. SOLAR ENERGY

Solar energy is the most democratic of renewable energy resources. It is available everywhere on the earth in qualities that vary only modestly. The role of solar energy is indeed going to be predominant. Because solar energy is available free at any place on the earth. Solar energy is renewable and will not deplete within the next several billion years.

Several applications of solar energy ranging from simple solar water heating to complex megawatt power generation systems are under extensive investigation. The function of the solar collector is to collect the radiation incident from the sun. Solar collectors can be grouped into two general classifications flat-plate (low to medium temperature) collectors and focusing (high temperature) collectors. Focusing (parabolic dish) collector systems are the most efficient of all solar technologies, at approximately 25% efficient, compared to around 20% for other solar thermal technologies [8].

Therefore the two-axis solar tracking system is constructed with two DC motors because the maximum temperature at the focus of the Fresnel lens is always required. This control system is controlled by PIC 16F877A and interfaced with assembly language.

2.1 Solar Tracking System

The problem with solar power is that it is directly dependent on light intensity. To produce the maximum amount of energy, a magnifying lens must be perpendicular to the light source. Because the sun moves both throughout the day as well as throughout the year, a Magnifying lens sheet must be able to follow the sun’s movement to produce the maximum possible power. The solution is to use a tracking system that maintains the reflector’s orthogonal position with the light source. There are many tracking system designs available including passive and active systems with one or two axes of freedom.

The goal of our paper was to design an active, dual axis, solar tracker that will have a minimum allowable error of 10° and also be economically feasible to market towards underprivileged countries [2]. We started by examining the prior work done in solar tracking methods to determine our course of action. From there we designed and tested several mechanical and electrical options and chose the ones with the most desirable characteristics. Finally, we built our final tracking system, tested and compared it to ensure that we met our original goal.theoretical model of the suns iridescence for the duration of a year is created and the angel and position is matched to the model [3].

Using one axis of tracking can provide a significant power gain to the system. Wikipedia claims that one axis trackers are placed into the following classifications of horizontal single axis tracker (HSAT), vertical single axis tracker (VSAT), tilted single axis tracker (TSAT), and polar aligned single axis tracker (PASAT). However, these terms don't seem to be used in most articles discussing tracking methods. One article did mention that a TSAT at a tilt angle of 5° increases the annual collection radiation by 10% compared to a HSAT, a HSAT increases the annual collection radiation by 15% to a VSAT, and finally a PASAT increases the annual collection radiation by 10% over a HSAT [2]. Thus for one axis a PASAT or TSAT configuration would collect the most solar radiation.

For an additional power gain a dual-axis tracking system can be used. The percent gain from going from a PSAT to a dual-axis system is small, but as long as the system doesn't use more power than gained, it still helps. Again Wikipedia mentions two classifications for dual axis trackers Tip-Tilt Dual Axis Tracker (TTDAT) and Azimuth Altitude Dual Axis Tracker (AADAT). The difference between the two types is the orientation of the primary axis in relation to the ground. TTDAT's have the primary axis horizontal to the ground and AADAT's have theirs vertical. The azimuth/altitude method seems to be largely used, based on its reference in multiple research articles on tracking. In the article by Sefa et al. the following was stated; "The results indicated that increases of electrical power gains up to 43.87% for the two axes, 37.53% for the east–west, 34.43% for the vertical and 15.69% for the north–south tracking, as compared with the fixed surface inclined 32 to the south.

III. EXISTING SOLAR TRACKING METHODOLOGY

The absorption of light by a Magnifying lens sheet is dependent on its angular position to the sun. A Magnifying lens sheet must be perpendicular to the sun for maximum solar absorption, which is done by using a tracking system. Multiple tracking systems exist, which vary in reliability, accuracy, cost, and other factors. A 5 tracking system must be chosen wisely to ensure that the tracking method increases the power gained instead of decreasing it.

3.1 Immobile Versus Mobile

Different power applications require different tracking systems. For certain applications a tracking system is too costly and will decrease the max power that is gained from the Magnifying lens sheet. Due to the fact that the earth rotates on its axis and orbits around the sun, if a reflector is immobile, the absorption efficiency will be significantly less at certain times of the day and year. The use of a tracking system to keep the Magnifying lens sheet perpendicular to the sun can boost the collected energy by 10 - 100% depending on the circumstances .

If a tracking system is not used, the Magnifying lens sheet should still be oriented in the optimum position. The Magnifying lens sheet needs to be placed where no shadow will fall on it at any time of the day. Additionally, the best tilt angle should be determined based on the geographical location of the Magnifying lens sheet. As a general guideline for the northern hemisphere, the Magnifying lens sheet should be placed at a tilt angle equal to the latitude of the site and facing south. However, for a more accurate position and tilt angel

3.2 Passive Tracking Systems

One possible option for tracking is a chemical/mechanical system. This system uses the idea of thermal expansion of materials as a method for tracking. Typically a chlorofluorocarbon (CFC) or a type of shape memory alloy is placed on either side of the magnifying lens sheet. When the Magnifying lens sheet is perpendicular with the sun, the two sides are at equilibrium. Once the sun moves, one side is heated and causes one side to expand and the other to contract, causing the Magnifying lens sheet to rotate. A passive system has the potential 7 to increase efficiency by 23%. These systems are far cheaper than active systems, but not commercially popular [3].

3.3. Active Tracking Systems

There are three main types of active tracker systems auxiliary bifacial solar cell system, electro-optical system, and microprocessor/computer system. Auxiliary bifacial solar cell systems are the simplest of the three active systems. A bifacial auxiliary solar cell (sensor cell) is fixed to the rotary axle of the tracker and is placed perpendicular to the main bifacial magnifying lens sheet array. The sensor cell is connected directly to a motor, usually a DC electromotor [4]. When the sun moves, the angle of incidence increases on the sensor cell, which eventually produces enough power to move the motor and the magnifying lens sheet array. The example by Poulek and Libra claimed their system was able to collect 95% of the energy with a ± 5° tolerance The electro-optical system is also another relatively simple system. Typically two photo-resistors are used as sensors for one-axis systems. These sensors are 8 positioned near one another and have a divider, a tilted mount at a calculated angle, or use a collimator to create a useful current and/or voltage difference between the two sensors. A combination of resistors, capacitors, amplifiers, logic gates, diodes, and transistors are used to form a comparison and driver circuit. The output of the comparing circuit powers a driver circuit, which in turn powers a motor and changes direction according to which sensor receives a higher amount of illumination. This orients the magnifying lens sheet to be perpendicular to the sun.

I V SOLAR ENERGY COLLECTION

Focusing a collimated beam of light at a point is another popular use of Fresnel lenses, and one for which Fresnel lenses are at least adequate. Again, the grooved side toward the infinite conjugate is the optically preferred configuration. Because the collimated beam is assumed to be uniform, there is a substantial loss through the lens in this case for marginal rays. The loss is caused by the increasing angles of incidence and emergence as the margin of the lens is approached. It can be predicted using Fresnel’s equations, which describe the reflection and transmission of light at an interface between media of differing refractive index. The loss due to reflection is graphed as a function of the angle between the incident ray and the (plane) interface.

There are two additional losses which must be considered in demanding applications. One is due to the unavoidable width of the vertical step between grooves. This loss is generally reasonably small in well-made Fresnel lenses, but light scattered from the step brightens the focal plane and thereby reduces the contrast of an image. The other loss is due to shadowing and blocking effects caused by the vertical step. This loss does not exist for rays parallel to the optical axis striking grooves “in” lenses, but is present in all other cases. For rays making a large angle (20˚or greater) with optical axis, it can be the most significant loss. Furthermore, blocked rays are also likely to increase the overall brightness of the focal plane. These losses must be evaluated by considering in detail the geometry of the lens and its relationship to the focal plane and the incoming rays. Fresnel Technologies, Inc. has had substantial experience in solving problems of this sort, and invites your inquiries.

V. SIMULATION RESULTS AND DISCUSSION

An overall system simulation for the tracker was created after deciding what and how to implement each main component of the tracker. The mechanical components consisted of the DC motors, the worm gears and the solar sensor array each described. Electrically, the tracker used the PIC microcontroller, the L298 circuit and rechargeable batteries to supply the power.

5.1 Digital System

Because of the drawbacks present in the analog control system, a microcontroller based, digital control system was also tested. The microcontroller allowed a minimal control circuit complexity, reduced power consumption and allowed for additional features to be introduced to the tracker.

The microcontroller selected had to have at least threeanalog-to-digital converter (ADC) inputs to take the three signals from the three sensors. It also had to have a minimum of eight digital outputs, threefor both of the motor L298s. Finally, the microcontroller used had to have a very low power consumption when active to keep the efficiency as high as possible. The most widely available microcontrollers that satisfied these requirements were either AVR or PIC microcontrollers.

5.2. Final System

The completed circuit for the tracker was created after deciding what and how to implement each main component of the tracker. Electrically, the tracker used the PIC microcontroller, the L298 circuit and rechargeable batteries to supply the power. The circuit is designed in PROTEUS and the program is developed in Micro C

5.3. Design in PROTEUS

Proteus ISIS is the best simulation software in the world for various designs with electronics & microcontroller. It is mainly popular because of availability of almost all microcontrollers in it. So it is a handy tool to test programs and embedded designs for electronics hobbyist & expert.

PROTUES combines advanced schematic capture, mixed mode SPICE simulation, PCB layout and auto-routing to make a complete electronic design system. The PROTUES product range also includes our revolutionary VSM technology, which allow to simulate the micro-controller based design, complete with all the surrounding electronic.

5.3.2 Coding in Micro C

Micro-c PRO for PIC is a full-featured ANSI C compiler for PIC devices from Microchip. It is the best solution for developing code for PIC devices. It features intuitive IDE, powerful compiler with advanced optimizations, lots of hardware and software libraries, and additional tools that will help you in your work. Compiler comes with comprehensive Help file and lots of ready-to-use examples designed to get you started in no time. The Fig. 1. Shows the simulation diagram of the proposed solar tracking system.

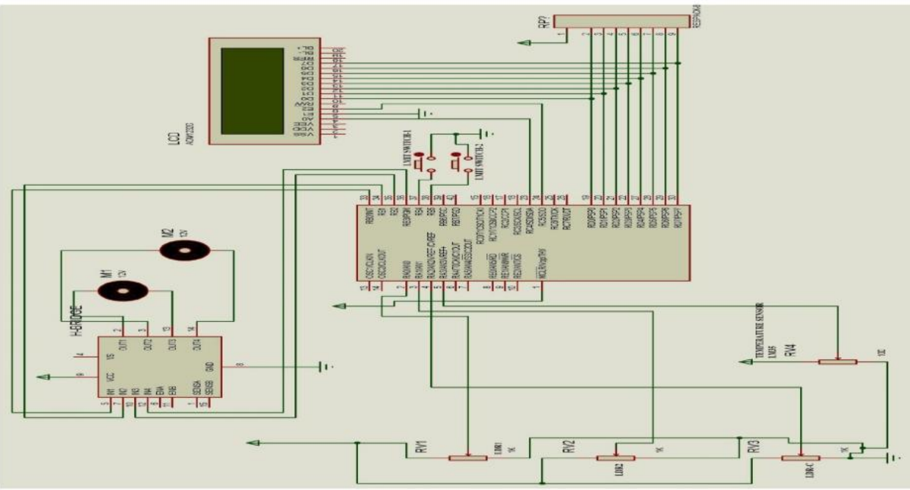

Figure 1. PROTEUS Simulation of Solar Tracking system

VI. HARDWARE IMPLEMENTATION

The purpose of a solar tracker is to accurately determine the position of the sun. This enables Fresnel lens interfaced to the tracker to obtain the maximum solar radiation. With this particular solar tracker a closed-loop system was made consisting of an electrical system and a mechanical system which is shown in Fig. 2..

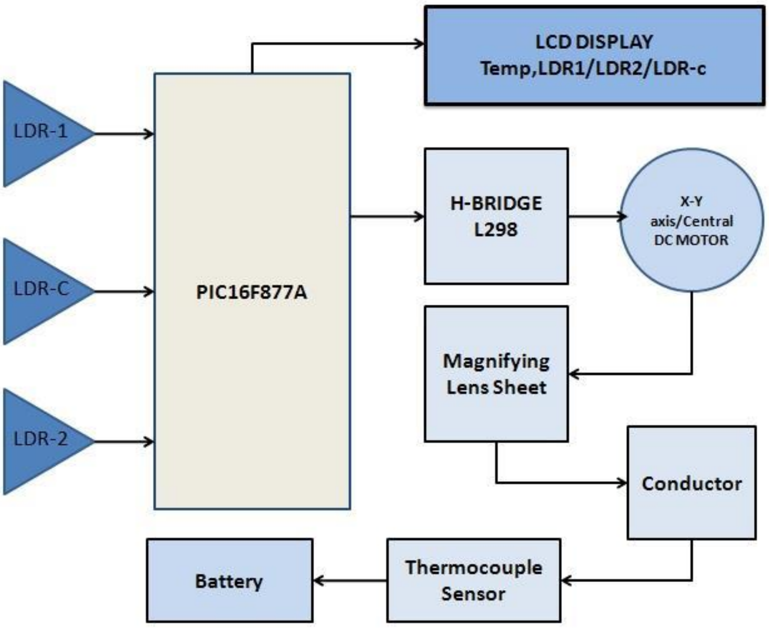

Figure 2. Hardware Implementation of Solar Tracking system

6.1 PCB Design

The PCB was designed to incorporate the circuitry in the smallest footprint possible. The circuits it holds are the L298 for the motor, the potentiometers for balancing the signals from the solar and two indicator LEDs used for troubleshooting the system. Because the requirements for both axes of the tracker are identical, the PCB was designed for one axis and two were made. This allowed a more compact board size, as well as ensuring that onewhole new board need not be made in the event of failure.

6.2 Interface with Microcontroller

Two LM 358 ICs are used as a window detector (window comparator). In this paper, the motor is ON when the output is below the set-point and OFF when the output is above the setpoint. ON/OFF action control is controlled with LM 358 window comparator shown. The first LM358's Pin 1 and Pin 7 are connected to the RB0 and RB1 ofPIC 16F877A and are used as the inputs of the 16F877A IC. The second LM358's Pin 1 and Pin 7 are connected to the RB4 and RB5 and are also used as the inputs of the 16F877A. These two LM358's Pin 2 and Pin 5 are joined and connected to the outputs of two LDR sensors (East/ West) and two LDR 437 sensors (Right/ Left sensor). The first and second LM358 is used as the window detectors. The third LM358 is used as a comparator and this comparator is used the start of the two axis solar tracking system. Pin 4 and Pin 14 of PIC are connected to the 5V dc power supply and Pin 5 is ground. Pin 16 and Pin 15 are connected to the two 22pF capacitors and 4MHz crystal for clock frequency to orchestrate the movement of the data around its electronic circuits. RA0, RA1, RA2 and RA3 are the outputs of the 16F877A and these outputs are connected to Pin 5 and Pin 6 of two L298s. In this paper, two L298 ICs are used for driving the DC motor. 12V dc power supply didn't really provide enough torque for the gear box motor to run smoothly. Finally, Darlington pair circuits are replaced between L298 IC and DC motor and are used for power amplifier [1].

6.3. Power Supply

In the initial design of the tracker, it incorporated a rechargeable battery to power the tracking system. The battery would be recharged by the magnifying lens mounted on the tracker so the system would be self-sufficient. To choose a battery, the power supply voltage had to be chosen that allowed the tracker to operate in entirety. During the testing phase of this paper, 5V was chosen arbitrarily as a starting point to help design the circuits. As the paper progressed, batteries were examined for the tracking system and exactly 5V batteries are hard to find in a rechargeable package. Taking into consideration that the tracker would be operating in remote parts of the world and the battery would have to be replaced eventually, the power supply was changed to a readily available 12V battery. However, in lieu of time and budget restrictions, the battery charging system was not incorporated in the final tracker prototype. 12V was kept as the power supply voltage so in the future; a rechargeable battery can be implemented into the tracking system.

6.4. Working System

After connecting the components and interfacing with the microcontroller, the system is made to run. Initially the electronic part of the system will start operating according to the program that has been fed to it. This in turn has an effect on the mechanical portion of the system.

6.4.1. Operation of Control System

The assembly programming language is used to interface with two-axis solar tracking system using PIC16F877A. At first, micro-switches are used to check the program and left/Right motion and East/West motion of the DC motors are tested with program. At the start of the program is placed delay time. After light level is one, the whole circuit is to start the operation. The software turns the motor on and off, or sets the speed within very short time. Thus, the controller spends an insignificant amount of 438 time on controlling the motor. In this paper, Time Delay is always placed between motor driving and motor stopping for stepping DC motor.

6.4.2. Operation of Electrical System

The electrical system consists of three PV sensors which provide feedback to a microcontroller. This microcontroller processes the sensor input and provides output to L298s. The entire electrical system is powered by a 12V source, which consists of 1 A batteries. The L298 controls the two DC motors, which are also part of the mechanical system. The mechanical system also contains two worm gear assemblies that adjust the PV sensors. The focus of the Fresnel lens is adjusted and it heats the conductor placed on the focal point. The thermocouple sensor is placed on the conductor that is heated. It converts the heat into voltage. The voltage output is fed to the battery. It charges the battery and used to power the electrical gadgets connected to them

6.5. Total System Testing

Once the azimuth-altitude dual axis solar tracker was built, the angular error and the power consumption were tested for. The cost of the prototype was analyzed as well. After the prototype was built, it was put through several tests of functionality to ensure that it met the original design requirements. The tracker’s angular error and power consumption were measured to calculate the tracker’s power generation in comparison to other solar collecting systems.

6.5.1. Software Testing

To understand how the tracking system would operate before it was constructed; an ideal simulation was created for one axis of rotation. Only one axis was simulated because under ideal conditions, both axes would operate identically. PROTEUS was chosen as the medium for the simulation because it could more accurately simulate the processes of the microcontroller than PSPICE or Multisim. The first part of the simulation was to collect the specifications of the system. The major portion of the simulation would rely on an accurate representation of how the sensors act during the day. The simulation runs the changing sun position through the magnifying lens sheet equations to get the voltages on the panels at the current position. Simulating the microcontroller, the difference between the two voltages is compared to some reference value that can be changed. If the difference is greater than the reference or less than the negative reference, the simulation increments the position vector at the rate of the tracker speed, 0.5203 rad/s in the direction correspond to which sensor is getting more radiation. If the difference is in between the positive and negative values of the reference, the position is maintained [6].

6.5.2. Hardware Testing

To produce a useful solar tracker the electrical system needs to give accurate control signals to the mechanical system, be reliable, and have low power consumption. Since analog systems deal with continuous voltages, this seemed ideal for providing smooth and accurate control of the mechanical system. Thus, the initial electrical system consisted of solar sensors, a comparator circuit and an L298. To improve this system’s performance some modifications were implemented different solar sensors, different solar sensor arrangements, hysteresis to the comparator, and pulse width modulation (PWM) for more precise motor control. Later in the design process the analog comparator circuit was replaced with a digital microcontroller for improved efficiency. Although the original electrical system was put on breadboards, the final system used two printed circuit boards (PCBs) to ensure reliability. Initially an analog system was considered, in which a comparator circuit functioned as the central processor. A simple wooden prototype was built first to allow for testing of the PV sensors and DC motors. These tests were used to form an overall system simulation. In the process of testing it was determined that a microprocessor would be used instead of the comparator circuit, due to the improved efficiency. As the final step an acrylic prototype was constructed, as seen in Fig. 3.

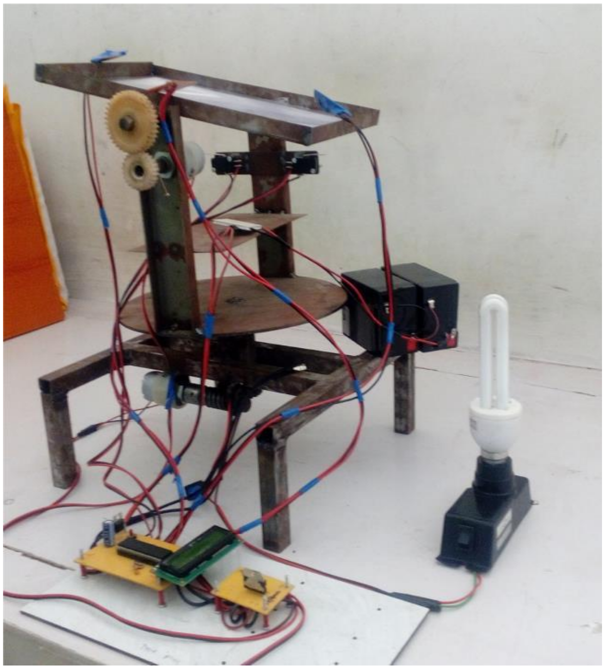

Figure 3. Experimental Setup of the Solar Tracking System using Magnifying Lens Sheet

6.5.3 POWER CONSUMPTION

To ensure that the tracking system actually produced more power than it used, measurements were taken for the power consumption of each individual component of the system. A single 0.49Ω (measured value) resistor was used as a power shunt to measure the current going from the battery to the tracker system The voltage measured by the voltmeter, VR1, divided by the resistance gives the current to the tracker. Multiplying the current by the supply voltage, 12 V, the power consumption can be calculated. Several measurements were taken to find the individual current draws to each section of the system. The first measurements were to the total system, with the shunt between the battery and the rest of the system. The currents were measured when the system was stationary, one axis was moving, the other axis was moving and both axes moving at the same time. To get just one axis to move, the sensor inputs to the microcontroller were incorrectly biased so that the system saw a difference and tried to correct it. For measuring the voltages when the system was moving, the voltages were taken at the highest observed value.

VIII. CONCLUSION

PIC (Peripheral Interface Controller) based system has various advantages; the electronic circuit components are less and cheaper than PC, portable hardware components, low power consumption rate, simple installation and operation. Besides PIC is used that is cost effective and easy to maintain. So two axis auto solar tracking system is constructed based on PIC and it can be used in generating of electricity and domestic use. This system may be used for receiving always maximum temperature at the focus of the reflector. The

Magnifying lens sheet is arranged with three LDR sensors for moving and changing place to face the reflector and the sun. Therefore the reflector is moving to face the sun to trace with two DC motors. These two DC motors are controlled with PIC16F877A under the programming of assembly language. The control of DC motor is more complex than the stepper motor but the stepping of DC motor is arranged with the gear system. This control is very simple, easier to design and less expensive to build.PIC16F877A is used to control two DC motors accurately with minimum hardware at a very low cost. This paper is also a trial and the mirror should be used the surface layer of the reflector because it has the best reflectivity. Gear system can also be used other high quality motors and a small Stirling engine can be mounted at the focus of the reflector to produce the electricity to pump water.

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