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Microcontroller-based solar energy tracker system with single axis orientation

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Abstract

Maximizing the conversion of sunlight into electricity through the use of photovoltaic solar cells has led to the operation of solar power generating systems below its expected efficiency benchmark. The problem posed thus is to implement a system that is capable of improving solar power production by 30-40%. In this paper a microcontroller based sun tracking system is designed to ensure that the solar panel is always parallel to the sun for maximum energy output. Microcontroller is used to implement the control circuit which in turn positions a motor used to orient the solar panel optimally. Light intensity detecting sensors were used to receive light rays and the signal processed through a microcontroller to rotate the solar panel towards the side with maximum intensity using the turning mechanism of a 5.2 degrees unipolar stepper motor. Thus, this tracking system is designed to automatically follow the sun and from the input received, it can actuate some mechanism to position the solar panel where it can receive maximum sunlight to produce more output energy.

Keywords: Microcontroller, Solar Energy, Single Axis, Orientation, Tracking System

1. Introduction

The photoelectric effect was first noted by a French physicist, Edmund Bequerel, in 1839, who found out that certain materials including silicon would produce small amounts of electric current when exposed to light.

Sunlight has two components, the "direct beam" that carries about 90% of the solar energy, and the "diffuse sunlight" that carries the remainder; the diffuse portion is the blue sky on a clear day and increases proportionately on cloudy days. As the majority of the energy is in the direct beam, maximizing collection requires the sun to be visible to the panels as long as possible. The energy contributed by the direct beam drops off with the cosine of the angle between the incoming light and the panel.

Due to the limited supply of non-renewable fuels, scientists nowadays are searching for alternative energy resources. Besides, fossil fuels have many side effects such as acid rain and global warming. Therefore, conversion to clean energy sources such as solar energy would enable the world to improve the quality of life throughout the planet Earth. The sun is the prime source of energy, directly or indirectly which is also the fuel for most renewable systems. Among all renewable systems, photovoltaic system is the one which has a great chance to replace the conventional energy

The sun travels through 360 degrees east to west per day, but from the perspective of any fixed location the visible portion is 180 degrees during an average 1/2 day period (more in spring and summer; less, in fall and winter). Local horizon effects reduce this somewhat, making the effective motion about 150 degrees. Rotating the panels to the east and west can help recapture those losses. A tracker rotating in the east–west direction is known as a single-axis tracker.

The sun also moves through 46 degrees north and south during a year. The same set of panels set at the midpoint between the two local extremes will thus see the sun move 23 degrees on either side, causing losses of 8.3%. A tracker that accounts for both the daily and seasonal motions is known as a dual-axis tracker. Generally, the losses due to seasonal angle changes is complicated by changes in the length of the day, increasing collection in the summer in northern or southern latitudes. This biases collection toward the summer, so if the panels are tilted closer to the average summer angles, the total yearly losses are reduced compared to a system tilted at the spring/fall solstice angle (which is the same as the site's latitude).

The solar trackers change the pattern of energy production in solar electricity generating plants. The normal pattern of solar electricity production throughout a day is a “bell shaped” curve with a peak around midday if the panel faces the northern aspect. This implies that before midday batteries alone provide power, but with solar tracker there is a more even production of power throughout the day thus reducing the stress on backup batteries.

Reduces the cost incurred during expansions from procuring more panels by increasing the efficiency of existing solar installations by up to 30%. Makes electricity generation economical in areas where grid connection or fuel transport is difficult.

Thus the primary benefit of this tracking system is to collect solar energy for the longest period of the day, by ensuring that sunlight rays are falling perpendicularly on the solar panel to give the maximum solar energy which is harnessed into electrical power with the maximum energy being between the period of 12noon to 2 pm, with the peak around midday when the sun is almost directly above the solar panel and so minimum energy is used to move the solar panel, further increasing the efficiency of the tracker, and with the most accurate alignment as the Sun's position shifts with the seasons.

The significant focus of this research is centered upon the use of microcontrollers in designing systems that require real time and accurate monitoring of electronic devices. This paper seeks to address the challenge of harnessing solar power as well as economical microcontroller based solar tracking system that can be implemented using the allocated time and resources so as to track the relative motion of the sun in the sky during daylight and to save the much needed power for sleep at night. A working model is being prepared in order to implement the idea using any hypothetical situation.

2. Literature Review

Certain important elements of each research were taken into consideration.
Daniel A. Pritchard's idea of a microcomputer was replaced in this work with microcontroller but no inverter or solar module was used in the work due to cost limitations. Bill lanes idea of a single axis design was used in this work, but we used only one Cadmium Sulphide (Csd) photocell instead of two to reduce the component count and then wrote the assembly language program to mimic the roles played by the second Cadmium Sulphide (Csd) photocell. In this paper, the usage of an 8051 Microcontroller and 1-axis Solar Tracking becomes the main element. Some hardware designs were also taken into consideration in order to design the Solar Tracking System.

2.1 Photovoltaics

Photovoltaics is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, electric current results that can be used as electricity.
The photoelectric effect as noted by French physicist, Edmund Bequerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, for which he later won a Nobel Prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954. It was billed as a solar battery and was mostly just a curiosity as it was too expensive to gain widespread use. In the 1960s, the space industry began to make the first serious use of the technology to provide power aboard spacecraft. Through the space programs, the technology advanced, its reliability was established, and the cost began to decline. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications.

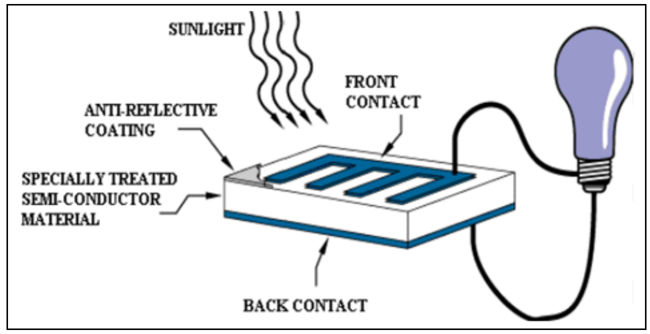

Fig 2.1: Basic solar cell operation

The diagram above illustrates the operation of a basic photovoltaic cell, also called a solar cell. Solar cells are made of the same kinds of semiconductor materials, such as silicon, used in the microelectronics industry. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current; that is, electricity. This electricity can then be used to power a load, such as a light or a tool.
A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Modules are designed to supply electricity at a certain voltage, such as a common 12 volts system. The current produced is directly dependent on how much light strikes the module.

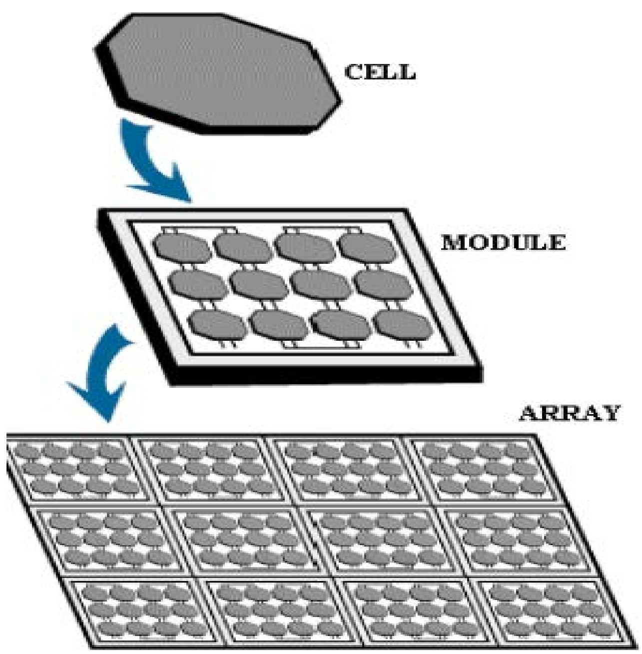

Fig 2.2: solar cell basic arrangement

Today's most common PV devices use a single junction, or interface, to create an electric field within a semiconductor such as a PV cell. In a single-junction PV cell, only photons whose energy is equal to or greater than the band gap of the cell material can free an electron for an electric circuit. In other words, the photovoltaic response of single-junction cells is limited to the portion of the sun's spectrum whose energy is above the band gap of the absorbing material, and lower-energy photons are not used.

One way to get around this limitation is to use two (or more) different cells, with more than one band gap and more than one junction, to generate a voltage. These are referred to as "multi-junction" cells (also called "cascade" or "tandem" cells). Multi-junction devices can achieve higher total conversion efficiency because they can convert more of the energy spectrum of light to electricity.

3. Materials and Methods

The system consist of hardware part which is the tangible components that drive the panel to the optimum position by performing a set of orders and the software part which issues the orders performed by the hardware part. The hardware part consist of the following component; Atmel89c52, LCD display, ADC0804, Unipolar Stepper Motor, ULN2003 Motor Driver, LDR, Resistors, and Capacitors.

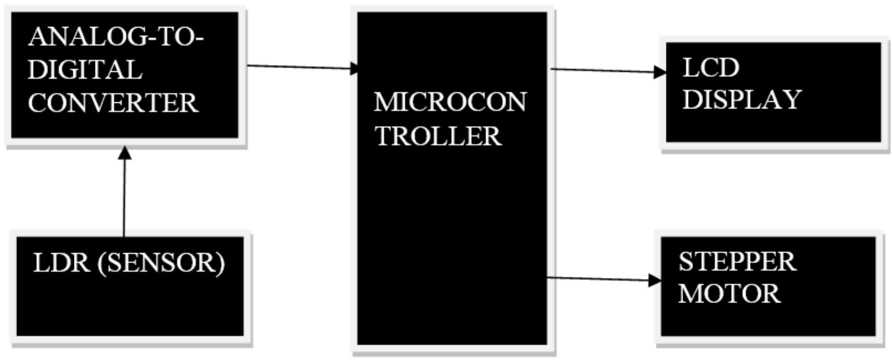

Fig 3.1: Block diagram of sun tracker

The Microcontroller is interfaced to analog-to-digital converter to detect changes in voltage level of a Light Dependent Resistor (LDR) interspersed in a voltage divider circuit. As the sun intensity varies, the voltage output varies too. This is due to the fact that the LDR changes its resistance with respect to the light intensity. It then sends the processed information to the display unit. The LCD display is programmed by the microcontroller to display the result as required. For the detail of other components refer to the main work.

System Behavior Algorithm

Prior to powering the system, the solar panel is at its default position (east).

The next step is to determine if the sun rises or not, the minimum intensity of light for the system to operate corresponds to the voltage divider output of 3V and above.

The microcontroller will check the sensor output and if it is less than 3V the microcontroller will rotate the panel through the stepper motor 5.2 degrees to the west. This movement won’t stop until the sensor output is 3V or the panel has been rotated through the full range of movement (180 degrees from east to west)

If the sensor output is less than 3V through the full range of movement the panel will be rotated back to the initial position(the east),wait for the sensor value to be equal to or greater than 3V and then rotate to track the maximum light intensity

If voltage value coming from the sensor is equal to or greater than 3V which indicates that the sun is rising the next step is to move the panel to get the maximum light intensity.

The panel will be moved to the west 5.2 degrees, the two voltage values respective to the old and new position will be compared by the microcontroller, if the new value is greater than or equal to the old value panel will keep rotating towards the west and the two voltage values is compared again. This movement will continue until the new voltage value is less than the old one, when that happens the panel will be rotated 5.2 degrees to the east. At this point the panel is in the right position to utilize the maximum light intensity.

The microcontroller will wait for four minutes before rotating the panel to the west 5.2degrees through the stepper motor, the old and new voltage values is compared and the appropriate position will be determined in the same manner as stated above. The four minutes interval is based on the fact that the sun moves one degree every four minutes.

When the panel has been rotated through the full range of movement and the voltage drops below 3V (darkness) it will be rotated back to the initial position.

The sensor output will be checked by the microcontroller and when it is equal to or greater than 3V the maximum light intensity will be tracked.

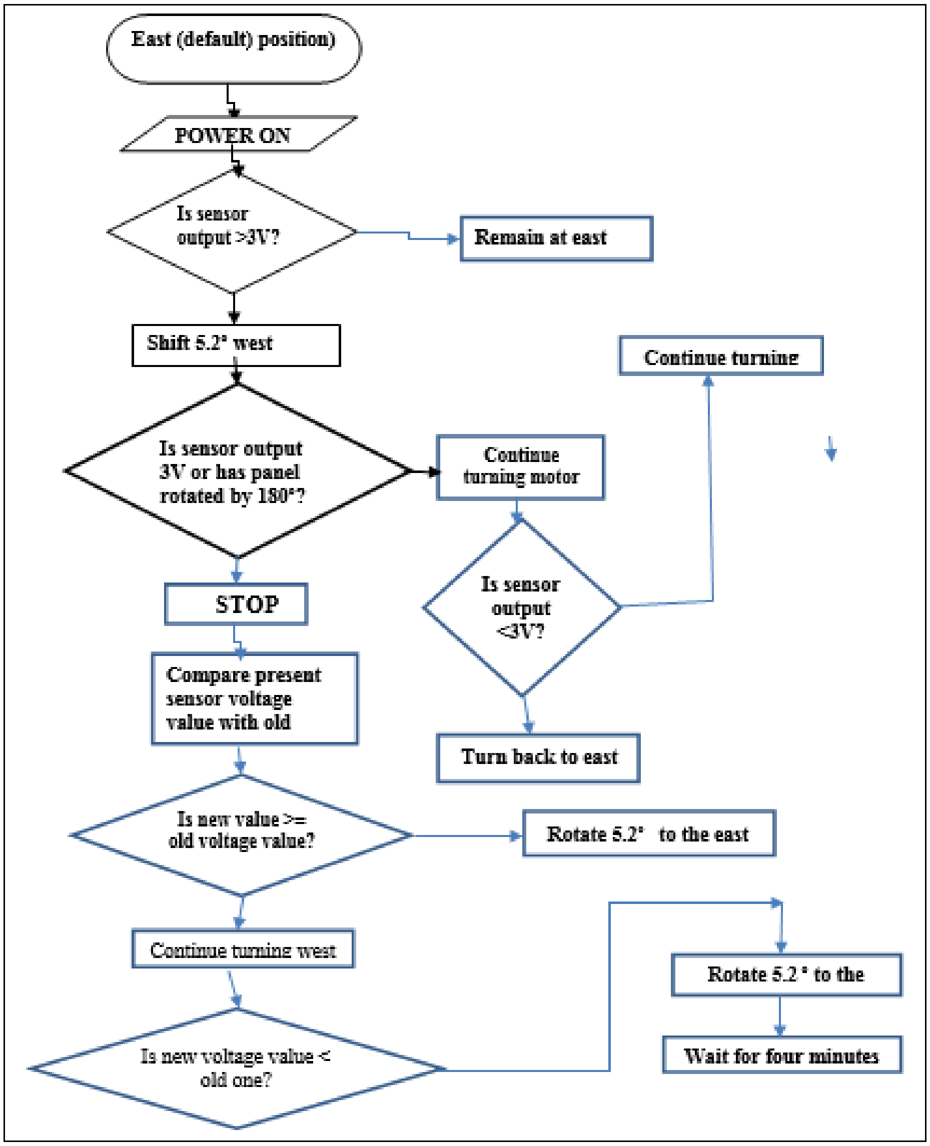

Fig 3.2: System Behaviour Flow Chart

Fixed and Tracking Collectors
Harnessing of solar energy can be done using either fixed or movable collectors.

Fixed Collectors
Fixed collectors are mostly mounted on the places with maximum sunlight and at relatively good angle in relation to the sun such as rooftops. The aim is to expose the panel for maximum hours in a day without necessarily involving tracking technologies and therefore a considerable reduction in installation and maintenance cost is realized. As such, majority of the collectors are fixed type. For fixed solar collectors therefore, it is very necessary to know the position of the sun at various seasons and times of the year so as to give the optimum orientation of the collector during installation to give the maximum solar energy all year round. Since the focus of this project was to design a solar tracker device to be used in Abia state (lat: 5.110474 long: 7.661109) as obtained from gaisma.com, the sun chart diagram of this locality is shown below.

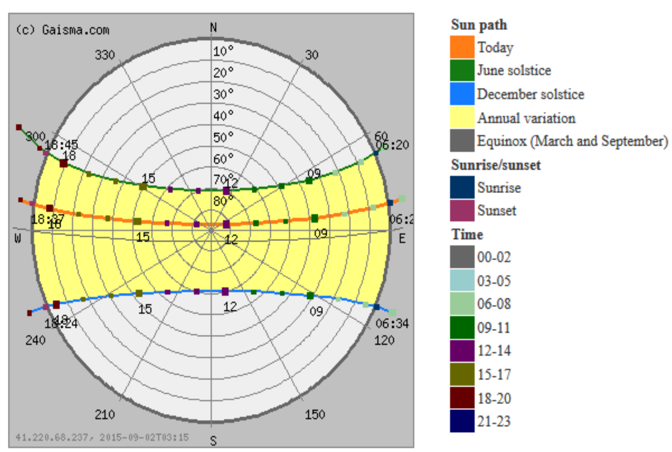

Fig 3.3: chart showing the position of the sun round the year in Aba city

By using this chart, we can almost definitively ascertain the position of the sun during different time and seasons of the year such that we are able to fix the payload, in this case a fixed solar panel or photovoltaic cell to give us the maximum energy output. As previously discussed, it should be noted that fixed solar trackers are cheaper and therefore more preferred around countries in the tropics region, Kenya being no exception. However, for countries beyond +10degrees North and -10degrees South of Equator, there is serious need for solar tracking since the number of sunshine hour's maybe less and/or the position of the midday sun may vary significantly.

Tracking Collectors: Improved Efficiency

For a tracking collector, the theoretical extracted energy is calculated assuming that the

Maximum radiation intensity $I = 1100\ W/m$ (watt per meter) is falling on the area which is oriented perpendicularly to the direction of radiation. Taking the length of day

$t = 12h = 43200s$, then intensity on the tracking collector which is always optimally oriented facing the Sun is compared to that of a fixed collector which is oriented perpendicularly to the direction of radiation only at noon. The collector area is marked as S_o.

CASE 1: The Fixed Collector

For a fixed collector, the projection area on the area oriented perpendicularly to the direction of radiation is $S = S_o \cos\theta$, where θ is changing in the interval $(-pi/2, +pi/2)$ during the day. The angular velocity of the Sun moving across the sky is $\omega = 2pi/T = 7.27\times10^{-5}\ rad/s$ and the differential of the falling energy is $dW = ISdt$. Neglecting the atmospheric influence, the energy per unit area is calculated for the whole day:

$$W = 21s/\omega$$
$$= 3.03 * 10^7 W/m^2\ day$$
$$= 8.41\ kWh/m^2\ day.$$

CASE 2: The Tracking Collector

For a tracking collector, by neglecting the atmospheric influence, the energy per unit area for the whole day is

$$W = IS_o\ t = 4.75 \times 10^7\ Ws$$
$$= 1.32 \times 10 kWh/m^2\ day.$$

Comparing the theoretical results from the two scenarios above, more energy is calculated from CASE II, for the tracking collector. However, the Sun's rays reaching the Earth's surface go through the thick layer of the atmosphere in both cases. Nonetheless, the tracking collector has a greater exposure to the Sun's energy in any given day.

4. System Implementation

The implementation of the system which is the hardware structure comprising analog-to-digital converter, Light Dependent Resistor, Stepper motor, LCD display and a microcontroller is breifly presented.

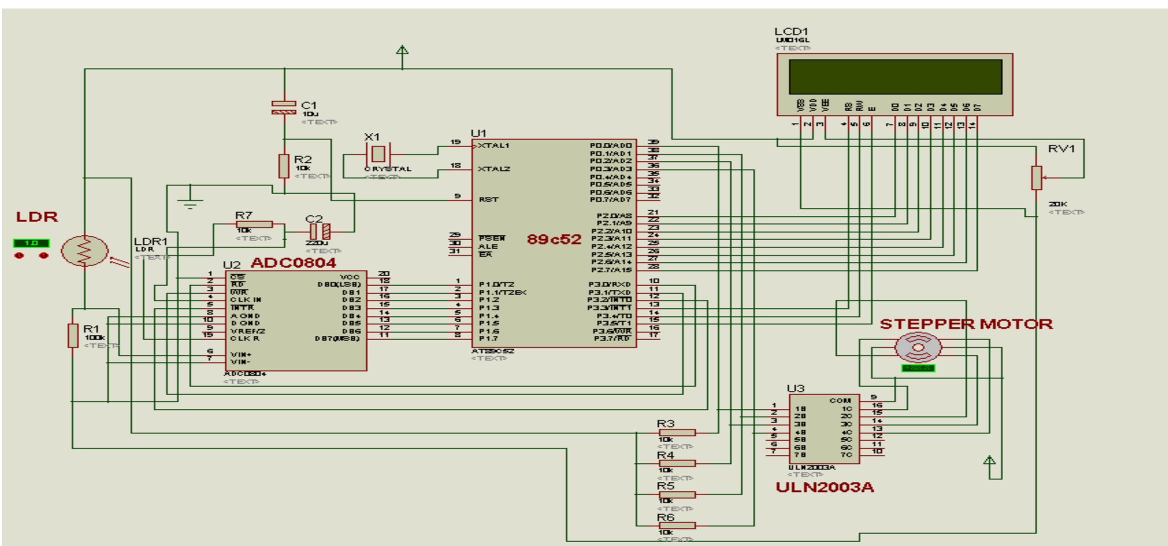

Fig 4.1: System circuit diagram

System Operation

This work is made up of different units (Sub-systems) or stages that are designed to operate in a specific way together with others sub units to achieve the expected functions.

From the LDR sensor, the sun intensity is determined by the reduction or increase in resistance of the Light dependent resistor. This is interconnected to an Analog-to-digital converter through a voltage divider circuit. As the sun intensity varies, the voltage output of the voltage divider varies which in turn changes the step size of the ADC output after conversion of the equivalent voltage at its input (i.e,output of the voltage divider). This digital output is fed into the microcontroller such that whenever it detects the step size corresponding to the highest intensity; it stops the stepper motor and as well displays the position on the LCD. Otherwise, it moves the motor to check for change in the sun intensity. As any change occurs, it responds to it by adjusting the solar panel to new angular position. As the sun sets, the Motor is returned back to root position and remains there until the sun rises again the next day. The whole process is repeated once again.

The IC, ULN2003A is used to drive the stepper motor because the controller cannot source enough current as to drive it. The LCD display unit gives the information on the angular position of the Solar panel in the ranges of 0^0, 22.5^0, 45^0, and 67.5^0.

Test Result

After the design was sketched, the source code is loaded in to the microcontroller

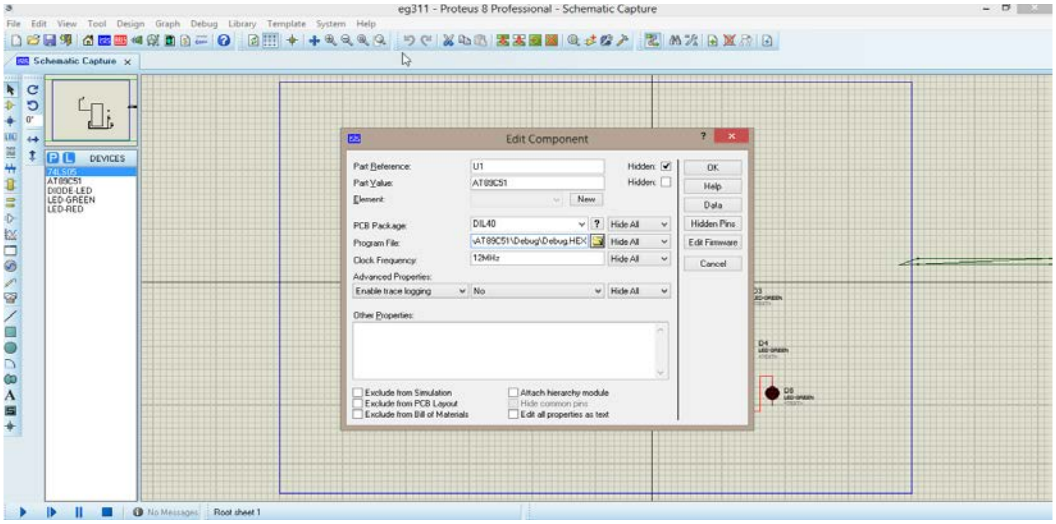

Fig 4.2: load source code into microcontroller

Check the CPU load to ensure the system is not over loaded, then click the play button.
LCD showing position of panel at V_{IN} greater than 3V

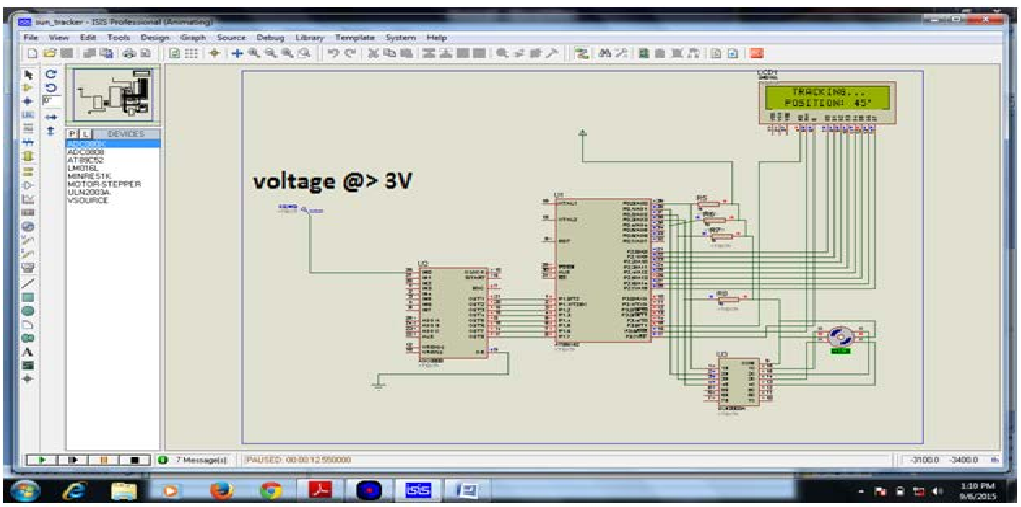

Fig 4.3: LCD showing position of panel at V_{IN} greater than 3V.

LCD showing tracker position at V_{IN} undefined

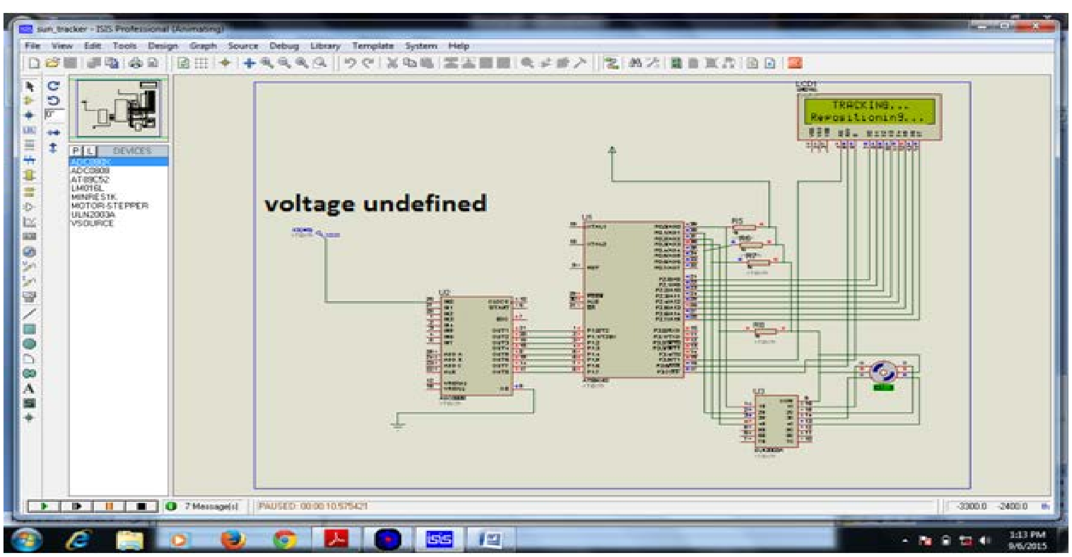

Fig 4.4: LCD showing position of panel at V_{IN} undefined 3V.

LCD showing position of panel at V_{IN} greater than 3V.

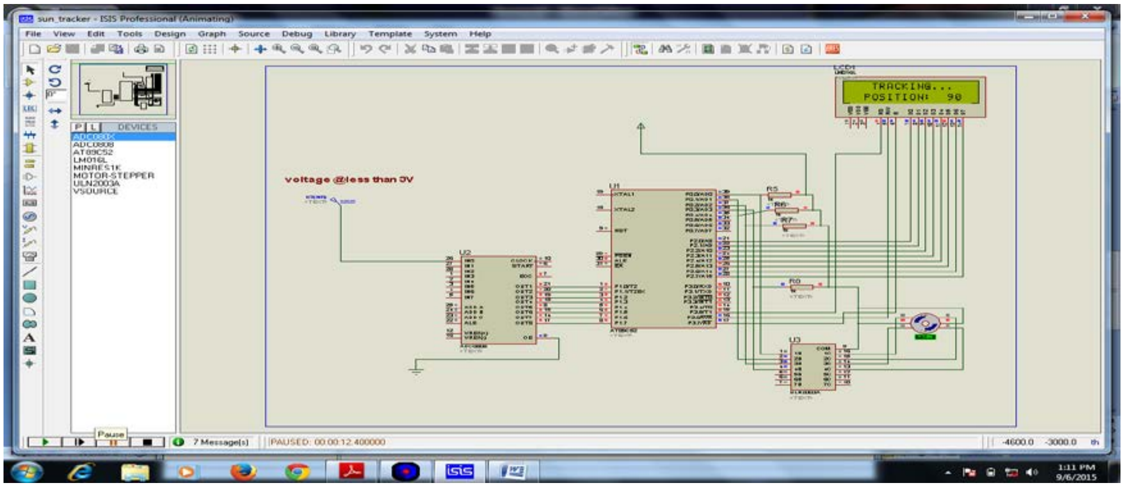

Fig 4.5: LCD showing position of panel at V_{IN} greater than 3V.

LCD showing position of panel at V_{IN} less than 3V (Nightfall).

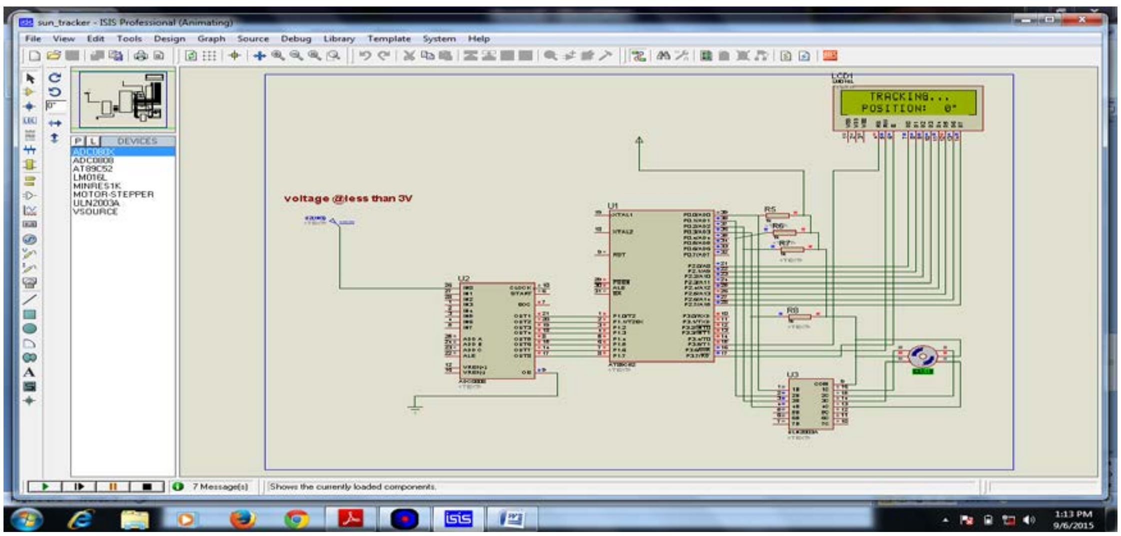

Fig 4.6: LCD showing position of panel at Vin less than 3V.

During the simulation/animation of the designed prototype the CPU load for the microcontroller was at 31% which indicates the capability of the system when designed to run for years without the components generating excessive heat. The brightness of the LCD could not be ascertained at this stage.
The hardware operation after the design implementation was without hitches.

5. Conclusion

The significant focus of this work is centered upon the use of microcontroller in design and control of electronic systems that require real time and accurate monitoring of electronic devices. Specifically, it demonstrates a working software solution for maximizing solar cell output by positioning a solar array at the point of maximum light intensity. The work seeks to address the challenge of harnessing solar power as well as economical microcontroller based solar tracking system that can be implemented using the allocated time and resources so as to track the relative motion of the sun in the sky during daylight and to save the much needed power for sleep at night. A working model is being prepared in order to implement the idea using any hypothetical situation.

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