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DEVELOPMENT OF A MICROCONTROLLER-BASED SOLAR TRACKING SYSTEM

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Abstract— Renewable energy exploration has rapidly gained importance as an alternative energy source with fossil fuels availability worldwide continue to deplete causing fluctuation in their prices. At the energy research and innovation level, it is required to have an understanding and appreciation of the technologies associated with renewable energy. One of the most prevalent renewable energy sources is solar energy. Research has been directed toward the use of trackers to increase the efficiency of a solar energy collectors to be able to harvest substantial energy. This was designed for to operate on single axis tracking system in this study. Feedback control theory with sensors was used to enable the solar collector to seek optimum position for the radiation of energy. A mechanism for automatic reset and restart was incorporated in the design of the tracking system. The constructed system satisfactorily tracks the sun from east to west and reset at sunset, with higher efficiency of solar energy harvested as compare to a fixed collector.

Index Terms— Energy exploration, renewable energy, fossil fuels, feedback control, solar energy, sensor theory, tracking system

1. Introduction

It is now widely accepted that the worldwide increase in energy consumption we are experiencing for many years will continue indefinitely. There is a limit to our reserves of fossil fuel. Solar energy is by far the most attractive alternative energy source for the future. Apart from its non-polluting qualities, the amount of solar energy resources available for conversion is in enormous magnitude to serve the surging present world energy requirements if properly harvested and stored since energy is the prime factor for the growth of a nation [1].

By going solar, we could be leading the way towards a cleaner world where all our energy demands are tapped from free and in-expendable sunlight source without leaving a harmful effect on the environment advertently reducing carbon emission and global warming. The alternative energy technologies are already here, efficient, effective and within financing reach. Solar panel is mainly made from semi conductor materials with silicon (Si) with efficiency of 24.5% used as major component [2].

The microcomputer has had positive impact on different aspect of our livelihood activities, and gradually playing a more significant role in the functioning of all industrialized societies. With advances in semiconductor technologies, the astronomically valued computing of the 1960s is now available for microcontroller.

The swift growth and vast appreciation of the microcontroller has transformed the design and control paradigm of systems and sub-systems. This is primarily because of its low-cost, small size, programmability and flexibility [3].

In today's advanced technological age, artificial intelligience to most industrial and domestic processes are now being introduced. There is a continuous request for versatile, multifunctional, less complex and highly flexible process controllers in today's society. This trend is to obtain high efficiency, reliable and easy to use electronic devices and systems [4].

Electronic control circuits are now providing these new levels of system performance requirements with much reduced system complexity, yet achieving high performance. The need to reduce the circuit complexity and other shortcomings of purely electronic system led to the introduction of the microcontroller. Intelligent central processing unit such as the SDK-85 is programmable and can be used to improve existing system flexibility and performance with reduced complexity [4]. With this reason in mind, calls for the main aim of this project which is to apply microcontroller to control a solar tracker.

1.1 Optimum Orientation of a Flat Collector

To obtain maximum radiation during the day, the flat collector should be positioned in such a way that the angle of incidence is zero and the beam radiation from the sun should be orthogonal to the collecting surface as shown in Figure 1.

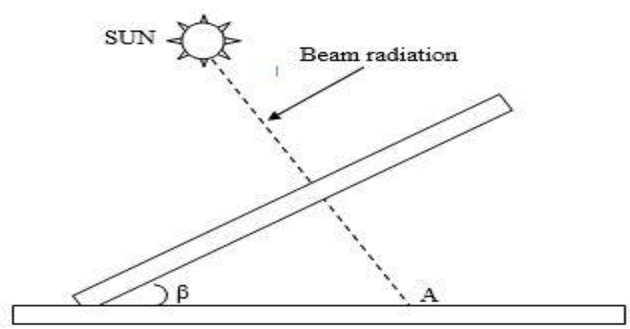

Fig. 1. Flat solar collector

A generally acceptable orientation for flat collectors is that the collectors should always point towards the direction of the solar beam (ϴ = 0) [5].

2. SOLAR GEOMETRY

2.1 Solar Tracking

Availability of solar energy is accompanied by erratic characteristics and unpredictability which are caused by the motion of our planet, including the earth's revolution around the sun, the earth's daily rotation about its own axis, and tilt of that axis

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with respect to the plant of the earth's orbit. The motions predictably yield characteristic effects. The mean distance between the earth and the sun is **1.4 x 10^9 meters** and due to eccentricity of the earth's orbit, this distance varies by **± 1.7%** [5]. Different angle position of the sun is as shown in Figure 2:

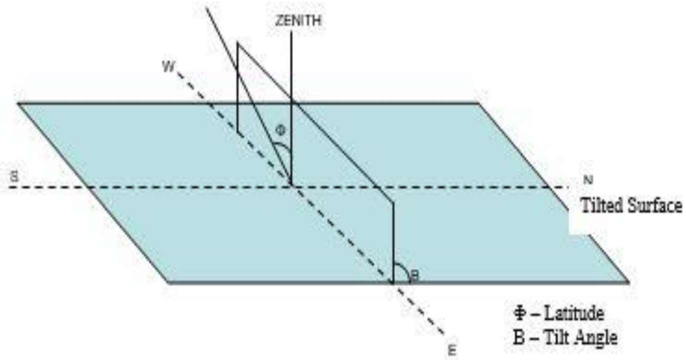

Fig. 2. Solar positioning angles

In the application of photovoltaic cells, solar tracking enhances concentrators' efficiency. Automation of the solar collector could be obtained where the unit can operate without the need of human intervention. Such system can track the sun so that the solar panels receive maximum radiation at all time [6].

2.2 Single Axis Tracking

In most application that requires tracking, one axis tracking is utilized and this becomes justifiable when cost addition is considered. However, for higher concentrations and high precision applications, two orthogonal tracking may be required. The rotation of the earth is the major action in solar radiation collectors, while the impact of other movements has very gradual effects which are mostly neglected in many applications without introducing much error. This makes single axis tracking more acceptable, as it represents a relatively efficient investment, with application in areas like research work and high precision tracking applications [7].

2.3 Scope of the Proposed Tracking System

A Solar tracking system is designed based on single axis tracking on the equatorial axis for tracking the sun from east to west daily. The system which is time based is to be controlled by the PIC16F877 microcontroller and its peripheral devices, to provide the correct pulse sequence for driving a stepper motor which is connected to the solar panel tracking module.

3. DESIGN OF THE TRACKING SYSTEM

The design and implementation of the entire solar tracking system was divided into three parts: - the hard ware, the system software, and the power supply unit. The design and implementation of each part has its own interface and operation with the others.

The entire system block diagram for the implementation is as shown in Figure 3:

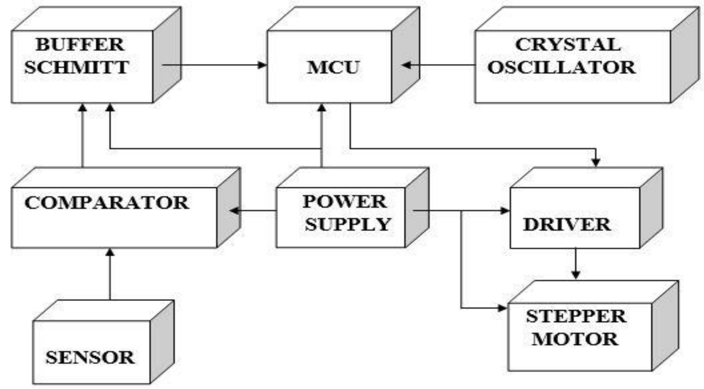

Fig. 3. Solar tracking system block diagram

3.1 Control Unit and Crystal Oscillator

For the control unit, PIC16F877A microcontroller IC was used and in applications where great time precision is not necessary, RC oscillator offers additional savings during purchase. Resonant frequency of RC oscillator depends on supply voltage rate, resistance R, capacity C and working temperature. It should be mentioned here that resonant frequency is also influenced by normal variations in process parameters, by tolerance of external R and C components, etc. [8]. So based on the above consideration, an RC oscillator was chosen and design procedure is shown in figure 4.

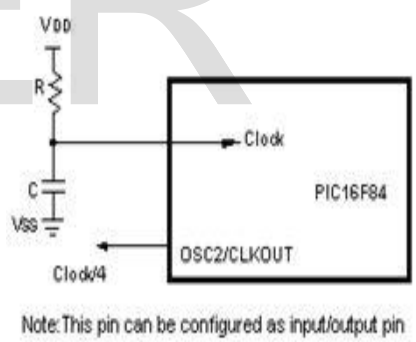

Fig. 4. RC oscillator connection

Figure 4 shows how a resistor capacitor oscillator are connected with PIC16F877A. With value of resistor R being below 2.2k, oscillator can become unstable, or it can even stop the oscillation.

3.2 Master Clear

The master clear (MCLR) is used for putting the microcontroller in a specific "known" condition [9].

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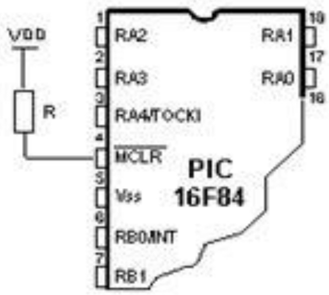

Fig. 5. RC oscillator connection

In order to prevent from bringing a logical zero to MCLR pin accidentally (line above it means that reset is activated by a logical zero), MCLR has to be connected via resistor or a capacitor to the positive supply pole as shown in Figure 5. A capacitor value of 100nF was used.

3.3 Stepper Pulse Sequence and Phase Driver

The tracking system is designed to cover an angle of 180^0 from 8am to 5pm daily. As such the resolution is given as

$$Resolution = \frac{180}{2} = 90 \text{ steps / (1/4) revolution} \qquad (1)$$

This implies that the number of seconds under consideration between 8am to 5pm is 32400 seconds with time interval given as

$$\boldsymbol{Time\ interval} = \frac{\mathbf{32400}}{\frac{\boldsymbol{revolution}\,(\mathbf{0.25})}{\boldsymbol{rev}}} = \mathbf{648}\ \boldsymbol{seconds}$$

Thus the 8155 microcontroller sends a pulse after every 648 seconds interval to drive the stepper motor.
The stepper motor has four phases. The bit pattern causes one of the four coils to be energized at a time shown in Figure 6:

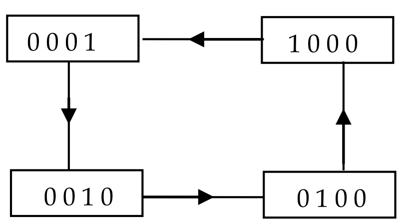

Fig. 6. State diagram for stepping

To drive the phase, the stepper motor sinks current beyond which the microcontroller and the circuit can source and this necessitates the use of an interface between the stepper motor and the microcontroller.

3.4 Power Supply

The power supply design was achieved using a 240/15V, 50Hz, 2A step down transformer, a bridge rectifier, a filter capacitor, and a current limiting circuit as shown in Figure 7:

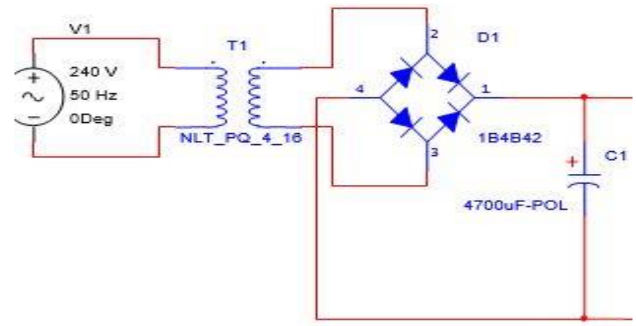

Fig. 7. Power supply circuit

for the full-wave rectifier:

$$V_m = \sqrt{2}V_s \qquad (2)$$

Where, Vm = maximum voltage of the output, V_s = secondary rms voltage of the transformer.

$$\text{But, } V_{dc} = \frac{2}{\pi} V_m \qquad (3)$$

The percentage ripple factor is given by,

$$r = \frac{V_r(rms)}{V_{dc}} \times 100\% \qquad (4)$$

for full wave rectifier,

$$V_r(rms) = 0.308V_m$$

$$\text{Therefore, } r = \frac{0.308V_m}{0.636V_m} \times 100\% = 48\%$$

However, the filtering capacitor is given by,

$$V_r = \frac{I_{dc}}{4\sqrt{3}fC} \qquad (5)$$

Hence the capacitor can now be calculated as,

$C = \frac{I_{dc}}{4\sqrt{3}fV_r}$ Where, *Idc*= *2A* $V_r = 0.308V_m = 0.308\times\sqrt{2}Vs$

$= 0.308\times\sqrt{2}\times 15 = 6.533V$ *with* $f = 50Hz$

The Filtering capacitor value is

$$C = \frac{2}{4\sqrt{3}\times 50\times 6.533} = 833\mu F \text{ with } 2200\ uF \text{ chosen.}$$

For the power supply limiting resistor, the LED can allow up to 35mA but will be limited to 10mA. The circuit is as show in Figure 8:

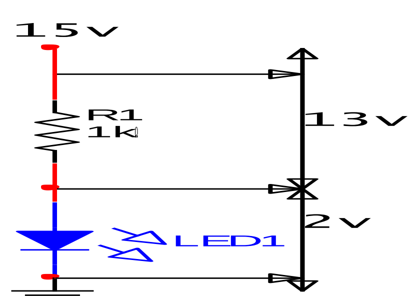

Fig. 8. RC oscillator connection

V_R=13V, IR=10mA = I_{LED} in series connection

R=$\frac{V_R}{I_R}$ = $\frac{13v}{10mA}$ = 1.3KΩ. Standard Value used 1KΩ.

3.5 Regulator

LM7805 with 5 volts rating was chosen because they provide up to 1A load current and have in the chips a circuit to prevent damages caused by overheating or excess handling capacity of the chips.

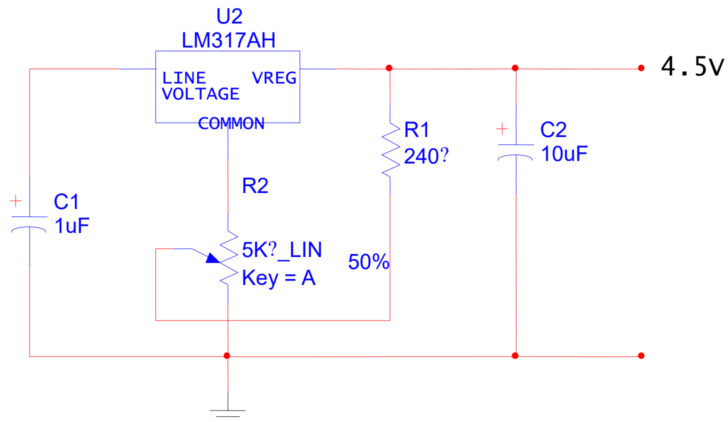

Fig. 9. RC oscillator connection

From Figure 9, the variable resistor was varied until the output voltage 4.5V was achieved and the current was up to 1.5A.

3.6 Crystal Oscillator

A light emitting diode and transistor are found inside the transistor photo coupler considered in this design. When the LED emits, the emission provides base current to the transistor optically, then biased as emitter follower which in turn is used to drive the base of the transistor driver TIP 41(Darlington configuration) while resistor 10Ω is chosen to limit the current of the collector.

V_R=3.6 I_R=10mA

$\frac{V_R}{I_R} = \frac{3.6}{10mA}$ = 360 Ω. ∴ Standard value used is 330Ω.

3.7 Comparator (LM324)

When the intensity of light is high, the 2.7KΩ resistor that is parallel with the Light Dependent Resistor (LDR), resistance characteristics reduce there by reducing the voltage from 2.5V, and then the non-inverting terminal is high than the inverting terminal. There is a high at the output and when passing through which makes the BC547 become low and activate the microcontroller. The capacitor creates delay when charging and the transistor conducts when it is fully charged. The circuit is as shown in Figure 10.

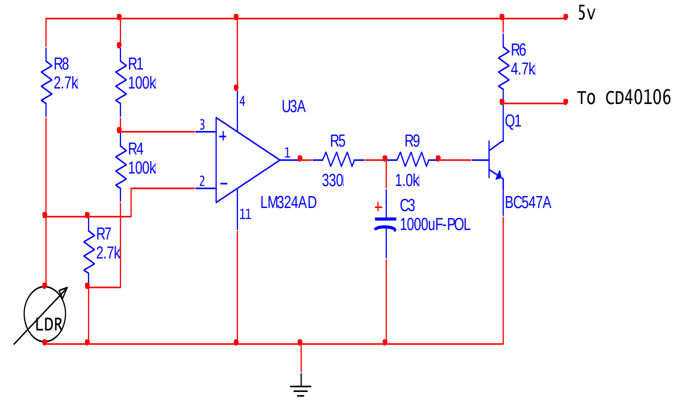

Fig. 10. LM324 comparator circuit

3.8 HEX SCHMITT Trigger

The CD40106BC Hex Schmitt Trigger is a monolithic complementary MOS(CMOC) integrated circuit constructed with N and P channel enhancement transistor [9]. The positive and negative-going threshold voltages, VT+ and VT-1 shows low variation with respect to temperature (typ0.0005v/°c at VDD = 10v) and hysteresis, VT+ - VT- ≥ 0.2 VDD is guaranteed. All input is protected from damage due to static discharge by the diode clamps to Vdd and Vss. The trigger used in this design consideration, the voltage ranges from 3V to 15V.

4. TESTING OF THE SOLAR TRACKING SYSTEM

4.1 Power Supply Testing

The power supply units of the 4.5V and 5V were tested for the voltage output under no-load and full load conditions. At no-load, the voltage of the 4.5V supply section was measure to be 4.4V while that of the 5V supply section was measured to be 4.98V. At full load, the respective corresponding voltages were measure as 4.4 and 4.98V for the 4.5V and 5V. The percentage voltage regulation VR is given as:

$VR = \frac{VNL - VFL}{VNL} \times 100\%$ VNL = no load voltage

VFL = full load voltage. For the 4.5V supply

VR = $\frac{4.5 - 4.4}{4.5} \times 100 = 2.2\%$. For The 5V Supply

$$VR = \frac{5 - 4.98}{5} \times 100\% = 0.4\%$$

The performance of the power supply was satisfactory since the percentage voltage regulations of the different supply voltage are low. Heat sink is used on the regulators chip to further enhance cooling of the regulator while they are loaded.

4.2 Delay Routine Software Testing

The software testing was done to confirm the operation of the main program and the delay subroutine of the proper sequence of lighting at the intersection under various conditions. The PIC simulator IDE was used for the testing. The crystal clock used was the PIC16F877 and it ran at a frequency of 4 MHz, but actual frequency of operation of the IC is given by:

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$$f = 4MHz \div 4 = 1MHz$$

Therefore;

$$T = \frac{1}{f} = \frac{1}{1\times10^{6}} = 1\mu s$$

The delay used in this work was based on the seven loops technique. The delay program shown below was used and it was loaded in the PIC16F877.

SOURCE CODE

```
TIMER ROUTINES
;;;;;;;;;;;;;;;;;
DELAY1MS:
        MOVLW 0XFA    ;1 msec delay, d'250'
        MOVWF 0X060
LOOP1:          NOP
        DECFSZ 0X060,F
        GOTO LOOP1
        RETURN
DELAY250MS:                     ;250 msec delay
        MOVLW 0XFA   ;d'250'
        MOVWF 0X061
LOOP2:          CALL DELAY1MS
        DECFSZ 0X061,F
        GOTO LOOP2
        RETURN
DELAY1S:                ;1 sec delay
        MOVLW 0X4       ; d'4'
        MOVWF 0X062
LOOP3:          CALL DELAY250MS
        DECFSZ          0X062,F
        GOTO LOOP3
        RETURN
DELAY1M:                ;1 min delay
        MOVLW 0XF0   ;d'240'
        MOVWF 0X063
LOOP4:          CALL DELAY250MS
        DECFSZ 0X063,F
        GOTO LOOP4
        RETURN
DELAY4M:
        MOVLW 0X04
        MOVWF 0X064
LOOP5:          CALL DELAY1M
        DECFSZ 0X064,F
        GOTO LOOP5
        RETURN
DELAY90M:
        MOVLW 0X5A
        MOVWF 0X065
LOOP6:          CALL DELAY1M
        DECFSZ 0X065,F
        GOTO LOOP6
        RETURN
DELAY20M:
        MOVLW 0X014
        MOVWF 0X066
LOOP7:          CALL DELAY1M
        DECFSZ 0X065,F
        GOTO LOOP7
        RETURN
```

4.3 CAD Mechanical drawing and the Constructed Prototype

The CAD drawing in Figure 11 provide a 3D view of the final design outlook and the constructed prototype that was used to carry out the test with provision for the solar panel location.

Fig. 11. 3D view and the solar tracking system

4.3 Results

The Table 1 presents the solar tracker test result when carried out during daytime. The daily motion of the sun is 360 degrees in 24 hours [11], which is 15 degrees every hour. It Kept tracking the sun through a 12-hour period during which the system will check every minute for voltage difference between LDR. The motor controller will extend or retract the linear actuators until the voltage difference equals zero.

During Day time

Table 1: The solar tracker testing result when carried out during the daytime

COMPARATOR / SENSOR	INVERTING INPUT	NON INVERTING INPUT	OUTPUT	BC547	PIC
EAST	2.54V	1.15V	LOW	OFF	OFF
MID	2.54V	1.14V	LOW	OFF	OFF
WEST	2.54V	1.16V	LOW	OFF	OFF

So, there is a high at the output and when passing through and the BC547 become low which make the microcontroller active. Thus, the output at the inverting terminal is higher than the non-inverting terminal. The capacitor creates delay when charging and when it is fully charged, the transistor starts conducting.

5. CONCLUSION

The project has presented a means of tracking the sun's position with help of microcontroller and stepping angle of 2.5 degree.

It demonstrates a working software solution for maximizing solar cell output by positioning a solar panel at appoint of maximum light intensity during the daytime. The system proved sufficiently stable and a relatively low cost of implementation, which makes it very feasible for use in solar to electricity conversion in both large and small scale. The simplicity of the design makes the system reliable for operation over a long period of time.

The design has also incorporated mechanism reset at sun, hence once installed, the system can go on automatically. Result of the comparative test shows that the tracking collector have better efficiency than with the collector is not fixed. Though the constructed prototype has limitations in hardware area as an initial set up, it still provides an opportunity for improvement of the design methodology in the future.

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