DESIGN AND CONSTRUCTION OF A SOLAR TRACKING SYSTEM (S.T.S) WITH TWO ROTATION AXIS

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Abstract: Solar Tracking Systems have attracted the interest for increasing the overall performance of solar collectors or PV-arrays, especially the ones with two axis of rotation. The requirement to built such an automated system, which is cheap, reliable and easy to construct it is described. It requires four sensors (photo-resistors) and two simple motors instead of step motors. It has been tested and runs smoothly during the day with a sensitivity, which depends on the geometry of the sensors, base i.e. sensors distance for letting the system trigger its go.

1. Introduction

There are many attempts to design and develop solar tracking systems either for solar collectors (flat plate, CPC) or PV-panels [1-7]. The problem is split in two parts:
1. the electronic automation part and
2. the mechanical part

As it is discussed in [2] the system with two axes of rotation exhibits higher total efficiency.

Therefore, the attempt is focused to design a cheap small-medium size S.T.S with a high degree of reliability and a good response sensitivity.

The one axis is horizontal (E–W) to permit the collector/ PV–panel to get such an inclination in reference to horizontal, which combined, with the rotation in the other axis, with a vertical or polar direction, to be able to follow the sun ’s disc as in fig.1.

Fig 1: Sun’s Trajectory in a day and the fundamental angles

It’s obvious that, the starting position of the collector or PV at sun rise-sunset is to be at vertical, while during the day its inclination will be less and at solar noon is to be:
β=φ−δ

Where, φ is the latitude and δ is the declination angle.

The azimuth angle of the collector at sunrise / sunset i.e. the limits of the angle, γ, can be determined by the formula (2) [8]
\[
\sin \gamma_z = \frac{\cos \delta \sin \omega}{\sin \theta_z} = \frac{\cos \delta \sin \omega}{\cos \beta} \quad (2)
\]

Setting: \( \omega = \omega_0, \omega_\theta \) where
\[
|\omega_0| = |\omega_\theta| = \cos^{-1}(\tan \phi \tan \delta) \quad (3)
\]

For sun tracking system it is obvious that \( \beta \) has to be equal to \( \theta_z \) [9] Hence the appearance of the last part of expression in eq (2)
\( \gamma_z \) can also be determined via a software package as developed by the first of the authors.

**S.T.S. Design Principles**

Several versions of S.T.S. can be design and developed, such as:

**Solution 1:**
The S.T.S consists of two rotation axes on which a frame is mounted with PVs or solar collectors plus two stepping motors which are triggered by signals out of a PC microprocessor.

This microprocessor should be programmed in order to give output signals, which would turn the frame with a solar panel with a predetermined angular horizontal velocity \((dy/dt)\) to be estimated as a function of day time from the equation (2):

This holds in case the rotation axis is vertical, on the other hand when the axis is polar the rotation velocity is equal to the hour angle change speed i.e. \(\omega_\theta=1/4 \ deg/min\) (4)

The same procedure should be followed for the rate of change of the inclination \(\beta\), with reference to horizontal.

In such as solution no sensor is required, instead signals are produced in prescribed (preset) intervals which provide for the proper values of \(\dot{\gamma}\) and \(\dot{\beta}\).

**Solution 2:**

This solution requires the proper electronic circuit to be built linked with a set of sensors which would provide signals for both rotation: azimuthal and inclination to horizontal.

The principle is self-described in fig 2a, 2b

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**Fig. 2a**

**Fig. 2b**

Fig 2a\&2b: 4 sensors (photocells or photo resistors) linked in couples (1,3) or (2,4) to trigger the system with a signal output in case 1 or 3 are differently illuminated by the sun. The same for (1,3) holds for (2,4).
In such a case a signal is produced by the comparator see fig 2b. Which gives the block diagram of the circuit. The signal produced by the comparator triggers the stepping motor via a multi-vibrator and hence it moves the frame towards a direction to equalize the illumination in both couples of sensors. Such an S.T.S needs a comparator see figs 2b and 2c and the stepping motor with its controller see fig 2d.

![Fig. 2c: Basic structure of the electronics of the STS using 2 sensors per rotation axis and a comparator to provide triggering signals.](image)

**Solution 3:**
This is another sub-family of S.T.S designs, which instead of two-step motors uses two common motors. Each one of them provides a trigger signal for rotation in one axis as long as the electronic circuit provides an output.

The circuit outlined below, produces a signal when one of sensors of the couple is less illuminated than the other. Such a circuit needs no comparator.

![Fig 2d : The circuit above is the controller of the stepping motor.](image)

The circuit, which runs on this principle, is shown in fig 3.
Here, the principle is that when one of the sensors (photo-resistors) is not equally, illuminated as its partner a signal is produced by the timer 555 which charges the relay and makes the motor move.
Fig 3: Solution 3 electronic circuit uses no comparator as in solution 2, but an unstable multi-vibrator. The details of the parts of the circuit are given below.

Parts List

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Reference ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>+Vcc Voltage Source, Ideal</td>
<td>1</td>
<td>U2</td>
</tr>
<tr>
<td>555 Timmer</td>
<td>2</td>
<td>U3, U1</td>
</tr>
<tr>
<td>Capacitor, 100nF</td>
<td>2</td>
<td>C3, C2</td>
</tr>
<tr>
<td>Connector</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>DC Motor Ideal</td>
<td>1</td>
<td>MG1</td>
</tr>
<tr>
<td>Diode, Ideal</td>
<td>4</td>
<td>D1, D2, D3, D4</td>
</tr>
<tr>
<td>Ground</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Node</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Polarized Capacitor, 100 nF</td>
<td>2</td>
<td>C1, C4</td>
</tr>
<tr>
<td>Potentiometer, [R], kΩ ±5%</td>
<td>2</td>
<td>R9, R1</td>
</tr>
<tr>
<td>Relay, Ideal</td>
<td>2</td>
<td>R6, R3</td>
</tr>
<tr>
<td>Resistor 1 kΩ 0Ω/°C 0Ω/°C²</td>
<td>2</td>
<td>R8, R2</td>
</tr>
<tr>
<td>Resistor 47 kΩ 0Ω/°C 1Ω/°C²</td>
<td>2</td>
<td>R7, R5</td>
</tr>
<tr>
<td>Resistor 1 MΩ 0Ω/°C 0Ω/°C²</td>
<td>2</td>
<td>R10, R4</td>
</tr>
<tr>
<td>Switch</td>
<td>2</td>
<td>S2, S3</td>
</tr>
</tbody>
</table>
This is the solution adopted by this team as it was considered friendlier and less costly compared to the other solutions. Conclusively the circuit requires 6 Volt DC, which is provided by of a small PV –panel with 10 PV –cells of 25W, a power to make the motor rotate the whole system.

**Sensitivity**

Let a couple of sensors face the sunbeam as in fig 4. Let the sensors are equi-illuminated. The geometry is such that:

- Sensors distance: \(2W = 6 \text{mm}\)
- Height of the diaphragm: \(h \text{ mm} = 5 \text{ mm}\)

The shadow as sun follows it’s path moves towards one of the sensors with velocity

\[
V_{sh} = \dot{\omega} \times h = (1^\circ/4 \text{ min}) \times 5 \text{ mm} = (\pi/180) \times (5/4) \text{mm/min} = 0.00218 \text{ mm/min}
\]

The shadow reaches the sensor in time

\[
t = \frac{w}{V_{sh}} = \frac{3 \text{ mm}}{0.0218 \text{ mm/min}} = 137 \text{ min}.
\]

This is a bad sensitivity, as in 137 min the sun will describe an hour angle

\[
\omega = 137 \text{ min} \times 1^\circ/4 \text{ min} = 34.25^\circ
\]

Therefore, the design changes the geometry to a diaphragm of \(h=20 \text{ mm}\) and \(2w=6\text{mm}\). Finally, the new \(t\) equals 34.4 min, which corresponds to a suns hour angle of 8.6°. That is the collector must rotate for 8.6° in every 34.4 min this is an acceptable sensitivity. This should be the guide to design the kinematics for the rotation.

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**Mechanical Design**

The frame which the collectors / PV- panels are mounted as designed, consists of:

1. Stand frame
2. Support frame
3. Horizontal axis and the relative DC motor.
4. Vertical axis and the relative DC motor.

**Discussion**

The S.T.S. constructed is quite easy and cheap and responds smoothly. The power dissipated is easily provided by a number of PV-cells mounted on the frame. The electronic uses the unstable mono-vibrator and not stepping motors as they are more expensive though more reliable and accurate.
Fig. 5

References