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Low Energy Mechanical Driver for Solar Trackers

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ABSTRACT

A device was designed to obtain a dual axis rotation of a plate which can be used for various applications like Solar Tracking devices, celestial observatoryetc. The major problem associated with solar trackers, is the consumed power by the tracker. Moreover, obtaining continuous tracking is very difficult with electrical systems which require much power for their operations. This device contains a design, especially to track the solar path to harvest the maximum solar energy, using an insignificant amount of electrical energy. This device was constructed to continuously rotate the solar panel using flotation power. Flotation power was produced using two floaters inside a specially designed vessel. Additionally, an electronically controlled system was designed to align the plate perpendicular to the solar radiation according to the monthly tilt along North – South direction, of the solar path.

1.0 INTRODUCTION

Electricity has turned out to be the most essential power requirement of the modern world. Therefore, the development of alternate electricity sources has become an important research area. Mainly, the usage of solar power has increased in recent times and research in improving the efficiency of solar power generation has gained a lot of attention. To collect the maximum energy from the sunlight, the solar modules should align with the sun's path and always be perpendicular to the solar radiation. Misalignment causes a significant loss of available solar energy and it is one of the major drawbacks of using photovoltaic modules. Solar tracking devices are used to overcome this problem. Trackers help to orient the payloads toward the sun and therefore, they can collect optimum solar energy for the longest period of the day.Due to the low energy conversion efficiency of solar cells, it is vital that the power consumption of a solar tracker is minimal.

Highlights of the designed (low energy) solar tracker are as follows. Daily movement of the panels to track the sun from sunrise to sunset (East to West) takes the most energy and therefore, the tracker uses a floatation device in a water vessel to drive the movement. By maintaining a controlled continuous water flow out of the vessel, the panels move continuously rather than step by step providing the highest accuracy. As the tilt of the suns path along North – South direction is low, monthly average tilt is taken into account and an electrical motor is used to drive this movement.

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2.0 PROCEDURE

2.1 The plate (photovoltaic module) mounting

The plate (3×4 cm^2) was mounted on the stand via a ball joint as shown in Fig. 1,at the center point so that the total moment around the center is zero for all the angles of plate.

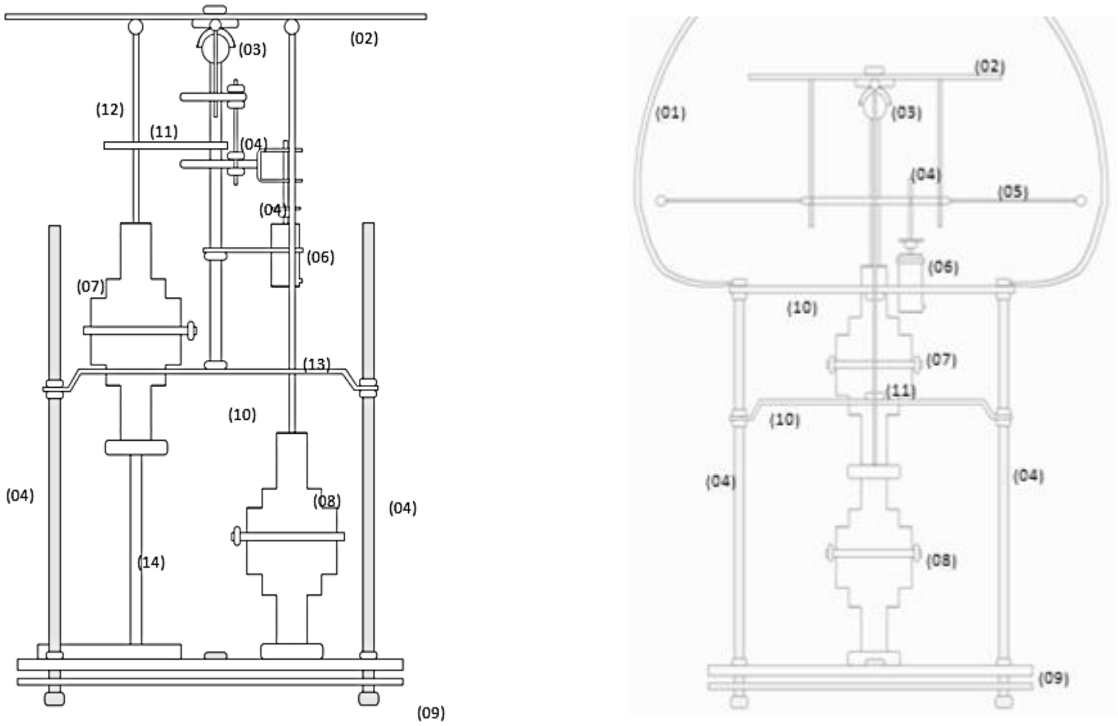

Fig. 1:End elevations of the device

(01) Curved bar with sensors installed
(02) Plate which represent the solar panel
(03) Ball joint
(04) Threaded bar
(05) Iron bar with magnet attached to the ends
(06) dc motor
(07) Floater vessel B
(08) Floater vessel A
(09) Wooden plate
(10) Iron plate
(11) Floater guide
(12) Floater B
(13) Floater A
(14) Wooden stand for vessel B

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2.2 Floaters

The floating power is used to drive the daily rotation of the plate. Theoretically only the friction force and the weight of the floater must be overcome by the displaced water volume from the floater. The instantaneous power which is needed to rotate the plate is insignificant. Floater A and B are used to drive the eastward and westward motion of the plate correspondingly. To prevent bending and displacement of the floater arm, guides were used. Length of the arm of the floaters A and B were calculated according to the following expressions.

Length of the arm of the floater A = $d' - l - d\tan\beta$

Length of the arm of the floater B = $d' - l - d\tan\beta - h$

Where d' is the distance between plate and the bottom of the floater vessel when the plate is horizontal, l is the height of the floater, d is the distance between the center of the plate and the force exerting point of the floater when plate is horizontal, β is the maximum angle of the plate to the horizontal position and h is the height of the floater vessel.

2.3 Floater vessels and water controlling

Force exerting point by the floater arm on the plate varies with the plate angle and therefore, the floater arm movement is not uniform. At the horizontal positions, lifting speed of the floater is minimized and it is increased with the plate angle. This variation can be compensated using vessel made with continuously varying or step varying diameter as the accuracy requirements.

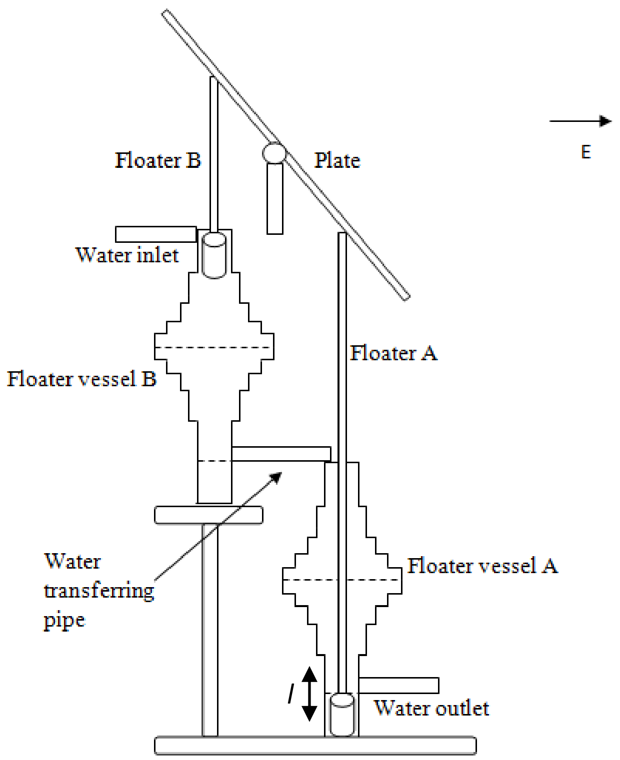

Fig. 2:Water supply of the system

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The height that the floater must be moved (h_i) corresponding to the plate angle Θ can be calculated as follows:

$$h_i = d \tan \theta_i \tag{1}$$

For the solar tracker, at the noon time, plate must be rotated 15.04° per hour to align plate with the hour angle of the Sun[1]. Therefore, if the flow rate at the noon time is set to *C*, then,

$$C \times \frac{60\, S}{15.04^0} \times \theta = h_i \times \pi {R_i}^2 = d \tan \theta \times \pi {R_i}^2 \tag{2}$$

Where R_i is the radius of the floater vessel in the step *i* and h_i is the height of that step.

The water volume under the level *l* must always remain inside the vessel A. At the beginning of the tracking cycle (at the sunrise), vessel B should be filled and vessel A should be empty as shown in the fig. 2andthe plate was faced to the east. Then the water inlet and outlet will be closed and water transferring pipe will be opened. The water gates (inlet, outlet and transferring pipe) are automatically controlled by the unit described in the next section. Therefore the water in the vessel B will be going to the vessel A and accordingly the plate will be rotated westward at the rate of 15·04° per hour.

If the tracking is limited between -75° to +75° hour angles, (this angles are sufficient for countries like Sri Lanka) afterrotating this 150°angle,plate must be rotated backward and return to the initial position. Therefore water inlet and outlet will be opened and the transferring pipe will be closed. Rotational speed of the backward direction can be calculated as follows:

Let the time required for Earth to rotate the remaining portion of the 360° cycle is *t'*, then,

$$t' = \frac{(360 - 150)^0}{\omega_0} = 837 \cdot 667 \text{ min} \tag{3}$$

whereω_0 is the rotational speed of the Earth[2].

$$\therefore \text{Eastward rotational speed} = \frac{150^0}{837 \cdot 667 \text{ min}} = 10 \cdot 74^0/h \tag{4}$$

According to above calculations, floater B will be filled and A will be emptied within 837.667 minutes. Flow rate (*C'*) of the inlet and outlet was adjusted as follows:

$$C' = \frac{\text{volume of the vessel} - \text{swallowed volume of the floater}}{837.667\, S} \tag{5}$$

Then the eastward motion must be started again. This must continuously proceed. In practice this continuous cyclic motion may be disturbed and therefore it has to compensate at least once a year. For that purpose, starting time for the eastward rotationmust be adjusted to the sunrise time.

3.3 Water gate controlling

Solenoids were used as the water gates. A magnet attached to the floater arm A and two reed switches S_a and S_b placed at the highest and lowest position of the floater as shown in the fig.3was used to sense the position of the floater and according to that, water gates are controlled via the circuit shown in the fig.4.Input current of the solenoids was supplied through the Normally Open switches of the relays L_5 and L_6. After 3 seconds, the voltage supply of the $L_5$and $L_6$is cut off through the relay L_4. RC timer was used to adjust the operating time period of the L_4. An external switch was connected to the voltage supply of the $L_5$and L_6 for manually controlling the water gates and they can be used to compensate for the water cycle if required.

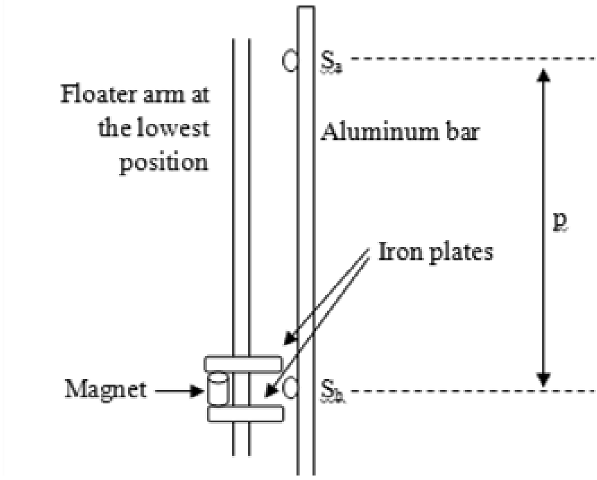

Fig. 3:Floater position sensing system

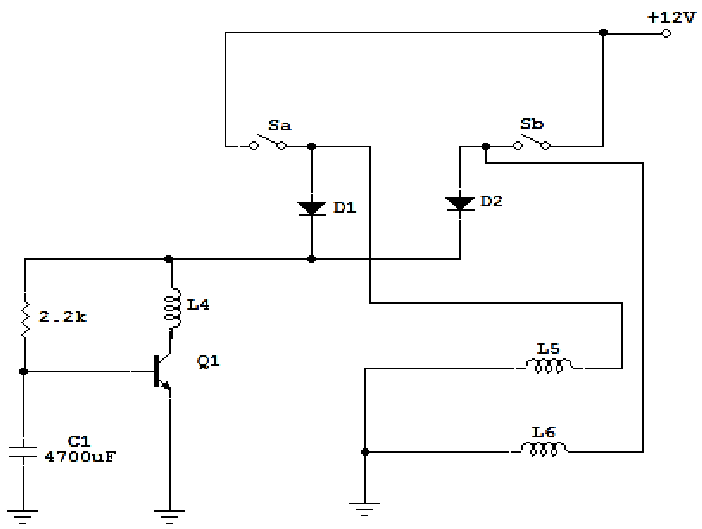

Fig. 4:Water gate controlling unit

3.4 Driving system of the monthly declination

A DC motor was used to obtain the monthly tilt of the plate along North – South direction. When a motor axis is rotating,the plate is tilted through a lever system. Direction of the tilt is determined by the direction of rotation of the motor axis. The iron bar with two magnets on its ends was mounted to the lever system so that it is also decline with the plate. Twelve reed switchers were placed on a curved bar around the plate and each switch is on the position which is corresponding to the monthly tilt of the plate. When the plate and therefore the magnet are reached to a switch, it will be closed. Outputs of the read switches are used to detect the plate tilt.

For the circuit functions,a seven bit binary number was assigned for each month. The smallest number was assigned for the month which has the lowest declination and that number increases with the declination. User can input the month to the system and it records as a binary number. A circuit was designed to rotate the plate to the appropriate position by comparing these two binary numbers.

4.0 CONCLUSION AND DISCUSSION

Operation and the accuracy of the designed solar tracker totally depend on the accuracy of the mechanical fabrication. When concerning the energy required for the system there are three water solenoids and each operates two times per day. Therefore, total power usage for them per day is about 144 J. Declination is changed once a month and electrical power of about 5 J isrequired for that movement. Water usage of the tracker per day is halved by placing one floater above the other. Then the water transfer between floaters happens viathe gravitational force. Water usage decreases with the decreasing of the distance between the force exertingpoint of thefloater and the center of the plate. The size of the floater vessel and the total structure also decrease with them.Variation of the lifting rate of the floater with the plate angle can be obtained by the diameter varying vessel or by the variation of flow rate.However, the first method is most applicable in practice and requires no electrical energy as for the second method.

Reed switches were used to sense the position, however even after the magnet had passed the reed switch, residual magnetism can affect the reed switch and it may cause a hysteresis error.The operating area of the reed switch used is about $0{\cdot}5\ cm^3$. Therefore, the magnetic screening was used to limit hysteresis error and the operating area of the switches.

It is recommended to use a separate rain water storage tank for supply water to the upper vessel. Also a wind mill can be used to lift the water to tank, so it becomesa sustainable system. Diameter of the supply tank must be larger than its height. It helps to obtain aconstant flow rate for the water inlet.

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