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Submission date: 28-Jun-2024 05:24AM (UTC+0700)

Submission ID: 2409575296

File name:
8233_A._Prasetyadi_Solar_Tracker_for_Vertical_Solar_Distillation_Apparatus_813181_842405580.pdf (2.81M)

Word count: 2648

Character count: 13028

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Solar Tracker for Vertical Solar Distillation Apparatus

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Keywords: Solar tracker; Vertical distillation apparatus

Abstract. A research on solar tracker system for vertical solar distillation apparatus is conducting. The common solar tracker is usually fit for horizontal distillation apparatus. Wind effect to the apparatus is not as big as the vertical one. The aims of the research are creating the solar tracker system for the vertical solar still which can face the problem of wind and daily solar movement. The other threat which has to be faced is diffuse condition of the solar rays on cloudy days. When the solar tracker doesn't have internal time reference, the diffuse condition on the cloudy days may put into unstable position. To face the problems some mechanisms are proposed. They are lock gear mechanism to handle the daily movement and windy condition, the RTC which is applied to predict the position of the collector when the day is cloudy, and the solar cell that is exploited as the sensor of the solar position as well as the source of the power for reducing the electrical component. Lock gear mechanism is designed to be controlled by the microcontroller which has to compare the sensor input and RTC. On the sunny and clear day, the sensor will be the main reference. On the night and rainy or cloudy condition, the reference will be RTC; therefore the system will predict the solar position. Normally closed brake is designed to keep the position of the collector. Such mechanisms will improve the performance of vertical solar distillation apparatus.

Introduction

Solar still is prominent method to produce clean and healthy water from polluted water. The main reason for such method is its economical value especially for the rural without abundant mainstream energy supply such as electricity. A drawback of the solar distillation is productivity of the apparatus. Many researches are proposed to increase the productivity of solar distillation methods which can be classified to two main approaches. The first one and the most conducted approach is enhancement of condensation process. Among these approaches are addition of condenser and reduction of the cover temperature [1, 5, 6]. The second common method is pre-heating approach. The methods are focused on enhancing the evaporation process.

The problem of evaporation is the energy supply and the problem of the condensation is the temperature and released heat. To increase evaporation, the methods exploit approaches which increase energy supply. To increase the condensation the methods exploit methods of reducing temperature and pressure.

A vertical solar still naturally is good in condensation due to the position of its cover. Vertical surface has better convection than horizontal [3]. Wind is also important in reducing the temperature of the cover which enhancing the condensation process. But it is lack in evaporation due to path of the solar rays especially in tropical areas. Therefore it is reasonable to increase the vertical solar still productivity through increasing the energy supply. The simplest approach of increasing energy supply is facing the solar still to the path of solar rays.

To be always faced the solar path, the solar apparatus need system called solar tracker. Some mechanisms have been proposed [2]. Most of them are designed for the photovoltaic [2, 4, 7, 8]. The other are proposed for horizontal solar still. On the other hand discussion of such mechanisms for vertical solar still is very rare. The solar tracker for PV doesn't consider fluid surface and flow while the solar tracker for solar still consider both. The other situation that should be taken into account is the weight of the apparatus. The solar still naturally is heavier than PV.

The vertical solar still has different characteristic operation than horizontal one. The most differing threats which are greater than the horizontal solar still are wind and solar path effect. For tropical area, the horizontal solar still gets its abundant energy during middle of the day, while the angle from the zenith is relatively the smallest one. The vertical solar distillation apparatus will has its abundant solar rays in the morning and afternoon, while the sun is near the horizon. The wind for horizontal solar still mostly cause lift forces, while the wind effect to the vertical solar still mostly is drag.

This article will discuss the theoretical aspect about solar rays and mechanism of proposed design of solar tracker for vertical solar still which is intended to be rigid enough and anticipate the solar path. The solar tracker will apply the mechanism for tracking in haze, cloudy condition and moving during night as well as to maximizing the solar harnessing.

The theory of the solar ray path will start the article. In this section, it will be showed the effect of the solar ray paths daily to vertical surfaces. The second part will be the discussion of the solar tracker design. The last part is conclusion and remark as termination of the article,

Solar Ray Path and Vertical Solar Still

Solar rays generally bring its greatest power to a surface, while the surface is perpendicular to the solar ray paths. In such condition, the reflection of the surface is minimal. It is also a simple concept that solar irradiance specific in perpendicular surface is the biggest. In such condition most of the solar rays which arrive to the surface will be converted to heat.

For a solar apparatus, to harvest the solar energy maximally, it is important to keep the surface of the collector perpendicular to the solar rays. A half-sphere coordinate with the apparatus as the center is exploited to define the position of the sun, where the rays arrive from. In such coordinate, a point above the observer (O) is defined as top. The point will be used to define zenith as the angle from the top to horizon. A horizon is boundary of a surface where the center (O) is located and perpendicular to the line from the top to the center. The horizon is circular shape through North, East, South and West position. The azimuth is defined as the angle around the horizon which is counted from the north. The description of the zenith and azimuth is figured on Fig. 1 below.

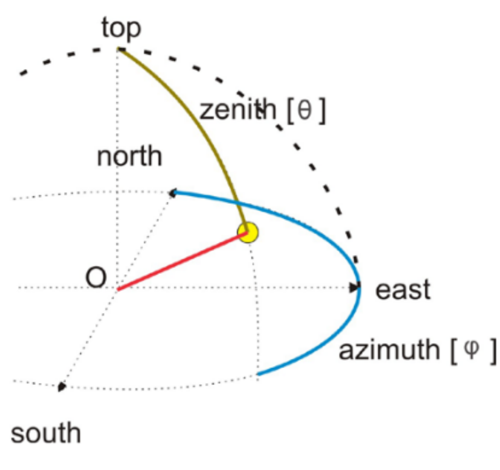

Fig. 1. A half-sphere coordinate for describing zenith and azimuth

From the perspective of a vertical collector with its normal on φ' azimuth, a sun with zenith θ and azimuth φ has zenith θ' which can be found using Eq. 1 or Eq. 2 below. The equations are:

$$\theta' = 2\,arc\,sin\left\{sin^2\left(\frac{1}{2}\alpha\right) + sin^2\left(\frac{1}{2}\beta\right)cos(\alpha)\right\}^{\frac{1}{2}} \quad (1)$$

or

$$\theta' = arc\cos\{sin\theta sin(\varphi' - \varphi)\}\ . \quad (2)$$

with $\alpha = 90^o - \theta$ and $\beta = \varphi' - \varphi$. The zenith $\theta'$is also the angle of the solar rays to the normal of the collector surface. Bigger θ' means less solar energy harnessed. The coordinate of the solar in the perspective of the vertical collector is described on Fig. 2.

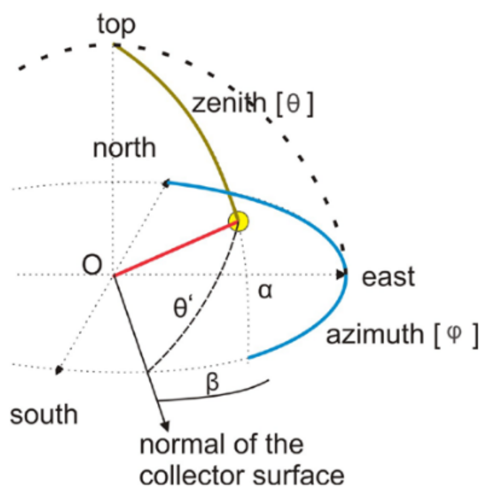

Fig. 2. Coordinate of the solar in the perspective of vertical solar apparatus. The angle of coming rays is θ'

Because the solar apparatus is vertical and it can't be rotated along zenith line, the adjustable position is only azimuth. Although the zenith is also changed because of the solar movement, the apparatus can't be moved along zenith line. Therefore β should be trimmed to make θ' as minimal as possible.

Speed of the solar movement according to an observer is a function of its position. When the solar is on equinox, it can be assumed that the solar moves 15^o for an hour. When the solar position is not at the same latitude with the observer, the speed of the solar movement is different in the perspective of the observer. It can be derived that the speed of the solar movement will be

$$\omega' = \omega\cos(\zeta). \quad (3)$$

$\omega'$is the speed of solar on observer perspective, $\omega$is speed of the solar on equinox and $\zeta$is the difference of the solar latitude and observer latitude.

The speed of the solar movement can be seen as the change of the zenith. The zenith is defined by the azimuth which is corrected by difference of the latitude of the observer and the latitude of the solar. For example, if the latitude of the observer is 10 NL and the latitude of the solar is 8 NL, the azimuth of the solar on the horizon is 92 degree in the morning and 268 degree when the sun is set.

The daily movement of solar can be put also into a cylindrical coordinate which z axis is north south direction. The movement of the solar is just described by the azimuth. The difference position of the latitude will give just orientation of the axis unto horizon. The position of the solar movement can be shown on Eq. 4 below

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} cos(\gamma_1) & 0 & sin(\gamma_1) \\ 0 & 1 & 0 \\ -sin(\gamma_1) & 0 & cos(\gamma_1) \end{pmatrix} \begin{pmatrix} sin(\gamma_1 - \gamma_2) \\ sin(\varphi_h) \\ cos(\theta) \end{pmatrix} \quad (4)$$

with $\gamma_1, \gamma_2, \varphi_h$ and $\theta$are latitude of the observer, current solar latitude, azimuth of solar at the horizon and zenith respectively. The zenith of the solar is defined from

$$\theta = asin\left(\left(sin^2(\gamma_1 - \gamma_2) + cos^2(\varphi)\right)^{\frac{1}{2}}\right) \quad (5)$$

The current azimuth which is applied to the equation (1) and (2) is derived from *X, Y, Z* on Eq. 4.

Solar Tracking Mechanism

To track the solar position for vertical solar still with its threats, some mechanisms are proposed. Each mechanism is proposed to handle threat that should be faced. They are mechanism to get optimum solar energy, mechanism to predict solar vector during haze and diffused condition, and mechanism to handle the windy condition. All of the mechanisms are proposed to be as simple as possible and need as little as possible energy resources.

To get optimum energy, as it is described in the predecessor section, only the azimuth angle of the solar still can be adjusted. It means that the tracker is single axis only. The mechanism will consist of 2 PV which also produce the power for the system. The solar cells are placed directly above the solar still. They also face the same direction to the solar still. Both PV will be separated by a plate which is vertical and perpendicular to the surface. When the normal of solar cells doesn't face the equinox, the different power will arise between both solar cells. The different power will drive the motor which set the PV to the equinox. Therefore, the solar cells will automatically set the optimal harnessing energy. The mechanism is shown on Fig. 3.

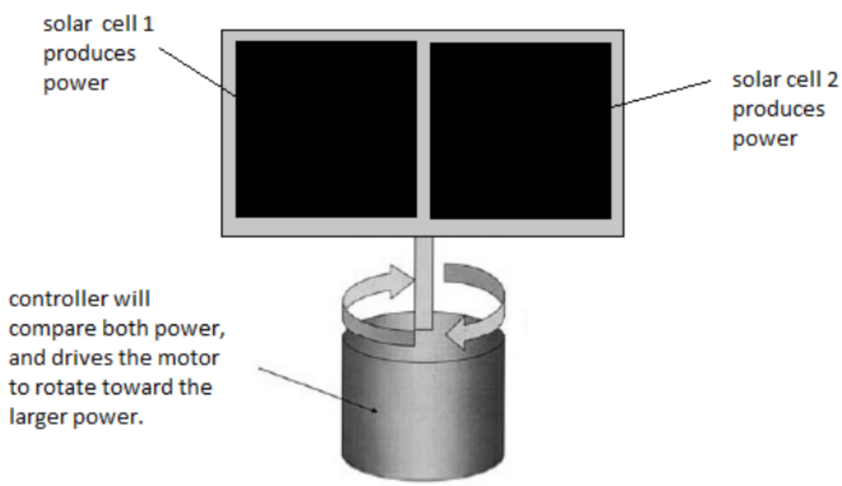

Fig. 3. Mechanism to track the optimal harnessed energy consists of a driving motor, controller and 2 PV which produce power for the motor and put as the position sensor. If both solar cells harvest unequal power, the motor will rotate

When the day is cloudy or haze and during the night, both PV will produce the equal power for long period. It is important to adjust solar apparatus automatically to the predicted next solar position. A mechanism using RTC is proposed to determine the position. The RTC will be added as reference to predict the solar position. RTC will supply time to controller. After 30 minute without movement due to equal power of the PV, the controller will make predictive new position and the motor will rotate to new position. The mechanism is described on Fig. 4.

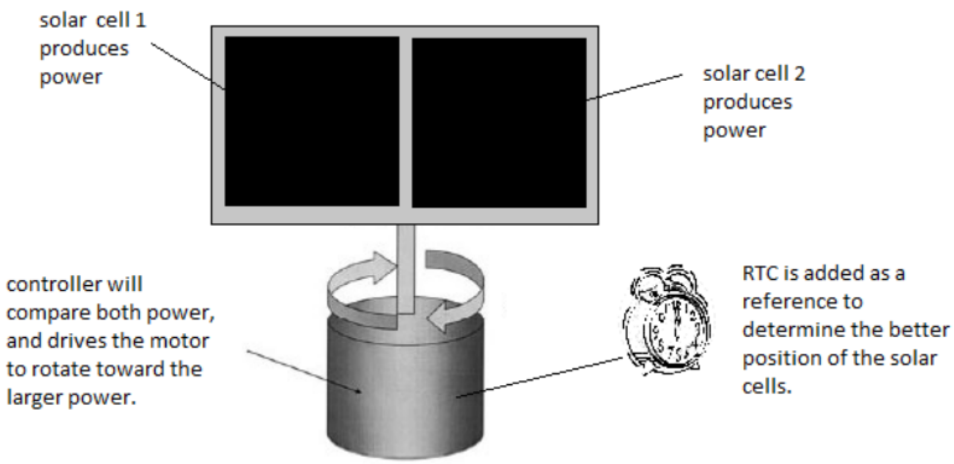

Fig. 4. RTC is added as the reference to predict the solar position so the solar apparatus could be faced the predictive position. This predictive position is an anticipation of the solar position which is unclearly determined using the sensor

Move easily by the different power mechanism puts the solar apparatus to more susceptible condition of the wind. A mechanism to handle this threat is proposed. A normally closed lock gear will be applied. When the power of both solar cells is equal, the lock will be active. In such condition, position of the solar apparatus will be locked. Therefore the solar still could not change whether the wind is blowing. Contrary, when both solar cells produce different power, the lock will open. When the lock is open, the different power of the solar cells drives the motor to spin as the 1st mechanism. Such mechanism can be seen on Fig. 5.

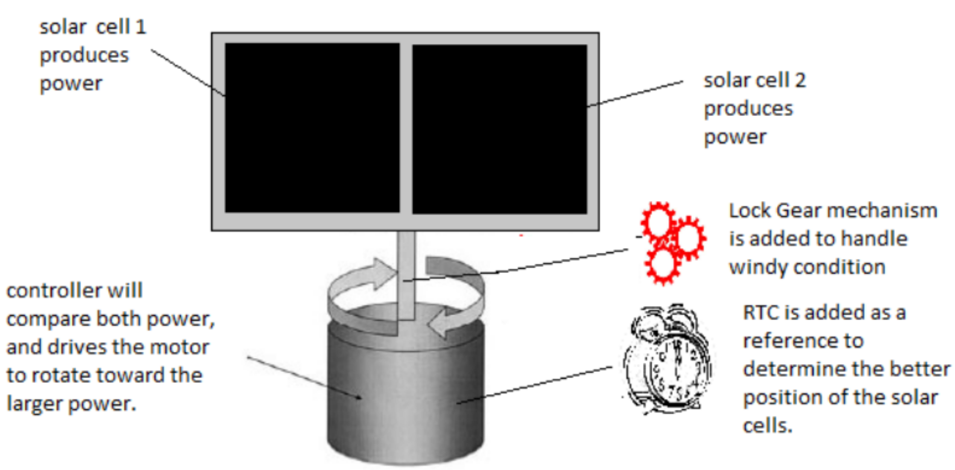

Fig. 5. Addition of normally closed lock will help to handle wind threat

All of the above mechanisms will use the motor speed reducer due to the speed difference of motor and daily solar movement. Motor has speed of 70 rpm or equal to 420 degree in a second, while the speed of solar movement is 15 degree for an hour or 4.2×10^{-3} degree for a second. To match the speed of solar movement, the speed motor will be reduced 400 times and the adjustment will be done while the difference is more or equal to 5 degree. Therefore, every movement will consist of 4.76 degree. Microcontroller will be used to control the mechanism. The diagram of controller model is shown in Fig. 6.

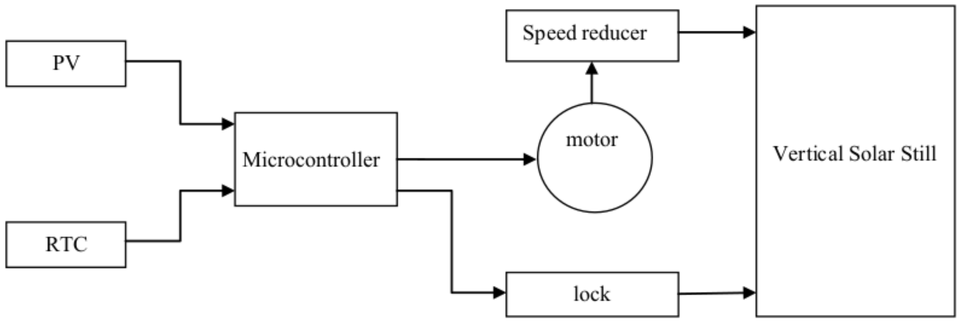

Fig. 6. Control mechanism of the system is a microcontroller based which has PV and RTC as the input and locking signal and motor driving signal as the output

Conclusion

A solar tracker mechanism is proposed to harvest solar energy for vertical solar still. The proposed mechanism combines simplicity of sensing and powering the driver using solar cells rather than LDR as the sensor and solar cells as the power supply. To predict the position especially in haze and dark condition, the RTC will be applied. The lock gear mechanism which is normally close system will be applied to handle the threat of the windy condition. The relay system is also depended on the solar cells sensors.

Acknowledgement

The authors express gratitude for the research which is supported by the Higher Education Ministry.

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