Fixed Nadir Focus Concentrated Solar Power Applying Reflective Array Tracking Method

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Abstract. The Sun is one of the most potential renewable energy development to be utilized, one of its utilization is for solar thermal concentrators, CSP (Concentrated Solar Power). In CSP energy conversion, the concentrator is as moving the object by tracking the sunlight to reach the focus point. This method need quite energy consumption, because the unit of the concentrators has considerable weight, and use large CSP, means the existence of the usage unit will appear to be wider and heavier. The addition of weight and width of the unit will increase the torque to drive the concentrator and hold the wind gusts. One method to reduce energy consumption is direct the sunlight by the reflective array to nadir through CSP with Reflective Fresnel Lens concentrator. The focus will be below the nadir direction, and the position of concentrator will be fixed position even the angle of the sun's elevation changes from morning to afternoon. So, the energy concentrated maximally, because it has been protected from wind gusts. And then, the possibility of damage and changes in focus construction will not occur. The research study and simulation of the reflective array (mechanical method) will show the reflective angle movement. The distance between reflectors and their angle are controlled by mechatronics. From the simulation using fresnel 1m², and efficiency of solar energy is 60.88%. In restriction, the intensity of sunlight at the tropical circles 1KW/peak, from 6 AM until 6 PM.

1. Introduction
Solar energy is one of the energies exploited by many people because of its abundant availability, but its utilization is also not optimal. This is because the nature of solar energy is affected by the rotation and revolution of the earth. The observation that can be done is to see the position of the sun as if moving from the equator to 23.5° LU back to the equator, continue to 23.5° LS, and back again to the equator [1].

Total energy produced by the sun has an average power of 1 KW/m² on the surface of the earth with energy up to 7 kWh/m²/day on average per year [2]. And it has sunshine hours annually about 2975 hours or 124 days while the average length of irradiation is about 8.2 hours per day [3]. Although the solar energy reaches the Earth is only 30%, the energy radiated within 30 minutes is capable of energy for a year [4]. The intensity of solar radiation averaged about 4.8 kWh/m² per day in all parts of Indonesia. One tool that can utilize solar energy is CSP (Concentrated Solar Power) using a Fresnel lens.

CSP's main constraint is its relatively low efficiency. So that the intensity of the CSP is always optimal, it is necessary to adjust the CSP position to the sun position automatically. John A. Duffie [5] suggests that efforts to minimize angles mean the effort to position the solar collector perpendicular to
the reflection of solar radiation, so as to maximize the energy of solar radiation. The tracking system is classified by its rotational motion.

CSP panel solar light direction is less effective if it is done manually by humans. Due to the ever-changing position of the sun, it is necessary to create a control system that can adjust the direction of the CSP panel by using a solar or sensor algorithm.

2. Modelling of the System

2.1. The Solar Coordinates of the Solar Path

The solar time clock, solar hour, the one-day period at the coordinates of the earth's surface, moves from east to west, parallel to latitude, from an average assume of 6 AM to 18 PM on the equator track. While the solar declination trajectory per year moves from the north, -23.45° North Latitude, December 21, southbound 23.45° south latitude, June 21, and turns north; a period of one year [6].

In the calculation, the sun hour angle to the coordinate point is expressed in an equation, with the 'degree: minute: second' value. The angle of the sun (elevation), obtained from the equation:

\[ h_s = 15^\circ h_{sn} \]

Where,
\[ h_s \] = angle of the sun
\[ h_{sn} \] = time angle

While the declination angle, as Figure 1a, is obtained by the equation [7]:

\[ \delta_s = 23.45^\circ \sin\left(\frac{284 + n}{365}\right) \]

Where,
\[ \delta_s \] = n-day declination angle
\[ n \] = n-day in one year
\[ n = 1 \] is January 1st

Changes the time-angle trajectory and the sun's declination of a tracker coordinate can be illustrated as shown in Figure 1.

Whereas, the azimuth angle on day \( n \) in a year is expressed by equation (2), by the AMount of 'degree: minutes: seconds'; with the description, \( \delta_s = n \)-day declination angle; \( n \) = day to \( n \) in one year, \( n = 1 \) is January 1st. Latitude (L).
2.2. Concentrated Solar Power
The solar concentration is a way to increase the heat of the sun by using an additional equipment. The principle of CSP is illustrated in Figure 2.

![Diagram of Concentrating Solar Power (CSP)](image)

**Figure 2.** Principle of concentrating solar energy [8]

In solar thermal concentrating, solar energy is optically focused before being transferred into heat. This concentration is obtained by reflecting solar radiation using a mirror or lens. The reflected light will be concentrated in the focus area [4]. There are two types of Fresnel: the refractive lens and the reflective mirrors, as shown in Figure 3. Fresnel bias lenses are mostly used in photovoltaic applications whereas many reflective mirrors are applied in solar thermal. Optical design Fresnel lens is more flexible and can produce a uniform flux density on the absorber [9].

![Diagram of Fresnel lenses](image)

**Figure 3.** a) Reflective fresnel lens [8]  
   b) Refractive Fresnel lens [8]

The efficiency of concentrator can be calculated its efficiency with equation (3) and (4), and the focus of the heat in equation (5).

\[
\eta_{receive} = \frac{Q_{absorbed} - Q_{lost}}{Q_{solar}} \tag{3}
\]

Where,
- \(\eta_{receive}\) = Efficiency
- \(Q_{absorbed}\) = Absorbed energy
- \(Q_{lost}\) = Lost energy
- \(Q_{solar}\) = Energy of the sun

\[
Q_{solar} = h_{optic} I CA \tag{4}
\]
$h_{\text{optic}}$ = efficiency
$I$ = Solar power (Watt/m$^2$)
$C$ = kali konsentrasi
$A$ = Area(m$^2$

Focus temperature, $T_{\text{max}}$

$$T_{\text{max}} = \left( \frac{IC}{\sigma} \right)^{0.25}$$ (5)

$\sigma$ = absorbvity

2.3. Electronic Solar Tracker

The Axis tracker is aimed at tracking the elevation of the east-west trajectory; by using analogous control hardware in a concentrated solar power system, parabolic trough concentrator [10]. And a declination axis tracker to track the coming sun every year from north to south and south to north.

Where the reflective equations of the elevation axis tracker are as follows:

$\rho (t) = \left( \frac{h_s - 90}{2} \right) (t) \quad (6)$

$\rho$ = reflector angle {-45°< $\rho$<45°}

Figure 4 shows the range of angular motion of the tracker to the change in the angle of the solar elevation as shown in equation (6).

And the reflective equations of the declination axis tracker are as follows:

$$\tau (t) = \left( \frac{\delta_s - 90}{2} \right) (t) \quad (7)$$

$\tau$ = reflector angle {-11,72°< $\tau$<11,72°}

Figure 4. Reflector angle to elevation time

Declination Tracker to track sunlight north and south, +/- 23.45° in north and south latitude in one year a period.
2.4. Proposed Array Solar Tracking

![Array Solar Tracker](image)

**Figure 5.** CSP Focus Nadir

The solar light direction system is driven by a solar tracker, then directed toward the Fresnel lens. And the Fresnel lens will focus the sunlight on one point called focus nadir, so the high temperature occur. The direction of the sun's rays is accomplished by utilizing a linear mirror array per axis (reflector). When the sun's rays come angled $\alpha$ to the reflector, the angular reflected angle of $\alpha$ nadir rays is also against the reflector on the same coming and leaving lines.

![Reflection of sunlight by the reflector.](image)

**Figure 6.** Reflection of sunlight by the reflector. (a) Elevation (b) Declination

3. Simulation and Result

The solar cycle at 6 AM until 6 PM is illustrated with a sine signal as above with a maximum intensity is 120000 lux which is equivalent to 1KW. However such power is not entirely acceptable to the flat collector because the flat plate collectors cannot fully capture the sun's heat at a given sun. To see the heat-receiving power of the equation below:

$$P_I = P_3 \cos \Theta$$  \hspace{1cm} (8)
\( P_f \) = Power received flat collector (Watt)  
\( P_s \) = Solar Power (Watt)  
\( \Theta \) = The resulting angle between the position of the current sun with the top position

The equation above can be made a graph of solar power to flat collector with cycle start at 6 AM until 18 PM expressed in figure 7:

![Figure 7. Graph of flat power efficiency to solar power](image-url)

So the graph it can be seen that the energy efficiency of flat collector is

\[
\eta_{\text{flat}}(\%) = \sum \frac{P_{\text{flat}}}{P_s} \times 100 \quad (9)
\]

\( \eta_{\text{flat}} \) = Flat efficiency (%)  

The above equation it can be seen that the solar collector with flat plate has an efficiency energy 78.99%. Before the solar light reflect to Fresnel, solar light through the reflector. So, the light will be the direction. The reflector has an efficiency 82%, efficiency depends on the materials used (stainless still).  

After sunlight is passed through the reflector, then Fresnel which serves to focus sunlight into heat at one point. From the efficiency can know how much power Fresnel with the following equation:

\[
P_{fr} = P_f \times \eta_{\text{reflector}} \quad (10)
\]

\( P_{fr} \) = Power fresnel (Watt)  
\( P_f \) = Power flat (Watt)  
\( \eta_{\text{reflector}} \) = Reflector efficiency (%)

To see how much power on the nadir, the efficiency value of Fresnel is required. Fresnel used is made of PMMA (Polymethyl-methacrylates) which has the efficiency of up to 94% sun absorption. So the nadir power is known from the following equation:

\[
P_n = P_{fr} \times \eta_{\text{fresnel}} \quad (11)
\]

\( P_n \) = Power nadir (Watt)  
\( \eta_{\text{fresnel}} \) = Fresnel efficiency (%)

The above equation it can be seen the value of flat power, fresnel power, and power at nadir. From these data it can be graphed as below:
The result of the equation shows that the utilization of efficiency solar energy is 60.88%.

The temperature of nadir obtained in the research with Fresnel utilization up to 789°C at 12 AM. High or low temperatures that are focused on the nadir point are obtained from the movement of the sun angle radiated to the reflector that is forwarded to the Fresnel. The reflector follows the direction of the sun assumed that at 12 AM with the flat reflector angle is 90°.

4. Conclusion
From the simulation results with the utilization of concentrated solar power by using fresnel lens is an effective way that can absorb solar energy well. The Fresnel lens of PMMA (polymethylmethacrylate) is the best Fresnel lens because it has the highest efficiency of 94%. With the utilization of Fresnel, the efficiency of sunlight utilization is 60.88%. With the temperature concentrated at 12 AM is 789°C with a reflector angle of 90°.

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