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Design, Analysis of Newly Developed Solar Tracking Mechanism-Conceptual Research Approach

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Abstract—*There is scope for a lot of research in the field of solar power generation, because none of the solar system made yet is perfect and effective, both in performance and in design. Solar Tracker is a unique invention for next solar power generation. It is an device which is the integration of smaller mechanical components specifically designed to generate higher efficiency in solar energy with respect to other solar energy devices such as solar panels , dry cells etc. It approximately tracks 30 to 40% solar energy more than the devices mentioned above. The solar tracker will increase the energy output of PV array 30% - 50% as compared to the fixed PV array with the same rated output power. Currently solar cells are becoming extremely popular for utilizing solar energy to use different ways such as producing electricity, transportation etc. So many solar panels have been installed all over the world and most of them are stable. They are installed in the direction of maximum radiation of sun light. Now the problem arises that the sun is moving. Therefore we cannot use maximum radiation receiving position only comes once in 24 hours. Solar tracker is the best solution for maximum radiation. By moving the solar panel effectively according to the movement of sun, we can always receive the maximum radiation. Now we have come up with an innovative idea in mind for tracking the sun effectively to get the maximum radiation, so we have developed an idea i.e the effective Solar Tracking Mechanism. Here in this mechanism, we have applied the principle of dynamic balancing of weights (attached on both ends of solar panel) in order to track the sun. In this paper, it introduces the principle of working, Design and Analysis of newly developed solar tracking mechanism. Also the trial has been taken on developed solar tracking mechanism and it results that the tracking mechanism is more efficient and accurate one. The Solar Tracking Mechanism is quite simple, cost effective and practical one and has much scope in future for further development.*

Keywords*: Solar Tracker, PV Array, Dynamic Balancing of Weights, Tracking Mechanism, design and analysis etc*

1. INTRODUCTION

The continuous evaluation of the technology determined a sustained increase of the conversion efficiency of PV panels, but none the less the most part of the commercial panels have efficiencies no more than 20%. A constant research preoccupation of the technical community involved in the solar energy harnessing technology refers to various solutions to increase the PV panel's conversion efficiency. Among PV efficiency improving solutions we can mention: solar tracking, optimization of solar cells geometry, enhancement of light trapping capability, use of new materials etc. The output power produced by the PV panels depends strongly on the incident light radiation.

The continuous modification of the sun earth relative position determines a continuously changing of incident radiation on a fixed PV panel. The point of maximum received energy is reached when the direction of the solar radiation is perpendicular on the panel surface. Thus an increase of the output energy of a given PV panel can be obtained by mounting the panel on a solar tracking device that follows the sun trajectory. Unlike the classical fixed PV panels, the mobile ones driven by solar trackers are kept under optimum in solar radiation for all positions of the Sun, boosting thus the PV conversion efficiency of the system. The output energy of PV panels equipped with solar trackers may increase with tens of percent's, especially during the summer when the energy harnessed from the sun is more important. Photo-Voltaic or PV cells, known commonly as solar cells, convert the energy from sunlight to DC electricity. PVs offer advantages over the other renewable energy sources in that give off no noise and require practically no maintenance. A tracking system must be able to follow the sun with a certain degree of accuracy, return the collector to its original position at the end of the day and tracks during periods of cloudy over. In this paper, it is being developed the proposed mechanism for tracking the sun continuously and it works by the principle of dynamic balancing of weights (attached on both ends of solar panel) in order to track the sun. Also the trial has been taken and it results that the tracking mechanism is more efficient and accurate one.

2. STUDY- LITERATURE RESEARCH

2.1 Evaluation of Solar Tracker

Since the sun moves across the sky throughout the day, in order to receive the best angle of exposure to sunlight for collection energy. A tracking mechanism is often incorporated into the solar arrays to keep the array pointed towards the sun. A solar tracker is a device onto which solar panels are fitted which tracks the motion of the sun across the sky ensuring that the maximum amount of sunlight strikes the panel throughout the day. When compare to the price of the PV solar panels, the cost of the solar tracker is relatively low. Most photovoltaic solar panels are fitted in a fixed location –for example on the sloping roof of a house, or on framework fixed to the ground. Since the sun moves across the sky though the day, this is far from an ideal solution. Solar panels are usually set up to be in full direct sunshine at the middle of the day facing south in the Northern Hemisphere, or north in the Southern Hemisphere. Therefore morning and evening sunlight hits the panel at an acute angle reducing the total amount of electricity which can be generated each day.

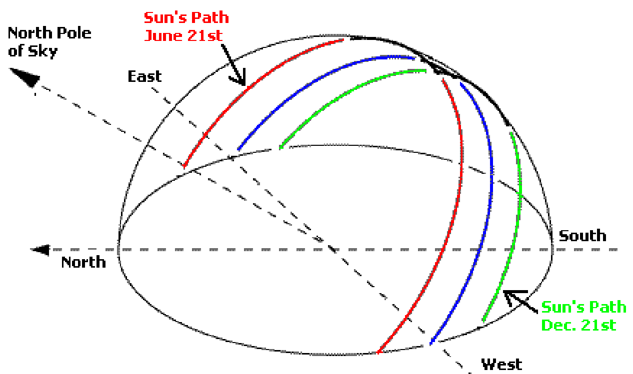

Fig. 1: Sun's Apparent Motion

During the day the sun appears to move across the sky from left to right and up down above the horizon from to noon to sunset. Fig. 1 shows the schematic above of the Sun's apparent motion as seen from the Northern Hemisphere. To keep up with other green energies, the solar cell market has to be as efficient as possible in order not to lose market shares on the global energy marketplace.

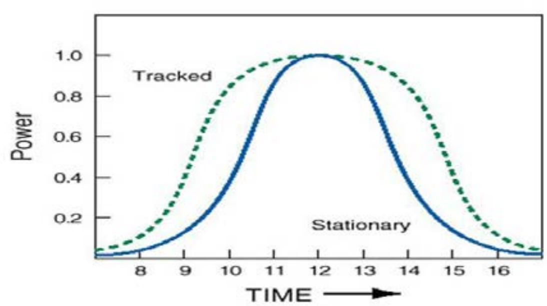

Fig. 2: Time vs. power plot for stationary and tracking PVs

The end user will prefer the tracking solution rather than a fixed ground system to increase their earnings because:

- The efficiencies increases by 30-40%.
- The space requirement for a solar park is reduced, and they keep the same output.
- The return of the investment timeline is reduced.
- The tracking system amortizes itself within 4 days.
- In terms of cost per Watt of the completed solar system, it is usually cheaper to use a solar tracker and less solar panels where space and planning permit.
- A good solar tracker can typically lead to an increase in electricity generations capacity of 30-50%

2.2 Using Solar Angles to Predict the Sun's Location

On one day every year, called the equinox, the sun is positioned directly above our planet's equator. On this day, the angle between a line that points to the sun and a line that points straight up (vertical) exactly matches the latitude of the place you are standing. If you live on the equator, then in the very middle of the day (solar noon) the sun will be directly above you, or at 0º from the vertical. If you live in Boulder, CO, which is in the northern hemisphere at the latitude of 40º, then on the equinox the sun will be 40º to the south from the vertical. The sun's position on the equinox is the average location of the sun throughout the year and is a great reference to use when designing a solar system for a specific location. But keep in mind, the sun is always moving. In the summer, the sun appears higher in the sky, which increases the duration of sunlight seen in a day, and in the winter it appears lower, which decreases the length of sunlight in a day. The sun is highest in the sky on the summer solstice. To be more exact, it is 23.45º higher than on the equinox, or at 40 - 23.45 = 16.55º to the south of vertical. The winter solstice is the day when the sun appears lowest in the sky. On this day, the sun is 23.45º lower than on the equinox, or at 40 + 23.45 = 63.45º to the south of vertical in Boulder. So, if you live in the northern hemisphere at latitude higher than 23.45º, then the sun will never shine from the north. This means the north side of your house would be a bad place for a solar panel (or a garden).

3. PRINCIPLE AND WORKING METHODOLOGY

3.1 Principle of Operation

The energy output of a PV panel changes based on the angle between the panel and the sun. The angle at which the sun hits a PV panel determines its efficiency and is what engineers use in the design of an efficient PV array for a specific location. Tracking systems continually adjust the angle and direction of their solar panels to achieve the greatest potential harvest at all times by literally tracking the sun's movement across the sky. This inherent advantage can net a 40% greater efficiency than traditional static systems, resulting in fewer panels (and in some cases arrays) needed to meet a particular energy requirement.

Fig. 3.shows the basic principle of the operation of proposed mechanism, the water tanks are attached at the both end of the frame/ panel mounting which tilts for weight displacement of this water tank. The one of the water tank act as a dead weight and other is as a variable weight from which we are going to

adjust the flow rate in such a manner that panel rotates with 15 degrees per hour (as sun moves with 15deg./hour).

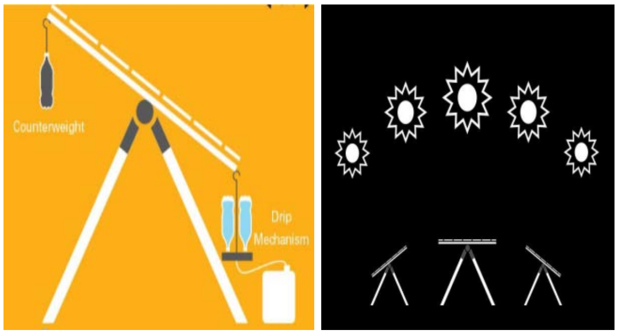

Fig. 3: Principle of Operation and tracking positions

The Innovative idea is that here water is used to track the sun means using weight displacement of water concept is used to rotate the panel and at the end of day, the filled tank with water may get fully empty and its daily work to fill the tank and give the start of flow of water for tracking the sun. The water filter is incorporated in the dripper mechanism so that water coming from the tank gets filtered. Therefore during the tracking of sun from morning to evening, the water in the tank gets filtered by daily routing activity. This means that the water used for tracking is not wasted and gets filtered daily. As by Lambert's co-sine rule for total incident radiations on particular surface area, the intensity of those radiations is given by following equation, In = I *cos Ɵ

Where, In= normal intensity of incidence radiations, I= average intensity of radiations, Ɵ= angle of incidence.

According to above equation, if it makes that angle exactly or nearly equal to 0 degrees (with vertical and incident radiation), it can get maximum intensity of radiation and hence it can obtain maximum power from solar panel. Fig. 4 shows the various tracking positions with respect to time from morning till evening. The solar panel tracks the sun from morning till evening by using the weight displacement concept.

3.2 Working Principle of the Mechanism

Fig. 4 gives the details about the working principle of the proposed mechanism, here below are few simple steps that could explains the working principle of the proposed mechanism.

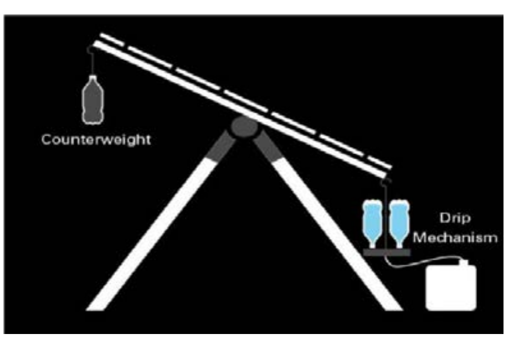

Fig. 4: Working principle of the mechanism

- Collect 20liters of Water.
- Setup water tanks into a drip mechanism.
- Adjust the flow rate.
- Attach counterweight to other side.
- As the water drips from the can and gets filtered, the mechanism tracks the sun.
- At the end of the day you have 40% more power and filtered water.

4. DESIGN METHODOLOGY

In design methodology, the different components for the proposed tracking mechanism are designed and then assembled it. The details of components are discussed-

4.1 Components Designed for the Mechanism-

4.1.1. Frame- The frame is designed so as to provide provision for mounting of solar panels. It also serves the need of carrying the load of water tanks and transferring the same to the shaft. A C- channel at the center of frame is provided with a number of equidistant holes so as to provide freedom for adjusting the position of water tanks from the center of shaft as shown in Fig. below.

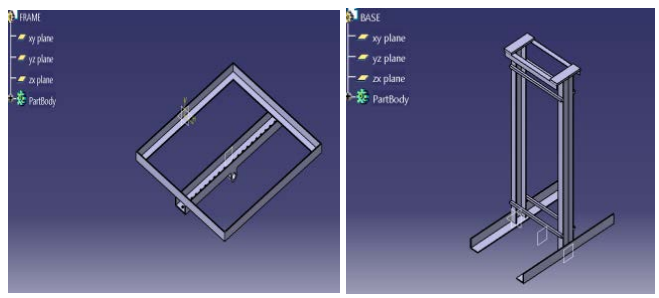

Fig. 5: Frame support and base stand

A bush is welded at the center of C-channel to enable a sliding joint between shaft and frame. It is to avoid rolling of frame relative to shaft a lock nut.

4.1.2 Shaft and Bearing -Shaft is a common and important machine element. It is a rotating member, in general, has a circular cross-section and is used to transmit power. The shaft may be hollow or solid. The shaft is supported on bearings and it rotates a set of gears or pulleys for the purpose of power transmission. The shaft is generally acted upon by bending moment, torsion and axial force The ferrous, non-ferrous materials and non-metals are used as shaft material depending on the application. For ductile material, the design by maximum shear stress theory is on safer side. Therefore maximum shear stress theory is most widely used while designing shaft. But for ductile materials the distortion energy theory is very accurate. Therefore distortion energy theory is used for designing shaft when very accurate results are required. Now the diameter of shaft is selected as 25 mm from standard steel shaft diameter commonly available and also it is checked against the load applied on it and found to be safe under applied load

Bearing is mechanical element which locates two machine parts relative to each other and permits a relative motion between them.

Input: F_r = radial load, N.

Application: static, Shaft diameter= 25 mm.

Type of bearing = ball bearing (single row deep groove ball bearing)

$$P0 = MAX[\,(XoFor + YoFoa)\ or\ For]$$

Where, P_0 = equivalent static load ,X_o = radial load factor = 0.6 (for single row bearing)For = radial load, N,Y_o = thrust factorF_{oa} = axial or thrust factor = 0 (no thrust load on bearing)

$$\therefore Po = \ max[(XoFor) or\ For]$$

$$\therefore Po = (0.6 * 500)\ or\ 500$$

$$\therefore Po = 500\ N \ldots\ldots..maximum\ of\ two$$

For the safety of bearing against the static failure, $Co \geq Po$, From the manufacturer's catalogue for 25 mm shaft diameter we selected a bearing number 6005 of series 60 (extra light series)

Make of bearing = SGS

Dimensions and basic load capacities of selected single row deep groove ball bearing are as follow-

Table 1: Manufacturer's catalogue for bearing

Series 60					
Bearing no.	Principle Dimensions			Basic capacity	
	Bore, d mm	Outside diameter, D mm	Width, B Mm	Static (C_0) kN	Dynamic (C) kN
6005	25	47	12	6.55	11.20

So from the comparison between Co and Po value, we found that $Co \geq Po$ i.e. selected bearing is safe against static failure. The bearing is selected and its Bearing No. UC205-14.

4.1.3 Base Stand- Base stand provides a rigid support to whole assembly. The two vertical columns are made from Mild Steel C –channel so as to provide firm support to carry the load. The c-channels also provide a good aesthetic look to the proposed setup. The sufficiently long L angle at the base helps to ensure stability to the proposed setup. Cross bars are welded between the two vertical columns to ensure rigid and robust construction of the most important component i.e. Base Stand.

4.2 Flow rate Designed Calculation for Tracking-

Consider, a beam AB 260 mm long hinged at center C and has two tanks at its each end as shown in Fig. below

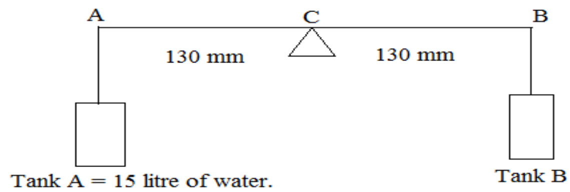

Fig. 6: Flow rate calculations.

Tank A is filled with 15 ltr. of water in it as a counterweight. Now, taking moment about center C

$Mass\ of\ tank\ A\ * 9.81 * H\ = mass\ of\ tank\ B\ * 9.81\ * h$……a…equilibrium condition

Where, h = head of water in tank B = 300 mm.

Differentiating above equation on both side by time t:

$15 * \frac{dh}{dt} = \frac{dm}{dt}$ *0.3……b

$$\frac{\text{dm}}{\text{dt}} = \text{mass flow rate of water from tank B}$$

$$\frac{\text{dh}}{\text{dt}} = \text{linear velocity of counterweight}$$

Relative speed of sun with respect to earth is 15degrees per hour i.e. 0.2616 radians per hour. (Angular velocity,ω),Therefore linear velocity of counter weight

$\frac{\text{dh}}{\text{dt}} = Distance(AC) * \omega$,Therefore, $\frac{\text{dh}}{\text{dt}} = 0.13 * 0.2616 =$ 0.034 m/hr.

By putting above value in equation b

we get$\therefore \frac{dm}{dt} = 15 * \frac{0.034}{0.3}$= 1.7 Kg/hr.

(Mass flow rate of water from tank B)

Therefore considering six hours of tracking, we get initial weight of water in tank B as Initial mass of water in tank B = $6 * \frac{1.7}{2} + counter\ weight$

= 5.1+15 = 20.1 Kg.

Table 2: Flow rate results.

Result table		
1.	Initial mass of water in tank A	15 Kg
2.	Initial mass of water in tank B	20.1Kg
3.	Mass flow rate of water from tank B	1.7 Kg per hour

Fig. 7: Frame support and base stand mechanism

5. DESIGN ANALYSIS

5.1 Frame Analysis

5.1.1 Base Stand analysis-

Let,P = crippling load at which column just buckled,E = modulus of rigidity, I = mass moment of inertia,L_e = effective length of column.

Frame (vertical support) is designed by using crippling load theory. Total load to carry by support is about 60 kg, so by crippling load. $P=\pi^2EI/Le^2$

(E=2.1E5N/mm2 for M.S bar, Le= effective length= L/2),So the by using crippling load theory, We get the crippling load =823.21N

Hence the vertical column is safe under buckling, so for considering optimum safety of the components the dimensions are kept as below-

-Base = L section of 0.61m in length and 0.9 m distance between two L section

-Vertical column =C-section of width 76.2mm* side length 38.1mm. -Height from ground is 1200mm.

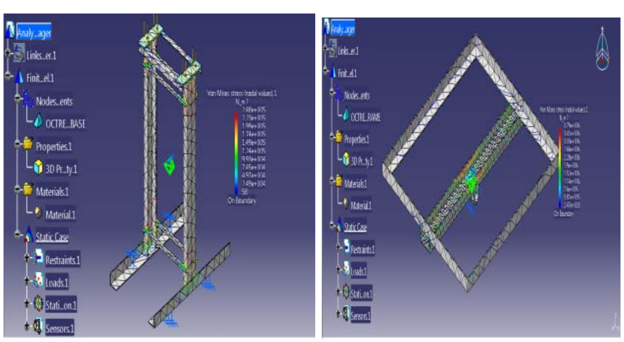

Fig. 8: Frame Analysis (Base Stand) in CATIA V5

5.1.2 Frame Support Analysis -The frame is loaded with 200N point load on each end and done analysis. From Analysis results above shown in figure, it concludes that our frame is safe for application as desired.

From the above analysis, it concludes that the design for base stand is safe under the buckling load as desired for our application

5.2 Shaft Analysis -Analysis results verify that the stresses generated in shaft are very less than yield strength and thus the shaft is safe for required application

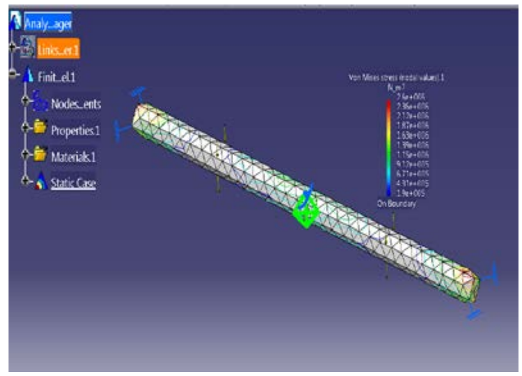

Fig. 9: Shaft Analysis in CATIA V5

6. TESTING AND RESULTS-

After design and analysis, the trial on experimental set up has been taken to check tracking accuracy; it is observed the following,

Trial 1: Now for testing, it is kept following parameters fixed

Flow rate: 3.4 ltr/hr. (outgoing water quantity)

Dead weight: 15 ltr

Distance between fixed weights: 260mm (hole to hole distance on middle C-channel)

For this trial it is obtained tracking with 30 degree/hr.

This trial is not more accurate because sun moves with 15 degree/hr. so it is decided to go for other trials to make it more accurate.

Trial 2: Flow rate: 1.7 ltr/hr. Dead weight: 15 ltr.

Distance between fixed weights: 130mm

For this trial we obtained tracking with 24 degree/hr.

This also not much accurate so it is decided to go for other trials to make it more accurate.

Trial 3: Flow rate: 2.4852 ltr/hr. (by calculations)

Adjusted flow rate: 2.46 ltr/hr.

Dead weight: 15 ltr.,Distance between fixed weights: 190mm,This trial is more accurate than first two as it is obtained the tracking accuracy 17 degrees/hr.

Therefore by keeping the flow rate more accurate, it is possible to obtain more accurate tracking system. After the trials, it is able to track the sun with 17degrees/hr. rotation of panel (error of 2 degrees)

Also from trials it is observed that the tracker is not more efficient after 12 O'clock for 1-2 hour as it offers some jerk to it due to weight shifting suddenly, so to overcome this drawback the restating element should be there to offer resistance for sudden jerk. So if one it can able to design spring with accurate stiffness, the tracker will be more efficient and accurate one.

7. SUGGESTED FUTURE CONSIDERATION -

The goals of this conceptual research work were purposely kept within what was believed to be attainable within the allotted timeline. As such, many improvements can be made upon this initial design. That being said, it is felt that this design represents a functioning miniature scale model which could be replicated to a much larger scale. The following recommendations are provided as ideas for future expansion of this research work:

- It can use wood and other locally available materials instead of Mild steel and thus reduce the cost further.
- A spring of appropriate stiffness could be designed to avoid sudden jerks.
- Provisions for safety of solar panels from rain.
- More accuracy can be achieved by providing measures against wind vibrations

8. CONCLUSION

From the design of experimental setup which works the principle of dynamic balancing of weights (attached on both ends of solar panel) in order to track the sun. If it compares tracking by the use of mass imbalance with existing fixed solar panel system, It is predicted that the efficiency of developed solar tracking mechanism is improved by 30-40% Moreover this tracking mechanism does track the sun in a continues manner and also this system is more efficient and cost effective in longer running. From the result it is found that, by automatic tracking system, there is 30% gain in increase efficiency when compared with non-tracking system. Even purification of water can be achieved

9. ACKNOWLEDGEMENTS

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