Design and Development of a SOLAR TREE

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ABSTRACT: In this work, a new product called, 'solar tree' has been designed to increase the power output by many folds by consuming solar energy. It can be installed on the sides of heavy traffic roadways and on roof top buildings. The tree consists of numerous solar panels connected to one another in series and parallel connections. The solar tree consists of number of branches welded to a stem and each stem has a solar panel mounted on it. It adds up voltage in series and current in parallel connection. The paper calculates the sun earth angles at different times of the day and designs solar tree based on these sun earth angles. It lights up a CFL lamp of 5 watts continuously for much time.

KEYWORDS: angle of incidence, solar tree, solar panel, sun-earth angles, series connection, parallel connection, zenith angle

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1.Introduction

With depleting conventional sources of energy, the world is looking towards renewable energy sources viz solar, wind, tidal etc. Sun, a star, radiates lot of solar energy onto earth surface and is a perennial source of energy. The amount of solar energy incident on the earth's surface is approximately1.5 x 10^{18} kWh/year. The density of power radiated from the sun (referred to as **solar energy constant**) is 1.373 kW/m^2.

Many individual solar panels are installed on poles and they produce electricity by absorbing solar energy. However, the space around the pole and below the solar panel is a huge potential to increase the solar power by many folds, suitably named, "SOLAR TREE". The present paper aims at building an array of solar panels by installing the panels on a welded stem to a pole. The tilt angle of solar panel and other parameters suitably depend on the coordinates of the local area of installation.

2.Literature Survey

Ali Rachini et al monitored grid connected photovoltaic system to evaluate the performance and the efficiency of conversion of solar energy into electricity. The monitoring system detects abnormal operations and power fluctuation in the grid connected PV system. It gives the possibility to optimize control laws and to implement interconnection strategies. It is used to evaluate the cost effectiveness of solar energy [1]. **Boyo A O et al** compared solar radiation data measured with the satellite and the ground measurement radiation was analysed.The ground measurement radiation consists of data at the ground level and in the atmosphere. The Kolmogorov-Smirnov test assesses statistical similarity between the two sets of data which was applied to global horizontal daily radiation data value from Gun-Bellani Pyranometer collected at Nigeria Meteorological Agency Oshodi, Lagos and Satellite data from National Aeronautics and Space Administration (NASA). The differences in data are because of the behavior of measured data at a particular station, such as recording errors and behavior of estimates made from satellite images [2]. **J C Mourmouris et al** did a case study for the island of Samothrace, Greece and analyzed that Samothrace has a high potential for energy resource exploitation (mainly Wind and Solar), but has social acceptance problems because of its social, economic and environmental situations[3]. **Abhishek Agrawal et al** studied the theoretical aspects of choosing a tilt angle for the solar flat-plate collectors used at different locations in India. Based upon the measured values of monthly mean daily global and diffuse solar radiation on a horizontal surface, the calculations are done. It is shown that if the angle of tilt is varied seasonally, four times a year then nearly optimal energy can be collected. Annual optimum tilt angle is found to be approximately equal to latitude of the location [4]. **Immanuel Alphonse et al** detailed the designing of a solar powered BLDC Motor Driven electric vehicle. Immanuel selected the appropriate components for the application and the various components for the same is subjected to various tests, cross checked with simulation results. The designing of the whole system depends on the application for which it shall be used, and accordingly the components are chosen. It was observed that according to the application, the motor was chosen first. From the rating of the motor, the battery which could satisfy its starting current and full load current was been selected, and then according to the rating of the battery, the solar charge controllers and the solar modules were selected. Finally the

BLDC motor mounted upon the frame realized the prototype of the vehicle which was tested at different load condition [5]. **Rustu Eke et al** studied the operating parameters of KA58 amorphous silicon PV module and investigated the parameters as a function of solar irradiation and atmospheric conditions using current-voltage curves.This was done from April to May at Mugla Sitki Kocman university PV outdoor test site.Current-voltage curves of thin film solar cells and modules are explained by single diode model, In a period of 12 months, the PV module exhibits different response to changes in solar irradiation and weather conditions[6]. **Farshid Mostofi et al** studied an optimization model of hybrid energy system for a hybrid system implemented in the north part of Iran is presented. The optimization solution is provided by HOMER software compared with a solution given by a genetic algorithm implemented in MATLAB software. The paper presents an interesting source for the implementation of hybrid systems in isolate areas. The main purpose of combination PV, wind, fuel cell and hydro units is to reach a reliable applying with minimum initial and operation cost. The results show that the optimized configuration produces high efficiency for LPSP of 1.23%. Implementation of this energy system will supply the area's demand as well as it has no emissions and reduces the environment pollutions [7].

3.Design of Solar Tree

To save roof top space of buildings is the need of solar tree. The solar tree consists of solar panels arranged in a spiral fashion around a pole such that shadow of one panel does not fall on other. Once developed, the solar tree can be installed in public places and along sides of roads. The solar tree can be installed at one corner on the roof top of a building and rest of the space can be used for any other purposes. Solar tree can also be installed on the ground. However, care should be taken that no shadow falls on the panels.

The figure 1 shows the circuit diagram of a typical solar tree with series and parallel connections. The panel 1 is connected in parallel to panel 2 while panel 3 is connected to panel 4 in a parallel connection. Both the parallel connections are connected in series. The whole circuit of panels (LB1 13003680) stores energy in a battery rated at 12 volts. The specifications of the panels are as given in table 1. The panels face southwest at an inclination of 35^0(Latitude is$28^0$35'). The solar tree is designed for new delhi region.

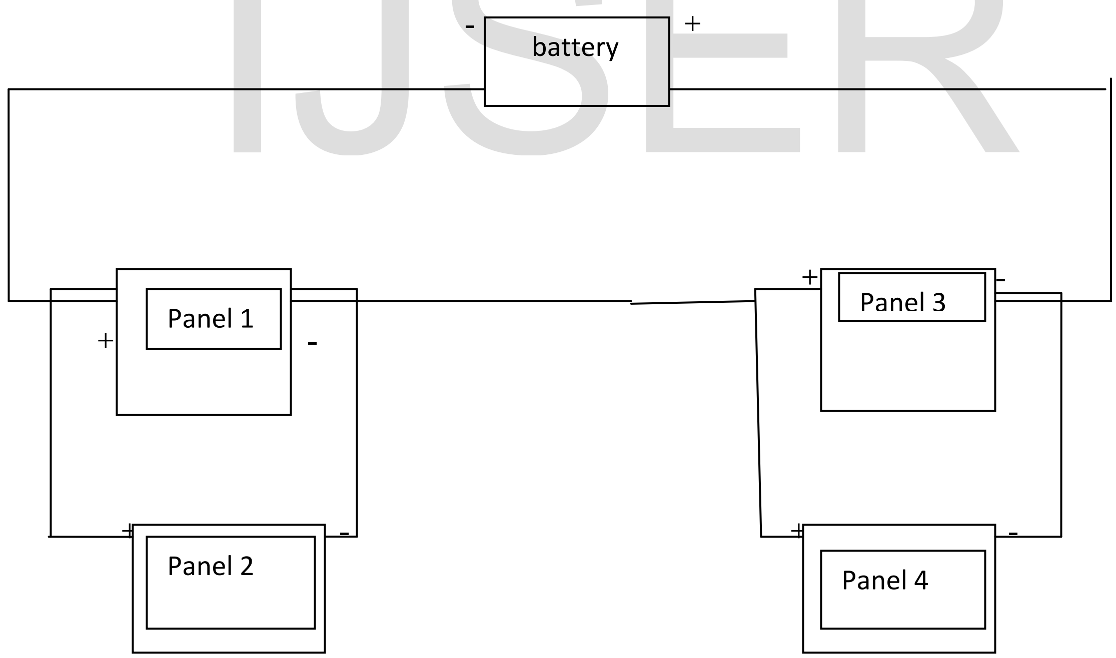

Fig 1: circuit diagram of solar panels

Table1. specifications of solar panel LB1 13003680

Characteristics	**Specifications**

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Pmax	5W
Imp	0.35A
Vmp	10.5V
Voc	10.5V
Tolerance	+-5%
Isc	0.35A

The solar radiation has been calculated for December 21st 2015 and sun earth angles have been calculated accordingly and all the data has been tabulated.

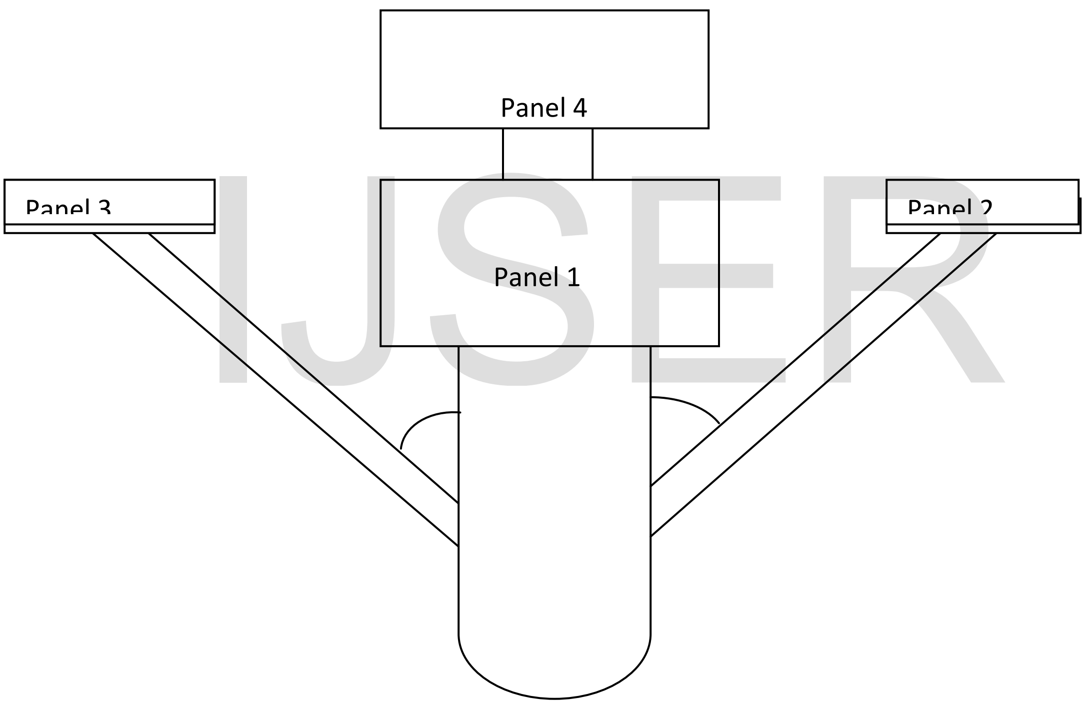

Fig2. solar tree diagram

Table2. Average days for months and values of n by months [8]

		For the average day of the month		
Month	n for ith day of month	Date	Day of year n	Declination (δ)
January	I	17	17	-20.9
February	31 + i	16	47	-13.0
March	59 + i	16	75	-2.4

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April	90 + i	15	105	9.4
May	120 + i	15	135	18.8
June	151 + i	11	162	23.1
July	181 + i	17	198	21.2
August	212 + i	16	228	13.5
September	243 + i	15	258	2.2
October	273 + i	15	288	-9.6
November	304 + i	14	318	-18.9
December	334 + i	10	344	-23.0

Table3. value of hour angle with time of the day(northern hemisphere)[8]

Time of day (hours)	6	7	8	9	10	11	12
Hour angle(degree)	- 90	- 75	- 60	- 45	- 30	- 15	0
Time of day (Hours)	12	13	14	15	16	17	18
Hour angle(degree)	0	+ 15	+ 30	+ 45	+ 60	+ 75	+ 90

Table4. surface azimuth angle for orientations in the northern hemisphere[8]

Surface orientation	**Azimuth angle (γ)**
Sloped towards south	0^0
Sloped towards north	-180^0
Sloped towards East	-90^0
Sloped towards West	+90
Sloped towards south-east	-45
Sloped towards south west	+45

4.Calculations and Results

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The sun earth angles have been calculated for minimum solar radiation on December 21, 2015 and tabulated. The solar panel faces south west since new delhi (28.58^0) lies in the northern hemisphere. The calculations for time taken to charge the battery and electrical consumption time by CFL lamp of 15watts have been done. The calculations are as follows.

Angle of Declination, $(\delta) = 23.45 \sin[360\,(284 + n)/365]$ (1)

No of days on December 21, n=355

Thus, $\delta = 23.45 \sin[360\,(284 + 355)/365]$

$= -23.45^0$

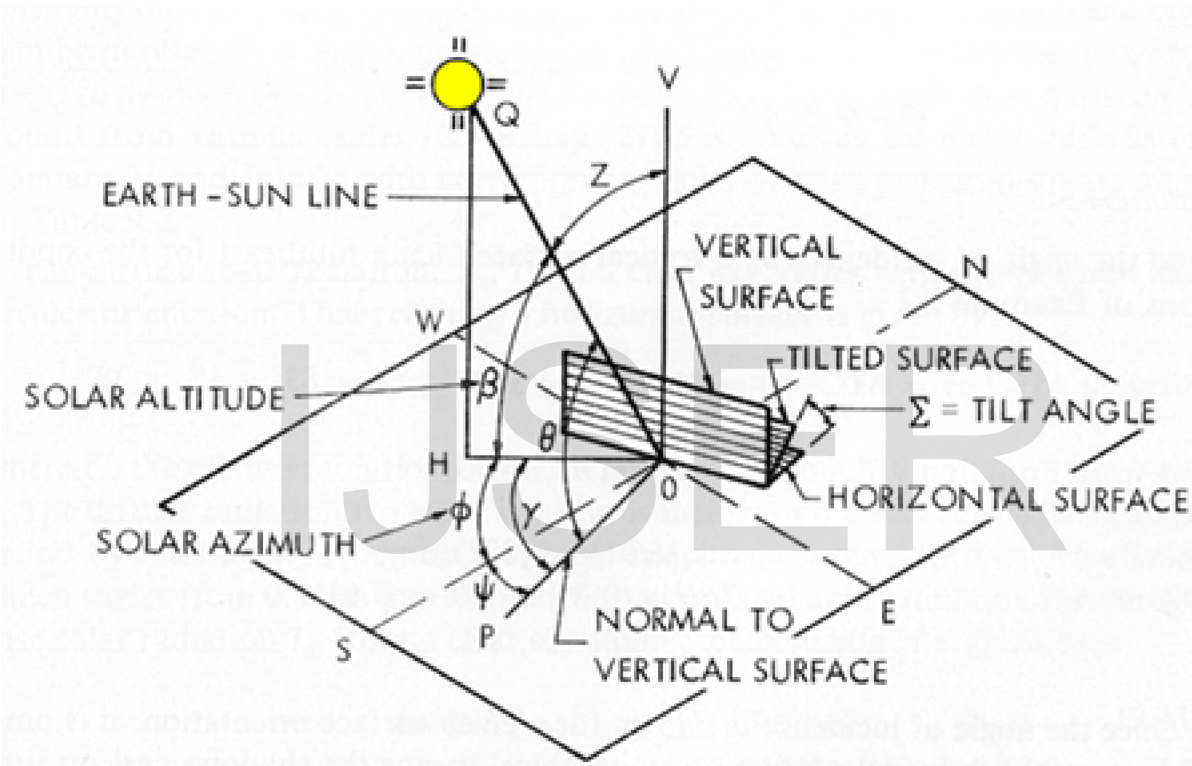

Fig3. sun earth angles

total angle between sunrise and sunset is calculated as

$2\,\omega_s = 2\cos^{-1}(-\tan 28.58 \tan(-23.45))$

$= 152.6^0$

sunshine hours are found to be

$N = 2\,(\cos^{-1}(-\tan Ø \tan \delta))/15$ (2)

$= 152.6\ /15$

N = 10.17 hours

At 6am in the morning, $\omega = -90$ (from table 3), $\gamma = +45$ (from table 4)

Angle of incidence,

$$\text{Cos } \theta_i = (\cos\text{Ø} \cos\beta + \sin\text{Ø}\sin\beta \cos \gamma) \cos \delta \cos \omega + \cos \delta\sin \omega \sin\beta \sin \gamma$$

$$+ \sin\delta (\sin\text{Ø} \cos\beta - \cos\text{Ø}\sin\beta \cos \gamma) \quad (3)$$

$$= (\cos(28.58) * \cos(35) + \sin (28.58) *\sin(35) * \cos(+45)) * \cos(- 23.45) * \cos(-90)$$

$$+ \cos(- 23.45) *\sin(-90) * \sin(35) *\sin(+45)$$

$$+ \sin(-23.45)*(\sin(28.58) * \cos(35) – \cos(28.58) * \sin(35) * \cos(+45))$$

$\text{Cos } \theta_i = 0.386$

$\theta_i = 67.28^0$

Zenith angle (θz) is given by

$$\cos \theta z = \cos \text{Ø} \cos \delta \cos \omega + \sin \delta \sin \text{Ø} \quad (4)$$

$$= \cos(28.58) * \cos(- 23.45) * \cos(- 90) + \sin(-23.45) * \sin(28.58)$$

$$= - 0.19$$

$\theta z =100.97^0$

At 12 noon, ω = 0 (from table 3), γ = + 45 (from table 4)

$$\text{Cos } \theta_i = (\cos(28.58) * \cos(35) + \sin(28.58) * \sin(35) *\cos(+45)) * \cos(-23.45) *\cos(0)$$

$$+ \cos(-23.45) * \sin(0) * \sin(35) * \sin(+45)$$

$$+ \sin(-23.45) * (\sin(28.58)*\cos(35) – \cos(28.58) * \sin(35) * \cos(+45))$$

$$= 0.8238$$

$\theta_i = 34.5^0$

Zenith angle (θz) is given by

$$\cos \theta z = \cos \text{Ø} \cos \delta \cos \omega + \sin \delta \sin \text{Ø}$$

$$= \cos(28.58) * \cos(-23.45) * \cos(0) + \sin(-23.45) * \sin(28.58)$$

$$= 0.615$$

$\theta z = 52.03^0$

At 5pm, ω = + 75 (from table 3), γ = + 45 (from table 4)

$$\text{Cos } \theta_i = (\cos\text{Ø} \cos\beta + \sin\text{Ø}\sin\beta \cos \gamma) \cos \delta \cos \omega + \cos \delta\sin \omega \sin\beta \sin \gamma$$

$$+ \sin\delta (\sin\text{Ø} \cos\beta - \cos\text{Ø}\sin\beta \cos \gamma)$$

$$\text{Cos } \theta_i = (\cos(28.58) * \cos(35) + \sin(28.58) * \sin(35) *\cos(45)) * \cos(-23.45) * \cos(+ 75)$$

$$+ \cos(-23.45) * \sin(+75) * \sin(35) \sin(+45)$$

+ sin(-23.45) *(sin(28.58) * cos(35) - cos(28.58) * sin(35) * cos(45))

= 0.568

$\theta_i = 55.4^0$

Zenith angle (θz) is given by

$\cos\theta z = \cos Ø \cos\delta \cos\omega + \sin\delta \sin Ø$

= cos(28.58) * cos(-23.45) * cos (+75) + sin(-23.45) * sin(28.58)

= 0.0181

$\theta z = 88.96^0$

Available solar radiation on an inclined surface:

extra terrestrial radiation is given as

I_{ext} = 1367*(1+0.033*cos(360*355/365)) = 1411.4 W/m^2 (5)

At 6am, beam radiation is given by the formula

$I_b = I_N \cos\theta z$ (6)

= 860*cos(100.97) = 163.65 W/m^2

diffuse radiation is given as

$I_d = (1/3)*[I_{ext} - I_N]*\cos\theta z$ (7)

= (1/3) *[1411.4 -860]*cos(100.97) = 34.98 W/m^2

conversion factor of beam radiation is given as $R_b = (I_N \cos\theta_i) / (I_N \cos\theta z) = 2.03$ (8)

conversion factor of diffuse radiation is given as $R_d = (1 + \cos\beta) / 2 = 0.909$ (9)

conversion factor of reflected radiation is given as $R_r = (1 - \cos\beta) / 2 = 0.09$ (10)

insolation or total radiation is given by the formula

$I_T = I_b R_b + I_d R_d + \rho R_r (I_b + I_d)$ (11)

= 163.65 *2.03 + 34.98*0.909 + 0.2*0.09*(163.65 +34.98)

I_T = 367.58 W/m^2

At 12 noon

I_b = 860*cos(52.03) = 529.114 W/m^2

I_d = (1/3)*[1411.4 – 860]*cos(52.03) =113.083 W/m^2

R_b =1.34

Substituting the values in eq(12), I_T = 823.364 W/m^2

At 5pm,

I_b = 860*cos(88.96) = 15.61 W/m^2

I_d = (1/3)*[1411.4 – 860]* cos(88.96) = 3.336 W/m^2

R_b = 31.38

Substituting the values in eq(12), insolation I_T = 493.24 W/m^2

Table5. calculated values of hour angle and different radiations

Time on Dec21, 2015	Radiation on horizontal surface (W/m^2) Total	Diffuse	Beam	Hour angle ω (deg)	Calculated radiation on inclined surface (W/m^2)
6am	198.63	34.98	163.65	- 90	367.58
12 noon	642.194	113.08	529.114	0	823.364
5pm	18.946	3.336	15.61	+ 45	493.24

The solar radiation on a horizontal solar panel and an inclined panel have been calculated and tabulated in table 4. The solar panel efficiency is taken to be 20 percent and calculations have been done to light a 5 watt CFL lamp

Solar panel photon conversion efficiency = 0.2 * solar radiation

= 0.2* 860 W/m^2 = 172 W/m^2

Total power produced by the panel = panel efficiency * panel area

= 172 *15*15 *10^{-4} = 3.87 W

Number of sunshine hours are 10.17 hours

Total power produced by the panel = 3.87 *10.17 = 39.4 watt-hours

Total power produced by the solar tree = 39.4 *2 = 78.7 Watt – hours

In order to increase the battery life, only 70% of battery stored energy is discharged.

Therefore, available power = 78.7*0.7 = 55.1 watt-hours

Rating of CFL lamp is 5watts, 12Volts

Power consumed by CFL lamp = 5watts

Amperage of CFL lamp = Power / voltage

= 5 /12 = 0.4 A

Usage of CFL lamp in a household is from 6pm to 11pm on an average

No of hours of CFL usage = 5 hours

Power consumed by CFL lamp = 5*5 = 25 watt-hours

Solar tree efficiency = power consumed by CFL Lamp / available power in battery

= 25 /55.1 = 0.454

The designed solar tree works at an efficiency of 45.4 percent with an available power in the battery of 55.1 watt-hours. The stored energy in the battery at 12volts is 78.7 watt-hours. Thus, it can be deduced that a set of two CFL lamps of 5watts can be lightened for 2.5 hours continuously or a single CFL bulb can be lightened for 5 hours continuously keeping the battery in a safe range of lifespan.

5.Conclusions

The present study increases the solar power output by the number of solar panels installed on a pole in comparison to a single panel pole system. The structure of solar panel system is given a tree shape. The panels are put on the structure in a spiral fashion. It proves to be a useful system to meet the energy demands of the world and to use a given space more efficiently. The present system of roof top solar systems can be replaced by solar tree and the roof top space can be utilized for recreation purposes. The solar tree can be installed on ground also in addition to roof top spaces. So, this solar tree proves to be advantageous in saving space and increasing the power output by many folds. It saves a lot of energy over the years to come. The number of solar trees that could be installed in a given space depends on the wattage needed.

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