Design and Development of Solar Tree to be install in Campus of TRUBA Group of institutes, Bhopal

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Abstract: The purpose of this work is to promote awareness, understanding, and adoption of renewable energy and proposed a complete design and mathematical analysis of Solar Tree which had been installed in TRUBA Group of institutes, Bhopal. The design and calculation of this solar tree is for domestic lighting and other applications used in a small house of 2BHK. In this work the energy requirements of the solar tree is calculated in kWhr/day. All the calculations are done considering solar radiation data for Bhopal, Madhya Pradesh at 23.30^{o} latitude and 77.38^{o} longitudes which is situated at elevation 523 meters above sea level. The load capacities and sizes of all other components of systems are also determined. The overall cost can be reduced using simple and innovative designs of Solar Tree.

Keywords: solar power, PV system, Solar Tree, Solar panel, PV radiation etc.

Introduction

Solar Tree or Solar Photovoltaic Trees are a solar structure that looks like trees. It can be framed from small scale as a bonsai tree to large scale as of the wind turbine. It is a solar artwork which is a combination of artistic and technological effort. it is relatively a new concept imagined to attempt application of new technology relating to harvesting and use of solar energy. In solar trees the photovoltaic panels are arranged in a Fibonacci series pattern in its place of leaves. The solar tree can produces much more power than a conventional flat arrangement of solar cells. It requires only 1% land as compared to the conventional flat arrangement [1].The panels of flat mounting for homes are inefficient, as the angle of sun's rays is not constant, particularly during the changes in seasons. These solar trees have been designed to provide different means of power to different urban and built environments. This includes the powering of mobile phones, electric cars, buildings and street lighting and covering large and small scale area. Solar trees are really a practical solution for urban street lighting. There is a rapid increase in the use of PV systems in India due to continuous reduction in prices of solar cells. But there are some hurdles for adoption of this technology in rural and remote areas due to the security of the system and its components from theft. Most of the rural street lighting PV system installed by the government is not in working conditions because of above-mentioned reasons and lack of maintenance. In this context use of PV technology for the domestic requirement in the form of the solar tree is the good alternative as compared to conventional flat or rooftop mounting [2].

Solar trees can be installed near, in front of the house or on a terrace, where there is no shading throughout a day. This paper illustrates design and development Solar Tree for domestic application considering the average requirement of small Indian house. A solar tree is a decorative means of producing solar energy and also electricity. It uses multiple no of solar panels which forms the shape of a tree. The panels are arranged in a tree fashion in a tall tower/pole. there is less response for use of PV system for domestic applications due to higher initial cost and area required for mounting such systems.

Working of solar tree

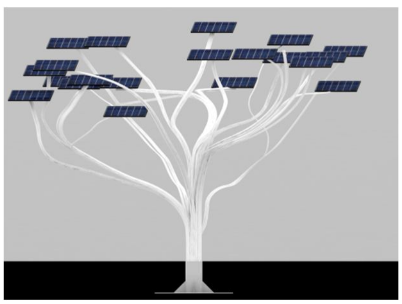

Figure 01: working of solar tree

It is difficult to store electrical energy for all electric power system. Solar tree panels charge batteries during the daytime. At dusk, the solar tree switches ON its LED automatically. The internal control can also regulate the amount of light produced on how much charge is left in the batteries. A sensor measures an amount of light in the atmosphere and triggers the solar lamps to switch ON automatically at sunset and OFF at dawn. Tracking system reduces solar cell output fluctuations caused by day and night cycle and weather shifts.

Literature Review

A P R Srinivas [3] 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.

Deepak M. Patil & Santosh R. Madiwal [4] Flat or roof top mountings of PV systems require large area or land. Scarcity of land is greatest problem in cities and even in villages in India. Solar Power Tree provides better alternative to flat mounting of PV systems. For domestic lighting and other applications use of Solar Tree is more relevant when PV system is to be used. In this article load or energy requirement of small house in India is estimated to 1.75kWhr/day. All the calculations are done considering solar radiation data at Kolhapur, Maharashtra (16.760). The load capacities or sizes of all other components of system are determined. Tracking system can be easily employed in Solar Tree hence its performance is better than flat mountings of solar PV system. The overall cost can be reduced using simple and innovative designs of Solar Tree. The total cost of Solar Tree is about Rs.60000 /- and payback period is estimated to 10 years.

Karim Hesham Fathy at el [5]They presents a developed charge controller which includes an MPPT. their work provid AC and DC power outlets to charge various electronic components such as mobiles and laptops in open areas. That is beside the inspirational advantage of the solar tree. The Solar Tree consists of Solar panels, charge controller (to charge batteries) and a DC/AC inverter for the AC loads. The panels used at our prototype provide DC power of 100 watts which will be accumulated to provide 500 watt hour daily for loads. Moreover, the tree is extendable to increase number of panels and provide more energy.

Kirti Vibhute & Ramakant Shukla [6] They describes a solar technology that imitates how trees convert sunlight into energy. Shrubs, plants and trees use an inbuilt structural design to representation their leaves, height dense to sunlight for photosynthesis. They do this finds out their survival. Recently with the rising population and energy demands, they find that the efficiency of the plant can also be improved by using the “SPIRALLING PHYLLATAXY” technique. The solar new technology presented in this paper has provides nearly high efficiency.

Sushma Gupta & Monish Gupta [7] This paper presents Solar Tree implementation as alternate source of energy in urban cities. India as the 2nd largest country of the world in the increasing demand of the energy and try to find a way from which efficient and abundant source of energy cab be available. Also solar botanic trees is a nonconventional source having many advantages of producing electricity as compared to the other sources. It is therefore the responsibility on the shoulders of the youngsters of the earth to think smartly and take the right decision. Everyone should starts as an individual to cooperate with the government to make life favorable for mankind.

Elisavet Dimitrokali at el [8] This study brought together a research team of physicists and designers and to conduct focus groups with design based methods and prototyping along with a computational 3D PV Tree design tool. A public exhibition followed to capture public perception on design concepts using 3D models, and a voting exercise. Overall it was found that PV Trees were received positively by the public with desires for them to be multifunctional by providing power yet also having a secondary function like a shelter.

Weiran Cao at el [9] They demonstrate a new form factor for organic solar cells, a “solar tree” or an electricity generating artificial tree with organic solar cells as leaves. They fabricated polymer, fullerene based organic solar cells on flexible plastic substrates that show similar performance to devices on rigid glass substrates using the inverted device structure. Large area flexible devices were fabricated and cut into palm leaf shapes with an active device area of 6.5 cm^2 using a steel rule die. 12 leaf shaped organic solar cells were then assembled to form a prototype “solar palm tree”. they use a low voltage, high current “fan mode” and a high voltage, low-current “LED mode”.

C.Bhuvaneswari at el [10] They introduces a new solar technology that emulates how trees convert sunlight into energy. They do this determines their survival. Based on this we describe the coconut tree growing u to 30m(98 feet) tall, with pinnate leaves 4-6m long to design a solar tree. With this arrangement they introduce a new idea to design a solar tree using nanowire solar cell. Nanoparticles exhibit a number of special properties relative to bulk material. Hence it is a revolutionary urban lighting concept that not just trees but other objects can also be decorated. These technologies eventually lead to the development of high efficiency solar cells.

Thoreau Rory Tooke at el[11] In this paper they describe the application of laser remote sensing technologies to examine the structural properties of the urban surface and present methods to quantify the diurnal and seasonal impact of trees on solar radiation in these areas. LiDAR data provides the three dimensional information required to populate geographic information system based radiation models, which are produced at hourly intervals for the summer and winter solstice and equinox in a multitude North American city. Trees in the study area attenuate on average 38% of available solar radiation at building rooftops. Integrating atmospheric conditions into the solar radiation model impacts absolute values but not correlation between tree structure and radiation estimates.

A.V. Parisi at el [12] In this work the first set of quantitative data of diffuse erythemal UV and UV-A radiation in tree shade at a sub-tropical Southern Hemisphere latitude is presented. Over the summer, approximately 60% of the erythemal UV radiation in tree shade is due to the diffuse component. Similarly, approximately 56% of the UV-A radiation in tree shade is due to the diffuse component. In tree shade these diffuse UV percentages are relatively constant from the morning to noon to afternoon periods. In comparison, in full sun, there is a decrease in the percentage of diffuse UV from morning to noon to afternoon. The exposures to diffuse UV on a horizontal plane in tree shade between 9:00 EST and 15:00 EST are of the order of 4 MED (minimum erythemal dose)and 14 J cm^{-2} for erythemal UV and UV-A, respectively. The high diffuse UV component in the shade may result in high UV exposures not only to unprotected parts of the body on a horizontal plane, but also in equally high UV irradiances to parts of the body, including the eyes and face, that are not UV protected.

Objectives

The main objectives of this present work are listed as follows:

- To study about solar power and its different applications.
- To promote awareness, understanding, and adoption of renewable energy.
- To make investigation about solar energy at Bhopal region.
- To make design calculation for the solar tree at Bhopal region.

Methodology

Solar irradiance reaching on the earth surface in three ways first one is Direct Normal Irradiance (DNI), second is Global Horizontal Irradiance (GHI) and third is Diffuse Horizontal Irradiance (DHI)

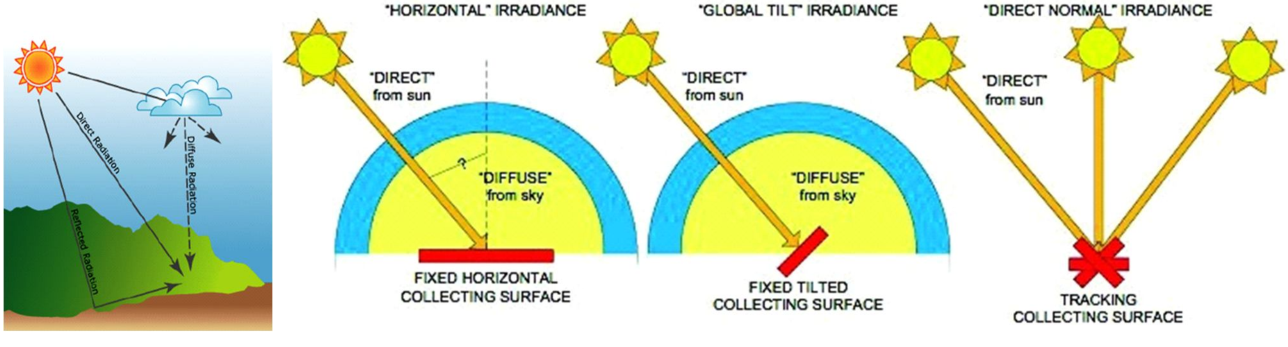

Figure 02: DNI, GHI & DHI Concept

DNI is the radiation received at per unit area on the surface which is normal to that rays coming from the direction of the sun. these rays can maximize by keeping the surface normal to incoming radiation. DHI is the radiation received at per unit area on the surface that is not subject to any shade from the sun, but it is scattered by the molecules in the atmosphere which comes equally in all directions. GHI is the total amount of shortwave radiation received from the sun on the surface horizontally to the ground.

DNI can be calculate using the following relation

$$\text{DNI} = \frac{\text{GHI} - \text{DHI}}{\cos(\theta_z)}$$

where θ_z is the solar zenith angle.
Optimum Tilt of Solar Panels by Month at the location in Bhopal Table 4.1

Jan	Feb	Mar	Apr	May	Jun
51°	59°	67°	75°	83°	90°
Jul	Aug	Sep	Oct	Nov	Dec
83°	75°	67°	59°	51°	44°

Source: NREL

Table 4.2. Load Estimation

Appliances	**Quantity**	**Rated Power (W)**	**Operating Hrs/ day**	**Total power (KWh/Day)**
Lighting for 2BHK	12@5, 9@1 and 3@2	60+9+6 = 75	4	75@4 = 300
Television	80@1	80	4	80@4= 320
Fans	60@3	180	6	180@6 = 1080
Computer	80@1	80	3	80@3= 240
Refrigerator	135@1	135	6	135@6= 810
Total Power consumption		300+320+1080+240+810 = 2750 Watt or 2.75KWh/Day		

Hence Total load or power requirement is approximately equal to 2.75kWh/day.

Selection of System Voltage

Based on requirements of the system voltage is selected. Since total AC-load is less than 5kW, the system voltage is selected as 24 Volt DC.

Determination of PV Array Size

By considering the efficiency of inverter /controller about 85% and battery bank and wire loss about 3%. The energy requirement from PV module

$$= 1/\eta_{\text{battery}} \times \eta_{\text{charge controller}} \times \eta_{\text{wiring}}$$
$$= 1/(0.85\times 0.85\times 0.97)$$
$$= 1.42$$
$$\approx 1.40 \text{ approximately}$$

Hence energy needed from Module (PV array)

$P_{\text{array}} = E_L \times 1.4$

Where E_L = Estimated Load for average daily energy consumption in Wh /day.

Hence: $P_{\text{array}} = 2750 \times 1.4$ = 3850 Wh. ≈ 4000 Wh approximately.

Since solar module are characterized for 1000 W/m2. The monthly average daily solar insolation data from MNRE website for Indian location have been used for Bhopal, (Madhya Pradesh) considering average daily sun hours equal to 5.67 when a module is mounted horizontally and six hours for an angle of Latitude: 23.30 Longitudes: 77.38: or at an angle with summer and winter correction.

Table 4.4. Mean Daily Duration of Sunshine Hours

Jan	Feb	March	April	May	June
9.6	10.1	9.9	10.7	10.6	9.1
July	Aug	Sep	Oct	Nov	Dec
7.5	8.0	9.2	10.1	10.1	10.1
Annual					
9.58					

The peak watt rating of module for present system may be

$$W_{\text{Peak}} = \frac{P_{\text{array}}}{\text{average daily sun hours on tilted surface at latitude angle}}$$

$$W_{Peak} = \frac{4000}{6} = 666.67 \text{ WP}$$

Total Array Current

The Total module current I_{dc} is calculated by dividing above peak watt rating by system voltage V_{dc} i.e.

$$I_{dc} = \frac{W_{peak}}{V_{dc}}$$

$$I_{dc} = \frac{666.67}{24} = 27.28\,A$$

Array Size

The number of modules in parallel Nmp

$$N_{mp} = \frac{I_{dc}}{I_{mpp}}$$

$N_{mp} = \frac{27.28}{2.8}$ = 9.75 ≈ 10 approximate in parallel

Approximately 10 modules will be in parallel.

The number of modules to be connected in series Nms

$$N_{ms} = \frac{\text{Nominal system voltage } V_{dc}}{V_{mpp}}$$

$N_{ms} = \frac{24}{17.89}$ = 1.34≈ 2

The total number of modules in series = 2. Total array size = 10 x 2 = 20

Battery bank Size

The total DC load requirement = $\frac{P_{array}}{\text{system voltage}}$ = $\frac{4000}{24}$ = 166.67 Ah

Considering battery autonomy for two days total requirement = 166.67 = 166.67 Ah

Considering battery efficiency and depth of discharge (DOD) equal to 80 %. Battery Capacity = $\frac{166.67}{0.8^2}$ =260.4 Ah.

We can select two battery of 150 Ah to meet this requirement. Hence selecting two 150 Ah batteries of 24 V DC rating with the parallel connection to get required system voltage and energy demand.

Inverter Size

The inverter size should generally 25-30 % bigger than total power requirement (W) of appliances.

Size of inverter = 4000 W x1.25 = 5000 W or = 5.00 KW

Hence the size of inverter equal to 5.00 KW or 5.00 KVA

Charge Controller Capacity

The standard practice of sizing the charge controller is to ensure that it can withstand the product of the total short circuit current of the array (I_{scA}= I_{scM} x N_{pm}) Thus, the desired charge controller current (Icc) is as given by equation

$I_{cc} = I_{scM} \times N_{pm}$

Where, I_{scM} = the short circuit current of the selected module.

I_{cc} = 3.04 x 7.75 = 23.56 A ≈ 24 A

System wiring sizing

The design of a PV power system is incomplete until the correct size and type of cable are selected for wiring the components together. The following cables links in the PV system must be appropriately selected:

The DC cable from the PV array to the battery bank through the charge controller.

I rated = $N_{mp} \times I_{sc}$ = 3.04 x 7.75 ≈ 24 A.

The AC cable from the inverter to the distribution board (DB) of the residence. Current Produced by Inverter Output is

$I_{oi} = \frac{\text{Total Power}}{V_{oi} \times p.f}$ $\quad I_{oi} = \frac{4000}{230 \times 0.8}$ = 21.74 A.

Referring 4 sq.mm wire standard wire gauge and its current carrying capacity for copper conductor wire used.

Result and discussion

The summaries result are tabulated in following table after getting all mathematical values.

S. No.	Investigated parameters	Numeric value of Investigated parameters
1	TOTAL POWER CONSUMPTION	2.75KWH/DAY
2	System voltage	24 VOLT DC
3	PV Array Size	4000 WH APPROXIMATELY
4	The peak watt rating of module	666.67 WP
5	Total Array Current	27.28 A
6	Array Size	10 X 2 = 20
7	Battery bank Size	260.4 AH.
8	Inverter Size	5.00 KVA
9	Charge Controller Capacity	23.56 A ≈ 24 A
10	System wiring sizing	21.74 A. 4 SQ.MM WIRE

Conclusion

After mathematical calculation hear various design parameters have been obtained for solar tree, the total power consumption have been calculated is 2.75KWh for which 24 VDC supply system with 4000 Wh photovoltaic array have been investigated. the calculated Peak watt is about 666.67wp and current is 27.28A, the total battery bank size is 260.4Ah. Now it has been concluded that the concept of solar tree is a very good options to fulfill the energy demand without power cut off and also minimize the grid dependence.

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