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Design and Implementation of a Solar Tree Structure for Efficient LED Street Lighting

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Abstract*: This paper shows the design of solar tree PV system for street lighting. In current days with enhancing the population and the energy demand, the Renewable Energy Source (RES) plays a major role and also, this energy could not cause any pollution and other natural hazards. The solar energy is more suitable one for this among other RES. India is a highly populated country, so the merit of such a solar energy that needs a very small space to produce energy efficiently. Flat or roof top mountings of PV systems are needed large land areas and problems in production of PV systems voltage due to partial shading of PV panels. Also, the scarcity of land is greatest problem in cities and particularly in urban areas in India. In order to overcome these harms, Solar Tree Structure Power Generation (STSPG) is developed. Hence, this article presents a design and fabrication of 120 Watts STSPG pilot plant for efficient LED street light application. The design structure of STSPG includes the support structure used to represent the leaves, the height, orientation and tilt angle of these leaves.

***Keywords* : Charge Controller, Leaf Wattage, LED, Solar Tree, Street Lighting.**

I. INTRODUCTION

Sustainable energy harnessed from restorable resources such as sun, wind, water, geothermal, tides, waves etc. is the purest form of energy that helps in diminishing the global warming problem. While numerous sustainable power source activities are enormous scale, inexhaustible advances are likewise fit where clean energy is regularly essential in human improvement. Solar power, that's effulgent light-weight and warmth from the sun, is controlled employing a vary of ever-evolving technologies like photovoltaic, heating, thermal and artificial photosynthesis [1,2]. It is considered as one of the main sources of renewable energy in future. Solar technologies are broadly portrayed as either passive solar or active solar relying upon the manner in which they catch, convert and disperse solar energy [3].

II. SOLAR PROFILE

A. Solar Irradiation of the Site

Irradiance is a measurement of solar power and is defined as the rate at which solar energy falls onto a surface. The sun-based irradiance is estimated by the power per unit region, so irradiance is commonly cited as W/m². The National Renewable Energy Laboratory (NREL), situated in Golden, Colorado, specializes in sustainable power and energy efficiency research and development. NREL is a government-owned, contractor-operated facility, and is funded through the United States Department of Energy.

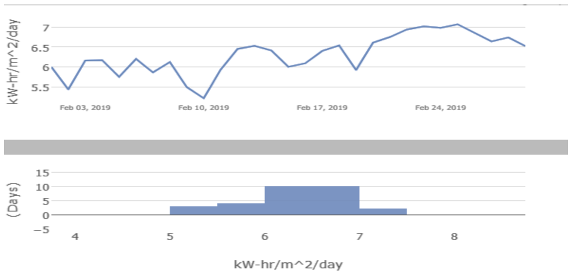

Fig. 1.Monthly insolation radiation.

According to the National Aeronautics and Space Administration (NASA) atmospheric science data center, the monthly averaged insolation clearness index and radiation incident on a tilted PV panel at the location of Bangalore, India is 6.25 KWh/m2/d [4]. Fig. 1 shows the monthly averaged radiation incident on Bengaluru City.

Table- I: Voltage Profile of the panels output in a day

Time	Average Outout Voltage (V)
8 am-11 am	20.74
11 am-1 pm	19.98
1 pm-3 pm	18.86
3 pm-6 pm	11.11

Table 1 shows the average voltage profile from 8 am to 6pm in a day, which is required for analysis and for designing of the solar tree structure. The voltage profile during a day from 8am to 6pm is represented in Fig. 2.

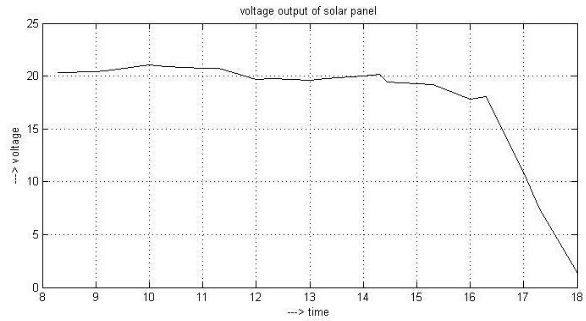

Fig. 2.Voltage profile plot during the course of the day.

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B. Solar Tree

Sun based tree sounds like the ideal answer for our future energy needs. The sun is always sending energy to the earth and we should simply to get it and after that utilize it [4]. Sun based energy is accessible in plenitude and considered as least demanding and cleanest methods for tapping the sustainable power source.Solar trees were introduced in 1998 as sun oriented fine art on streets and open spots. At that point this innovation is embraced as sun powered trees. In Europe these are utilized from numerous years. In 2006 in Europe the vitality utilization is 10%. 2000 billion kWh is utilized from sun-oriented trees and 2900 million ton carbon is killed. In October 2016 sun-based trees are utilized in Vienna, Austria. These are likewise utilized in Graz, Austria.A sun-based tree is a brightening method for creating sunlight-based energy and furthermore power. It utilizes different no of PV panels which structures the state of a tree. The panels are masterminded in a manner in a tall pinnacle/shaft. The measure of energy created by this tree is more than that of ordinary level cluster of sun-based cells.This resembles a tree in structure and the panels resemble leaves of the tree which produces energy. The trees are available in nature and they can deliver their own sustenance material by the procedure called photosynthesis. Here normal trees are considered for comprehension about the sun powered tree. The sunlight-based tree is a tree where the stems associated go about as the parts of the tree and the panels resemble the leaves. Green leaves are creating sustenance materials for individuals in like manner the sun-oriented tree leaves are delivering energy for the general public. Thus, it is fitting to call it as a tree.

III. GENERAL LAYOUT AND COMPONENTS OF SOLAR TREE

A. Design of Mechanical System

The mechanical structure of the solar tree includes the branches and poles. The structure consists of 12 fixed panels, with a maximum output of 120 Watts. The angles of the panels are determined by the area available and making sure the shadow of one panel doesn't affect the performance of the other panel [6].

B. Design of Structure

As the entire structure of a sun powered tree is mounted on a shaft (steel or iron), it needs a solid establishment. The common work comprises of the establishments of the post and battery bank [6]. The tallness of the tree and number of panels and also their direction decides the profundity and size of establishment for the shaft [1].

C. Construction Design of Structure

- The foundation of the solar tree includes foundation of the pole and also the space given to place battery. Dimension of the foundation is (4x1.5x3) ft.
- The height of pole (tree trunk) is 24.7 ft. and the length of each main branch is 4 ft. The length of the sub branches are 1.5ft on which the panels are mounted using rods and L-angles.
- For the street lighting, two DC LED lights of 40W each are used.

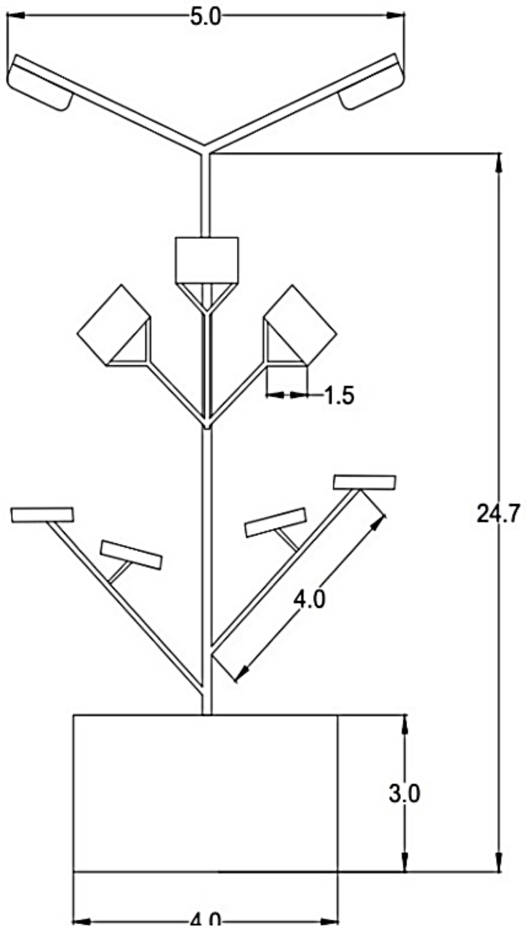

Fig. 3.Solar tree structure side view.

The Fig.3 represents the side view of the entire structure with dimensions given in feet.

D. Solar Cell Circuit

General and widely used solar cells are designed by the one diode model (Equivalent Circuit) [7]. The equivalent circuit of solar cell circuit is shown in Fig. 4.

The output current of solar cell is given by,

$$I = I_L - I_D \quad (1)$$

The diode current is given by,

$$I_D = I_o\left(e^{\frac{V}{n_s V_T}} - 1\right) \quad (2)$$

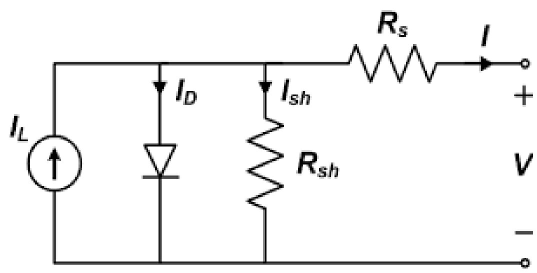

Fig. 4.Model of solar cell.

Thermal voltage equivalent is given by,

$$V_T = \frac{nkT}{q} \quad (3)$$

Thermal voltage equivalent is given by,

$$I = I_L - I_o\left(e^{\frac{V+IR_s}{n_s V_T}} - 1\right) - \frac{V+IR_s}{R_{sh}} \quad (4)$$

Where,
I - Output Current (A)
I_o – Diode Saturation Current (A)
V – Voltage Output (V)
R_s – Resistance in Series (Ω)
R_{sh} - Shunt Resistance (Ω)
K - Boltzmann Constant (1.3807 x 10^{-23} J/K)
T - Operating Temperature (Kelvin)
I_D – Diode Current (A)
I_L - Ideal Current (A)
q – Electron Charge (1.6021765 × 10^{-19} coulomb)
V_T – Thermal Voltage Equivalent (V)

E. Capacity of the Battery

To determine the storage of the storage system it is necessary to estimate the maximum number of days the system will operate without solar power, the load demand, efficiency and discharge rate of the battery. The energy stored in the batteries can be used during night and in cloudy days when no sunlight is available.

$$\text{Storage Capacity of battery} = \frac{N*E_L}{D*\eta_o} * \eta_o \quad (5)$$

Where,
N - Number of days without solar power
E_L - Load Demand
D- Discharge rate of battery
η_o - Output efficiency of battery

F. Electrical Load Calculations

To design the solar tree, it is necessary to know the type of electrical connected and to determine the power consumed by the load so that the PV system will supply accordingly [8]. The theoretical calculation for required power is estimated by the following equation,

$$E_T = \sum_i^n W_i * h \quad (6)$$

Where,
E_T – Theoretical required energy (Wh)
W_i – Nominal Power required (W)
h – Daily use (hour)

G. Charge Controller

The motivation behind a controller is to screen the yield of each PV leaf/board, keep up greatest power extraction from the PV boards, which is done through a MPPT dependent on maximum power transfer theorem [9]. It likewise screens the charging and releasing of the battery, counteracts overcharging and undercharging of the battery, removes smoothened signal from Light Dependent Resistor (LDR) and controls the operation of Light Emitting Diode (LED) [1].

IV. DESIGN PARAMETERS

In general, there is no specific design of a solar tree. But many hypothetical designs and concepts have been invented and implemented to a certain extent.

A. Area Ratio

The main purpose of opting for tree-branch style is to minimize the area consumed on the soil by the PV Tree. The area ratio is "The proportion of the real region of the leaves to the land impression territory of the structure".

B. Angle of Orientation of Panels

Normally, the natural trees are capable of capturing sunlight efficiently due to their random orientation in different possible directions. The incident angle of solar radiation changes over the course of different seasons and varies due to climatic conditions. Hence, to optimally capture the sunlight the panels are oriented in different angles.

C. Number of Layers of Leaves

The 2nd layer of leaves in the natural tree captures sunlight which escapes the first layer. The same concept is applied to the solar tree also. Due to this particular arrangement maximum amount of sunlight can be captured by the panels.

D. Tilt Angle of the Leaves

This arrangement is also similar to the natural trees where in the leaves will be tilted their bottom-line tangential locations. According to the study of Mazumder [6] small angle of tilt ±20° resulted in more Sunlight capture, though a higher angle tilt ± 40° had detrimental effect. So, the tilt angle of the leaves will vary according to the height, solar irradiation profile, location and weather conditions at which the solar tree structure is placed.

E. Panel/Leaf Wattage

In this study, power rating of every leaves has the same capacity.

Table- II: PV panel specification of the Solar tree and its total capacity

Specification	Total Capacity
Maximum Power	10W
V_{oc}	21.6V
I_{sc}	0.64A
V at P_{max}	17.5A
I at P_{max}	0.57A
Number of cells	36
Number of panels	12
Total capacity	120W
Operating temperature	-40°C to 85°C

The above table represents the ratings of each PV panel used in the solar tree structure, which is helpful to decide the load to be used and the operating voltage, current and temperature ranges.

F. Design of the Tree Structure

The design of the tree is the backbone for the complete structure. The PV systems can be integrated into a natural tree structure according to various constraints such as:

- Height and weight to decide the stability of the tree structure.

- To choose appropriate height of the main pole to detain more sunlight and eliminating shadows from nearby objects around the tree.
- The branched must be sufficiently strong to withstand the weight of the solar panels and also be rigid enough during bad weather.

V. COST ESTIMATION OF THE SYSTEM

The Table 3 gives the cost break up of all the major components, foundation costs and cost of the mechanical structure. Other miscellaneous costs which are variables have not been mentioned in the above table.

Table- III: The Cost Estimation of the System Components

Component	**Quantity**	**Unit Cost (Rs.)**	**Cost/Component (Rs.)**
Solar Panels	12	650	7,800
Battery	1	16,300	16,300
Charge Controller	1	650	650
Fabrication of solar tree Includes Mechanical structure and foundation costs Metal bar (circular), Metal bar (rectangular), Metal strips, Nut bolts, Rubber bush. Plastic box ,wires, fuses ,circuit breaker etc.			25,000
Total cost			**49,750**

VI. CONCLUSION

This paper has presented the design and construction of solar tree used for street lightning. Sunlight based tree is a progressive urban lighting idea that speaks to an ideal beneficial interaction between spearheading plan and front line eco-good innovation. To satisfy the expanding energy request of the general population, sparing of land, the sunlight-based tree idea is extremely effective one and ought to be executed in India to give power without the issue of power cut and the additional energy can be given to the network. Due to global warming, the temperature is always on a higher range usually than assumption range so that can be used and generate electricity in large quantity. As this is the efficient way to produce electricity without any maintenance or other activities and gives us a continuous output for long time.

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