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Designing and Calculating Pay-Back Period for an Ideal Solar Tree-Commercial Use

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Abstract. Industries are heavily dependent on fossil fuels. Considering their swift dwindling rates, the motive to seek and adopt alternatives has taken charge. The sun and its solar energy is one such alternative source of energy, which is generally regarded as rich and actually "free". The generation of electricity from sunlight using photovoltaic convertors is the most widespread and mature technology for harvesting solar energy. In spite of the benefits associated, solar PV technology has drawbacks in terms of land requirements (notably in urban communities), community perception (due to the lack of amusing aesthetics) and capture efficiency. The cost of setup and implementation of such plants is significantly expensive as well. These challenges can be tackled in an effective and artistic manner by devising the concept of a solar tree. The paper examines the different components of the solar tree as well as its design. The many commercial designs, as well as the solar tree's uses, are also covered. The development and implementation of solar tree technology can be a big leap in adopting alternative sources of energy, considering that the same would be a lucrative investment after a short span of 26 months of initialization. Further research and development can pave way for nanowire cells that can significantly improve the theoretical efficiency of the system.

Keywords. Solar Tree, ergonomic approach, nanowire technology, organic cells

1. Introduction

With traditional fossil fuels rapidly depleting, global warming, climate shift, and ever-increasing energy needs, the search for sustainable and green energy sources has become one of our time's most serious challenges [1]. Solar energy is composed of the sun's light and heat and is used through a variety of current energy sources including solar heat, photovoltaic, solar fuel, artificial photosynthesis, solar thermal energy, solar structure, and so on [2][3][4][5][6]. Photovoltaic (PV) power is the most prevalent application of solar energy [7][8][9][10]. The amount of solar radiation and the local environmental variables determine PV production. For proper evolution of solar energy conversion systems, evaluation and estimation of solar radiation is distinctly important.[6,11]. The incidence angle of the sun's beams changes from day to day and year to year. As a result, solar panels installed at particular angles may be underutilized. Hence, we need to find an optimum solution for the given problem statement.

2. Solar Tree

A solar tree, also known as a solar photovoltaic tree, is a solar construction that resembles a tree. They can be erected in a variety of sizes ranging from small to enormous, such as bonsai trees and wind turbines. This relatively recent concept was developed in an effort to make use of emerging technology connected to the generation and utilization of solar energy. PV technology in the form of solar trees is a fantastic alternative to typical flat or roof installs for personal usage [12]. Solar panels must be placed in such a manner that the Sun's rays are focused on its surface to collect the greatest electricity from it. This may be performed by following the Sun indefinitely by deploying tracking systems with massive moving components, but on the other hand, have considerable limitations related to structural instability problems, especially at high wind speeds, lower system life, and greater maintenance costs [13]. To attain the maximum yearly average sun irradiation, solar panels with a stable orientation or minimum seasonal modifications are recommended.

2.1. Components of Solar Tree

From the aspect of this paper, it is important to understand different parts of solar system which help in generating electricity, while capturing solar light. Voltage regulator and Inverter are the components which help in transferring the energy stored in batteries by regulating the flow of energy between system and loads.

2.2. Methodology

We have expressed our belief in this paper that the Solar Tree may be utilized for commercial electrification, which is a huge step toward reducing electricity prices and dependency on grid power, which is presently unstable in India. It assists in the contraction of global warming since it contributes as a clean source of energy. Estimating the load: We are trying to design a solar tree which can be used for commercial purposes. Hence the total load (power requirement) is approximately equal to 20 (or 5x4) KWh/Day. We have decided to divide the tree into 4 segments based on which the calculations have been done for single segments. System Voltage Selection: The amount of voltage is chosen based on the system's demand. The system voltage is set to 48 Vdc because the total AC demand is around 5kW. Estimating PV Array Size: Inverter/controller and battery bank have been assumed to run at 85% efficiency, while wire loss is estimated to be at 3%. Now calculating the energy that will be required from PV module

$$= 1/(\eta_{\text{battery}} * \eta_{\text{controller}} * \eta_{\text{wiring}}) = 1/(0.85 * .085 * 0.97) = 1.41 \approx 1.40 \quad (1)$$

Hence energy required from Module (PV array)

$P_{array} = 1.4 * E_L$ (Where E_L = Average daily energy consumption in Wh /day.)

Therefore,

$$P_{array} = 1.4 * 5000 \text{ Wh} = 7000 \text{ Wh} \quad (2)$$

Because solar modules are rated at 1000 W/m2, For Indian locations, data was taken from the MNRE website. When a module is mounted horizontally, average daily solar hours are 5.5, and six hours when the module is mounted at an angle of latitude (16.76) or at an angle with winter and summer correction as mentioned in Table 1 and Table 2.

Table 1. Monthly Average of Insolation Incident on a Horizontal Surface (kWh/m2/day)

Lat 16.765	**January**	**February**	**March**	**April**	**May**	**June**
22-year Average	5.29	5.92	6.54	6.63	6.35	4.26
Lat 16.765	**July**	**August**	**September**	**October**	**November**	**December**
22-year Average	3.66	3.79	4.65	4.92	5.07	4.93

Table 2. Daylight Hours (Monthly Averaged)

Lat 16.765	**January**	**February**	**March**	**April**	**May**	**June**
22-year Average	11.2	11.6	12.0	12.5	12.9	13.1
Lat 16.765	**July**	**August**	**September**	**October**	**November**	**December**
22-year Average	13.0	12.6	12.2	11.7	11.3	11.1

For our system peak rating for module will be

$$W_{peak} = P_{array} / \text{Daily sun hours (Averaged)} = 7000/6 = 1166.66\ W_P \quad (3)$$

Total Array Current: The division of peak watt rating by system voltage V_{dc} gives total module current I_{dc} i.e.

$$I_{dc} = W_{peak} / V_{dc} = 1166.6 / 48 = 24.3\ A \quad (4)$$

Blue Bird Solar India has produced solar modules that we have chosen. The following are the features of the MONOCRYSTALLINE Micro series:

Peak Power P_{max} (W_P) : 270 W
Maximum current I_{mpp} (A) : 9.68 A
Maximum voltage V_{mpp} (V) : 27.90 V
Short circuit current I_{SC} (A) : 10.22 A
Open circuit voltage (V_{oc}) : 36.80 V
Module Efficiency (%) : 20.20

Array Size: It is defined as the no of modules that are connected in parallel N_{pm}

$$N_{pm} = I_{dc} / I_{mpp} = 24.3/9.68 = 2.5 \quad (5)$$

Approximately 3 modules will be connected in parallel.
Modules that will be connected in series N_{sms}

$$N_{sm} = \text{Nominal system voltage } (V_{dc}) / V_{mpp} = 48/ 27.90 = 1.72 \quad (6)$$

We have to round off calculated value hence 2 modules will be connected in series
Total Arrays = 3 * 2 = 6

Size of battery: DC load requirement (Total)

$$= P_{array} / \text{System Voltage} = 7000/ 48 = 145.83\ Ah \quad (7)$$

Considering battery autonomy for 2 days

= 145.83 * 2 = 291.66 Ah (8)

Taking into account the depth of discharge (DOD) and battery efficiency of 80 %.

Battery Capacity = 291.66 / (0.8x0.8) = 456 Ah (9)

To meet the needed system voltage and energy consumption, two 240 Ah batteries with a 48 V DC rating are connected in parallel. Despite the fact that higher battery ratings result in higher costs, we can still construct a reliable system.

Size of Inverter: The size of the inverter should generally be 20-25% bigger than total power required (W) for appliances.

Inverter Size = 7000 W * 1.25 = 8750W = 8.7 kW (10)

Hence inverters should bear the capacity equal to 8.7 kW or 8.7 kVA.

Charge Controller Capacity: To calculate size of charge controller, we need to make sure that it can withstand the product of the factor of safety (F_{safe}) and total short circuit current of the array ($I_{SC}(A)$). The safe factor is essential to allow for acceptable system expansion. As a result, the intended charge controller current (I_{cc}) is calculated.

$I_{cc} = N_{pm} * F_{safe} * I_{sc}(M)$ (Where, $I_{sc}(M)$ = short circuit current of selected module)

$I_{cc} = 3 * 10.22 * 1.3 = 39.8 A \approx 40 A$
(11)

Sizing of system wires: Choosing the right size and kind of cables is imperative for connecting the various components of a PV power system. The necessary cable connections must be chosen with care in the PV system

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

$I_{oi} = P_{total} / (p.f. * (V_{oi}) = 8750 / (0.8 * 230) = 47.5 A$ (12)

4 Sq.mm. wires (cable) will be used for 47.5 Amp current rating

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

$I_{rated} = I_{sc} * F_{safe} * N_{pm} = 3 * 10.22 * 1.3 \approx 40 A$ (13)
We chose 5 sq.mm wire because of its regular range and current carrying capacity for copper conducting wire (cable).
The results obtained are mentioned in Table 3.

Table3. Estimating size of proposed Solar Tree System

Component	**Description of component**	**Capacity for one side**	**Capacity for entire solar tree**
Load Estimation Total	Estimated Load	5 kWh/day	20kWh/day
PV Array	Load of PV array	.883 kW	.883kW
	Series Modules	2	2(*4)
	Parallel Modules	3	3
	Total Modules	6	24
Battery Bank	Capacity of Battery	455 Ah	455(*4)
	Series Battery	0	0
	Parallel Battery	2	8
	Batteries required	2	8
Voltage Regulator/ Charge Controller	Capacity of voltage regulator/charge controller	40 A	40 (*4)
	Voltage Regulators required	1	4
Inverter	Inverter Capacity	8.7 kVA	8.7kVA (*4)
Wires	The alternating current cable that connects the inverter to the residence's distribution board (DB)	4 sq.mm	4 sq.mm
	The direct current cable that connects the battery system to the Photovoltaic array via the charge controller	5 Sq.mm	5 sq.mm

3. Design of Solar Tree

A prototype of the proposed tree system can be built to test its utility and feasibility. The PV module is supported by a suitable support base and mounted on a single tall mast (trunk). The solar panels are organized in a "phyllotaxy" design. The two handles are M.S. pipes with a diameter of 3 inches and a height of about 6 feet. The trunk is divided into two sections, allowing the solar tree to rotate and be always sun facing. The lower segment remains fixed, while the upper segment, to which panels are attached, may rotate. At the end of the lower stem (pipe), nut is welded, and a screw that may spin in that nut is fused at the bottom of the higher stem. This arrangement is superior to the pivot bearing arrangement because it rotates as needed [14]. The PV panels are supported by the four arms of the rolled tube which are welded to the upper half of the stem. The solar panel is attached to the brace on the wooden arm. Figure 1*a,* 1*b* describes top and the side.

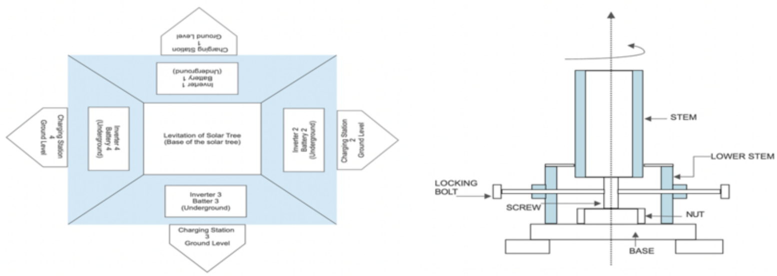

Figure 1*a.* Top View **Figure 1*b.*** Side View

Figure 1. Structure and Design of Solar Tree

3.1. Cost Analysis

The overall costs of different components are mentioned in Table 4.

Table 4. Overall Costs involved

Component	Model	Qty	Unit Cost (Rs)	Cost per Component
Module used	BBS24MF270	24	14,600	3,50,400
Batteries used	Exide 6LMS200	8	19,600	1,56,800
Voltage Regulator	12-24-48V/40A Make Su-Kam	4	12,000	48,000
Inverter	Fusion (NXI 310) 11 kw on grid solar inverter	4	90,000	3,60,000
Fabrication cost for solar tree (Metal bar(rectangular), wires, circuit breaker, Metal bar(circular), Nut bolts, Rubber bush, fuses, Metal strips, Plastic box)				3,00,000
Total Cost (Co)				12,14,800

3.2. Payback Period Analysis

The payback period is measured as the period it takes for an asset's net cash outflow to repay the money invested in it.

For our case we have taken the example of OLA S1 Pro, it is one of the best electric scooters out there in the market. The Ola S1 Pro requires approximately 3.97KWh of electricity to get fully-charged, which means 3.97 units of electricity give us an ARAI certified range of 181 kms.

Total Kms that can be driven solely with help of our designed solar tree

= (Total Electricity Produced/ Electricity Consumed) * Range of scooter

$$= (20000/3970) * 181 = 911 \text{ km per day} \quad (14)$$

Now we will compare our model with the daily used gasoline powered vehicles. For our case we have assumed Activa 6G, the most popular 2-wheeler available in Market.

Now to drive 911 (which is the range our electric scooter is giving with help of our solar tree) gasoline two-wheeler will require

=911/52 (Mileage of Activa) = 17.5 litres of fuel

Price for which will be (Pe) = 17.5*100(Avg. price of Gasoline) = Rs 1750 (15)

3.2.1. Calculating Payback Period

It is important to take into consideration the maintenance of Solar Trees. We have taken that figure to be 5,000 monthly and defined it as maintenance charges (Mc)

$$Pe * 365 * Py = Co + (Py * 12 * 5000) = Co + (Py * 60{,}000)$$

$$Py\,(Pe * 365 - 60{,}000) = Co$$

$$Py = Co/(1750 * 365 - 60{,}000) = 12{,}14{,}800/5{,}78{,}750 = Py = 2.09 \quad (16)$$

Payback time for our Solar Tree = 2.09 Years

4. Conclusion

The extraction of energy using a solar power tree is a relatively unconventional approach. We can get the same output as that of a solar farm from numerous solar trees while at the same time using only 1% of the land area. The development of the solar power tree is done keeping in mind the energy needs of the new developing electric vehicle market.

It is observed that a solar power tree can power at least 5 electric scooters daily from 0-100 percent which can further run up to 900 kms. Charging electric scooters with help of solar energy will reduce the impact of pollution which were caused by the usage of fuel or coal. The depletion of coal and other fossil fuels required for electricity production can also be tackled using this technology. We designed the solar tree and calculated its payback period which came out to be 2.1 years, which means that it requires high initial cost but post that we can be profitable just after 26 months of starting. Solar trees can be further modified to generate electricity for different purposes and can be restructured and redesigned.

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