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Quantum solar tree- design and production for domestic applications and future trends

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Abstract
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.

Keywords: PV system, Solar Tree, phyllotaxy pattern, PV system, Solar panel, system sizes, manual tracking

Introduction
Solar Tree or Solar Photovoltaic Trees are a solar structure that looks like trees. They can be framed from small scale like a bonsai tree to large scale like the size of the wind turbine. It is a solar artwork which is a combination of artistic and technological effort. This is relatively new concept is conceived in an attempt to use new technology relating to harvesting and use of solar energy.

In solar trees, PV panels or cells are arranged in a Fibonacci series pattern instead of leaves. The solar tree produces more power than a conventional flat arrangement of solar cells. It requires only 1% land as compared to the conventional flat arrangement [4]. 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. Some residential solar systems are designed to track the sun but these systems increase the cost of solar energy because they are expensive and require maintenance. These solar trees have been designed to provide different means of power to different urban and built environments. These ranges from powering 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. Hence presently PV systems prove to be suited mainly for urban & corporate use. Still, there is less response for use of PV system for domestic applications due to higher initial cost and area required for mounting such systems.

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 [1]. 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.

Fig 1: Conventional flat mountings solar PV system.

Different arraangeemnts of solar trees

The concept of solar tree or arrangement of PV cell in a Fibonacci series has been stated by many researchers in their work. Such combination of the solar cell can be done on trees like coconut, palm or other natural trees to reduce the cost of mounting [1]. To increase the collection efficiency, the nanowire cell can be utilized instead of present PV cells. The Nanowire cells can collect 15 times more solar energy as compared to conventional cells [2]. The concept of nano leaf is an idea to maximize the various forms of energies such as solar, thermal and piezoelectric power by stalks, branches, and twigs of a tree [3].

Fig 2: Artistic design of Solar Tree.

Fig 3: Typical Solar Tree.

Generation of 2MW power from PV module system requires the land of 10 Acres approximately for housing the panels only. In India there is scaricity of land in urban and even in rural areas. Solar power Tree a tall pole-like structure would take only 1% of land area in comparison to general PV housing [4]. With due adjustment of load over the pillar or pole, solar panels can be fixed throughout the tall pole following a pattern of spiraling phyllotaxy pattern as found in a natural tree. To get the maximum sun in a day time the top panel should not obstruct the bottom panels. The each panel will be hanging through their connecting stem system attached to the main trunk (Pole) and can rotate following the sun's path throughout a day. It can also be locked at any position to withstand the wind pressure due to heavy storm affecting over the main pole/ trunk. The panels will be naturally facing towards the sun at an angle as required so that they can collect maximum solar energy in a daytime. The system can be mounted at the roadsides, the islands in between wide roads / highways, on the boundary walls of paddy lands etc.

Fig 4: Mounting of Solar Tree near the house

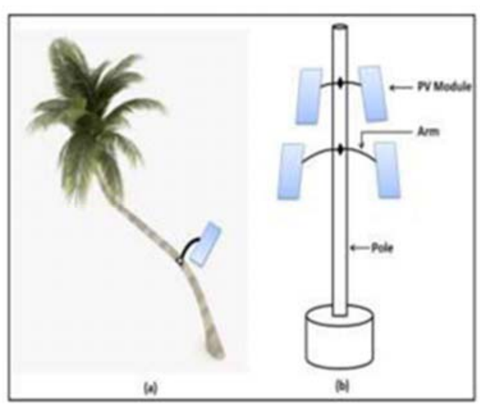

Fig 5: Mounting of PV panels to natural trees & simple pole structure.

The Tree structure can be easily constructed on the terrace or anywhere near the house of an individual. Maintenance and dust cleaning is also not a big issue. In order to accept the solar tree concept as the strong solution for urban and rural electrification, public perception about this technology is very essential [5]. The People who will be using this technology, their idea, opinions can give better insight into applications of the solar tree for street lighting and other applications. By conducting surveys and exhibitions of different models of Solar Trees presented by many researchers can make a good platform for the progress of this technology.

Working of solar tree

It is difficult to store electrical energy is 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 a 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.

Methodology

In this work, we have presented our thought that Solar Tree concept for domestic electrification is big step to reduce electricity bills and dependence on grid power which is unreliable nowadays in India. It also provides clean energy source to reduce the global warming. Energy demand (load) of the small family is considered and taken for determining the capacity of proposed system and system component sizes.

Load estimation

The average load profiles are considered depending on daily usage duration in a day. Following electrical appliances are for total load estimation.

Table 1: Daily energy demand of small house.

Appliances	Rated Power(W)	Qty	Hrs/day	KW	KWh/day
Lightning bulbs	7	4	5	0.028	0.14
	20	2	4	0.04	0.16
	6	2	4	0.012	0.048
T.V	40	1	4	0.04	0.16
Fans	60	2	4	0.12	0.48
Computer	80	1	3	0.08	0.24
Refrigerator	100	1	5	0.1	0.5
Total				0.42	1.728

Hence Total load or power requirement is approx. equal to 1.75kWh/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 Vdc [7].

Determination of PV Array Size

Peak Watt Power

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

= 1/ (ŋ battery x ŋ charge controller x ŋ wiring) ….. (1)

= 1/ (0.85x0.85x 0.97)

= 1.42

≈ 1.40 approximately.

Hence energy needed from Module (PV array)

Parray = ELx1.4…………. (2)

Where EL = Estimated average daily energy consumption in Wh /day.

Hence

P array = 1750 Whx1.4

= 2450 Wh.

= 2500 Wh approximately.

Since solar module are characterized for 1000 W/m^2. We used monthly average daily solar insolation data from MNRE website for Indian location. At Kolhapur, (Maharashtra) considering average daily sun hours equal to 5.5 when a module is mounted horizontally and six hours for an angle of latitude (16.76^0) or at an angle with summer and winter correction.

Table 2: Monthly Averaged Insolation Incident on a Horizontal Surface (kWh/m^2/day)

Lat 16.765	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
22-year Average	5.29	5.92	6.54	6.63	6.35	4.26	3.66	3.79	4.65	4.92	5.07	4.93

Table 3: Monthly Averaged Daylight Hours (hours)

Lat 16.765	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
22-year Avg.	11.2	11.6	12.0	12.5	12.9	13.1	13.0	12.6	12.2	11.7	11.3	11.1

The peak watt rating of module for our system will be

W peak = 2500/6 = 415 WP

Total Array Current

The Total module current Idc is calculated by dividing above peak watt rating by system voltage Vdc i.e.

Idc = Wpeak / Vdc ……………. (3)
= 415/ 24
17.29 A.

We have selected solar modules manufactured by Vikram Solar India. The specifications of ELDORA Micro series is as follows.

Peak Power Pmax (WP)	:	50 W
Maximum voltage Vmpp (V)	:	17.89 V
Maximum current Impp (A)	:	2.8 A
Open circuit voltage Voc	:	21. 77 V
Short circuit current Isc	:	3.04 A
Module Efficiency (%)	:	12.35.

Array Size
The number of modules in parallel Nmp
Nmp = Idc / Impp…………… (4)
= 17.29/ 2.8
= 6.175
Approximately 6 modules will be in parallel
The number of modules to be connected in series Nms
Nms = Nominal system voltage (Vdc) /Vmpp….. (5)
= 24/ 17.89
= 1.34
Rounding above calculated value, the total number of modules in series = 2. Total array size = 6 x 2 = 12.

Battery bank Size
The total DC load requirement = Parray /System Voltage… (6)
= 2500/ 24
= 104.16 Ah
Considering battery autonomy for two days total requirement = 104.16 x 2 = 208.32 Ah
Considering battery efficiency and depth of discharge (DOD) equal to 80 %. Battery Capacity = 208.32/ (0.8x0.8) =325 Ah.
We can select one battery of 180 Ah and other of 150 Ah to meet our requirement. But current handling capacities of both batteries are different, which causes an adverse effect on the life of low rating battery. Hence selecting two 180 Ah batteries of 24 V DC rating with the parallel connection to get required system voltage and energy demand. Though high ratings of batteries lead to increase in cost, we can build a reliable system. Following are the recommended battery specifications. Model-SU-KAMHPT180

Inverter Size
The inverter size should generally 25-30 % bigger than total power requirement (W) of appliances. Size of inverter = 2500 W x1.25
= 3125 W
= 3.125 kW.
Hence the size of inverter equal to 3.125 kW or 3.125 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 (IscA= IscM X Npm) and a certain safe factor (Fsafe). The safe factor is necessary in order to allow for a reasonable system expansion. Thus, the desired charge controller current (Icc) is as given by equation (7).
Icc = IscM X Npm X Fsafe ………… (8)
Where, IscM = the short circuit current of the selected module.
Icc = 3.04 X 6.08 X 1.3
= 24.02 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:
1. The dc cable from the PV array to the battery bank through the charge controller. I rated = Nmp X Isc X Fsafe……… (9)
= 3.04 x 6.08 x 1.3
≈ 24 A.
Referring standard wire gauge and its current carrying capacity for copper conductor wire we used 4 sq.mm wire (cable).

2. The AC cable from the inverter to the distribution board (DB) of the residence. Current Produced by Inverter Output is-
Ioi = P total / (Voi X p.f.)………….. (10)
= 3125/ (230 X 0.8)
= 17 A.

For 17 Amp current rating, we used 2.5 Sq.mm. wires (cable)

Results Obtained from the Sizing of the proposed Solar Tree System

Table 4: Estimated sizing of the proposed Solar Tree System

Component	Description of component	Capacity
Load Estimation	Total Estimated Load	1.75kWh/day.
	Capacity of PV array	4.15kW
PV Array	Number of modules in series	2
	Number of modules in parallels	6
	Total number of modules	12
Battery Bank	Battery bank capacity	325Ah
	Number of batteries in series	0
	Number of batteries in parallel	2
	Total number of batteries required	2
Charge Controller/ Voltage Regulator	Capacity of voltage regulator/charge controller	24A
	Number of voltage regulators required	1
Inverter	Capacity of the inverter	3.125 kVA
Wires	The dc cable from the PV array to the battery bank through the Charge controller.	4 Sq.mm.
	The AC cable from the inverter to the distribution board (DB) of the residence.	2.5 Sq.mm.

Fabrication of Solar Tree (Prototype)
A prototype of proposed system is fabricated to test the feasibility of Solar Tree system. Solar PV Panels are mounted on a single tall pole (stem) with the help of suitable supporting base. The arrangement of solar panels maintains a 'Phyllotaxy' pattern. Two stems is fabricated from M.S. pipe of 3"diameter and about 6 feet in height. The stem is made in two parts to facilitate rotation of solar Tree for tracking the sun. The lower part is fixed and the upper part has the provision of rotation on which panels are mounted. At the bottom of lower stem (pipe) a nut is welded and at the lower part of upper stem, screw is welded, which can rotate in that nut. This arrangement is better than pivot bearing assembly because it rotates as per requirement [4]. The bearing assembly rotates more freely which is not desirable and difficult to stop or control the rotations when there is high wind flow. The upper stem part locked by tightening the locking bolts. Structural support for panels cross base is used so that the structure is balanced and bear the load acting on it. To support the PV panels four arms of round bent up pipe are welded to upper part of the stem. Solar panels are mounted on angle brackets on these arms of the tree. Angle joints is adjustable and are made up of stainless steel and can be adjusted with the help of Allen key. With this system, solar panels can be inclined to latitude or any other required angle (winter and summer correction) manually to get maximum sun radiations. Refer fig 6. (a) and fig 6. (b).

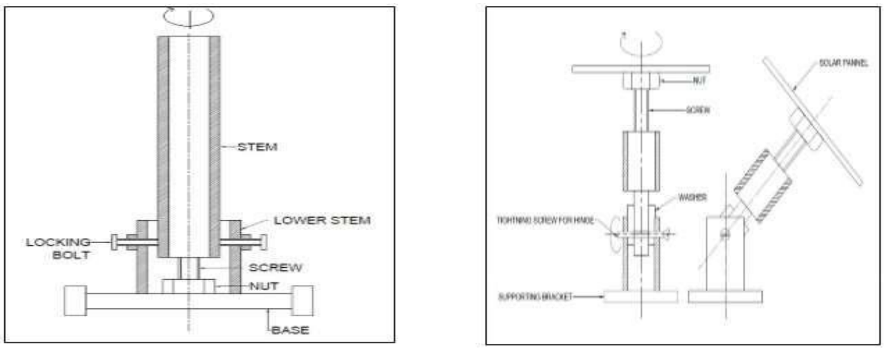

Fig 6 (a): Manual Tracking arrangement of Solar Tree **(b)** Mounting of solar panel on bent arms at required inclination for maximum output (Two axes)

Fig 7: Prototype of Solar Tree

Cost Estimate of System
The cost estimate of the systems components is summarized in Table 3.

Component	Model	Qty	Unit cost (Rs.)	Cost Per component (Rs.)
Modules	Vikram Solar ELDORA Micro series	12	2500/- per module	30000/-
Batteries	SU-KAMHPT180	2	10000/-	20000/-
Voltage Regulator	Su-kam 12V/24V 30A Solar Charge Controller Su-kam Make Voltage(V) : 12V-24V Current(A) : 30A	1	2000 /-	2000 /-
Inverter	Custom Built 2 KW 24VDC TO 220/230VAC Pure Sine Wave Power	1	5500 /-	5500 /-
Fabrication cost of solar tree Metal bar (circular), Metal bar(rectangular),. Metal strips, Nut bolts, Rubber bush. Plastic box, wires, fuses, circuit breaker etc.				2500/-

Payback Period

The payback period of proposed system is calculated by dividing the overall cost of the system to average yearly electricity bill of average Indian family which is Rs.450 /- per month. Neglecting maintenance cost.

$$\text{Payback Period} = \frac{\text{Overall cost of system}}{\text{Average yearly Electricity Bill}}$$

$$\text{Payback Period} = \frac{60000}{5500} = 10$$

Conclusion

The solar tree concept is very successful to fulfill the increasing energy demand of the people, saving of land, and should be implemented in India to provide electricity without the problem of power cut-off and reduce the dependence on grid power. Daily average energy requirement of the small Indian family is calculated about 3.5kW. Such systems can be mounted on the terrace, in front of the house or near the wall avoiding shading areas. The initial investment cost of the solar tree is also equal to same capacity PV systems as other system components are similar.

The overall cost of the domestic solar tree can be reduced by using the available local material. To reduce cost the design of tree structure should be simple and innovative. The performance (MPP) of solar tree better than conventional rooftop mountings as manual or low-cost auto tracking system can be easily incorporated. The initial investment cost is the major concern in PV system. The payback period of proposed system seems to be high but due to continuous increase in the cost of grid power and reduction in the cost of PV cell due to technological advancement long payback period can be compensated.

The same design procedure can be extended to other locations and applications involving higher energy consumptions. Government aid and financial support for PV system equipment installation are highly recommended. Collaborative research work amongst Chemists, Physicists and Engineers will resolve the problem. At the last Solar Tree shall not harm ecology and should work harmony with natural trees.

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