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Solar PV tree design: A review

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ABSTRACT

Sunlight is often deemed as the only abundant and truly "free" energy resource. Among all the different techniques available to harness solar energy, the most popular and mature technology is the photovoltaic conversion of sunlight into electricity. Despite its merits, solar PV technology has issues with the land requirement (especially in urban areas), capture efficiency and public perception (due to the absence of pleasing aesthetics). The concept of a solar tree is capable of addressing these problems effectively with elegance. In this paper an attempt is made to review the components of the solar tree and its design. The various commercial designs are also discussed along with applications of the solar tree. The paper also addresses the challenges involved with this technology and suggests future research direction.

1. Introduction

The quest for green and sustainable energy sources has become one of the biggest challenges for our time, due to the swift exhaustion of conventional fossil fuels, climate change, global warming and forever growing energy demand [1]. Solar energy consists of light and heat from the Sun, it is harnessed using various progressing technologies such as solar heating, solar photovoltaic, solar thermal electricity, solar fuels, solar architecture and artificial photosynthesis [2–6]. The most popular application of solar energy is through the photovoltaic (PV) systems [7–10]. Solar PV performance is dependent on the local climatic conditions and availability of solar radiation. Solar radiation assessment and estimation is very much helpful for proper design of solar energy conversion systems [11,12]. The angle of incidence of Sun rays fluctuates throughout the day and over the year. Therefore, solar modules fixed at a particular angle may not be fully optimized. The installation of solar PV modules has the burden of land requirement which will always be a premium commodity, especially in land restricted urban areas. Rooftop solar PV is an attractive option, but it too has limited space for modules to be arranged in an array. Sun tracking PV systems can be designed but they significantly raise the total cost of energy generation as they are costly and require maintenance. A new and promising way to integrate solar PV into the constructed environment is through Building Integrated Photovoltaic systems [13–17]. However more novel structures balancing efficiency, land requirement and general public acceptability might be required. Solar PV trees can be one such innovative concept.

In this review article, the concept of solar tree technique is explained through its design parameters, required components and a review of currently installed models of the solar tree. A detailed comparison with traditional PV system is done to explain the importance of this novel technique. The challenges involved in this technique are considered and suggestions are proposed to overcome them. Finally recent developments of the solar tree are discussed.

2. Concept of solar PV tree

The concept of a "Solar PV Tree" is a unique blend of art and technology to form a solar PV sculpture [18]. This novel idea was considered as an attempt to use the new technology of solar power and artistic aesthetics. A solar tree is basically a decorative means of producing renewable electricity. It has a tree like an edifice and panels are arranged as leaves on the branches of the energy tree. It's just like a natural tree but with solar panels instead of leaves. "TREE stands for T = Tree generating R = Renewable E = Energy and E = Electricity" [19]. Solar tree embodies a steel structure, on top of which solar panels collect Sun's radiant energy to charge mobile phones, laptops and small electronic gadgets [20]. It can also be used for charging street lights [21]. Since panels are arranged at different angles, a solar PV tree is able to capture incident Sunlight throughout the day irrespective of the position of the Sun. The three-dimensional structure of solar tree can enhance the total surface area for Sunlight capture [53].

The objectives of a solar tree concept are

a) To raise awareness among citizens about renewable and sustainable energy.

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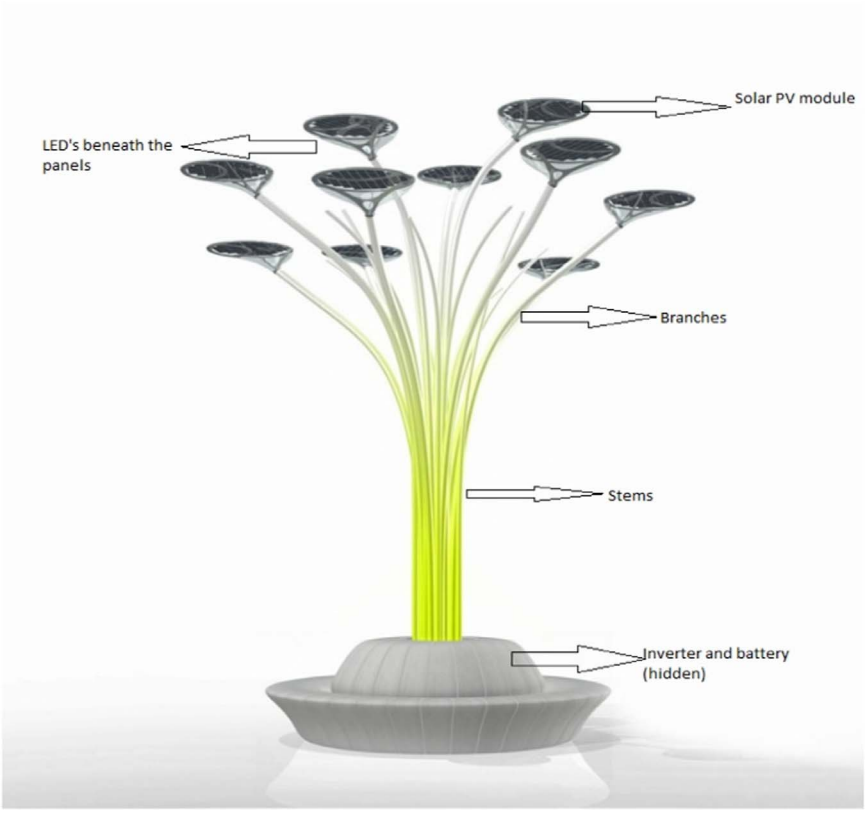

Fig. 1. Common layout of a solar tree [24].

b) To improve the public perception of solar photovoltaic technology by making it aesthetically pleasing.
c) To enhance the efficiency of solar PV systems using a three-dimensional structure replicating a natural tree.
d) To reduce the land required to harness solar energy.

The components and general layout of a solar tree are shown in Fig. 1.

2.1. Basic components of a solar tree

- **Photo voltaic modules:** Solar cells made from silicon have recorded maximum efficiency for domestic and commercial use, it is estimated that 80% of total solar panels sold worldwide are made from silicon [22]. The first generation of solar cell technology included monocrystalline and polycrystalline solar cells, while second comprised of amorphous silicon and thin film technologies. The third generation introduces some new and exciting solar PV module technologies like Copper zinc tin sulfide solar cell (CZTS), Dye-sensitized solar cell, Organic solar cell, Polymer solar cell, Quantum dot solar cell etc. [23]. Despite the development of newer technologies, silicon continues to be the most widely used solar cell technology.
- **Cables for connecting modules:** Photovoltaic modules are subjected to atmospheric conditions like precipitation, snow accumulation, solar irradiations and high temperature. To have secure connections between the modules there exists a need for cables with excellent mechanical strength for use in conditions with high mechanical tension, in dry and wet conditions, higher temperature conditions and high solar insolation, also in buildings with a high risk of explosion and fire [3].
- **Inverter:** The purpose of an inverter is to convert the DC voltage produced by solar panels into AC voltage of grid frequency. Conversion efficiency is the most important characteristic of an inverter. Modern devices can be operated with an efficiency of around 98% [13]. The other important tasks of the inverter are power optimization i.e. maximum power point tracking (MPPT), monitoring the energy yield of the PV plant and securing the plant in an event of faults by disconnecting it from the grid. In a solar tree every panel receives a different irradiance, as a result it will have a different I-V and P-V curves, and hence the voltage set by the inverter will result in severe losses in conversion. To avoid this issue a battery can be used for energy storage and for supplying constant power to the inverter.
- **Batteries:** The batteries used in solar photovoltaic systems must adhere to demands of “unstable grid energy, heavy cycling (charging and discharging) and irregular full recharging” [5]. Deep-cycle batteries have been used in renewable and sustainable energy applications throughout the world for decades. Some of the popularly used batteries in solar PV system applications are “lead acid batteries, lithium ion batteries, lithium ion polymer batteries, nickel cadmium batteries” etc. [5].
- **Steel structure:** There is no standard structure for the solar tree, it can be creatively designed in order to make it look pleasing to the public eye and consume less area while avoiding shading effect on leaves/panels. One such novel design is of Ross Lovegrove's Solar Tree (Fig. 2). Ross Lovegrove’s design consisted of a sinuous tree constructed of steel pipes, measuring 5.5 m, supporting a light bubble in which 38 solar PV panels, each with 38 watt-peak rating, are connected to a hidden 12 V battery system which lit an assortment of 1 W LEDs at the tip [24].

- **Charging points/ LED's:** Solar tree panels charge batteries during the day time and a simple mechanism can automatically switch on its LED’s at night time. An internal control circuit regulates the amount of light produced. A photo sensor is employed to monitor and record the amount of light in ambiance and trigger the LED’s to ON state at Sunset and consequently to OFF state at Sunrise [25]. The charge stored in the batteries can also be used for charging mobile phones, laptops and electric vehicles.