PERFORMANCE ANALYSIS OF SOLAR TREE

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ABSTRACT

Increased demand for conventional energy like coal, natural gas, and oil, forcing researchers to develop renewable or non-conventional energy resources. Renewable energy sources such as fuel cells, wind and solar have received considerable attention because of the ever-increasing demand and electricity expectations. The most prominent and mature technology, including various technologies for harnessing solar energy, is the photovoltaic conversion from sunlight to electricity. Among all the available methods, direct conversion of sunlight into electricity through photovoltaic (PV) phenomenon is the most mature and popular process. Progress of PV technology in market is perspicuous; however, it has still some drawbacks such as notable land requirement in cities, energy conversion efficiencies that already reached the theoretical limits and social acceptance issues due to aesthetic details. To overcome the aforesaid challenges, solar PV tree concept has been recently developed, and the simplicity, compact structure and elegance of this novel technology have been in the focus of researchers. This paper reviews the components, advantages, applications and performance of solar tree. This paper also examines some challenges of solar tree systems.

Keywords: Solar tree, Photovoltaics, Applications, Performance, Challenges

I. INTRODUCTION

There is a steady growth in demand for energy, which necessitates the upgrading of both renewable and nonrenewable technologies. The shift in technology toward renewable energy sources is a sign that the demand for and importance of this type of energy is increasing. Solar energy's supremacy in the renewable energy sector is due in large part to its efficiency and ease of use. For a sustainable and eco-friendly future, the government encourages everyone to develop the best and most efficient solutions. The sun's rays and heat were the primary sources of solar energy. Solar heating, solar photovoltaic, solar thermal, solar fuel, and artificial photosynthesis are all examples of modern technologies that utilise solar energy. The most frequent way solar energy is used is through photovoltaic (PV) panels. As a result of the PV panels, solar energy may be harvested. It is possible to generate electricity from solar irradiance if the PV panels are positioned in direct sunlight. Solar panels must be oriented in such a way that the sun's rays are concentrated on their surface in order to collect the maximum amount of electricity from the sun. It is important that the panels in the solar power generating system are placed at an angle to maximise the amount of sunlight they receive. To generate even more electricity, it needs a suitable building above the landing area in an open area to house the solar panels. A huge land surface area is needed to accommodate the panels on rooftop solar PV installations, therefore they are built. Even in metropolitan regions, solar PV technology has issues related to land requirements, capturing efficiency, and the public image (because of lack of congenial esthetics). These pricey and labor-intensive solar photovoltaic (PV) systems may track the sun and boost overall energy generating expenses by a significant margin. These challenges may be addressed with beauty and efficiency by using the solar tree concept (Dey and Pesala, 2020).

In the same manner that natural trees provide energy and power, solar trees do the same in a decorative fashion. The solar tree has branches and leaves made of linked solar panels. 'TREE' stands for Tree Generating Renewable Energy in the Solar Tree. "Energy" and "Electricity" are both E terms. With PV modules at the top in various forms and orientation angles, a solar tree is a natural tree-shaped metallic structure. In the context of renewable energy generation, solar trees may be described as a kind of art. PV modules are positioned like leaves on the branches of a typical SOLAR TREE as depicted in Figure 1. "TREE" stands for "tree-generating," "renewable," "energy," and "electricity" in addition to "energy."

Figure 1: Solar Tree
(Source: Dey and Pesala, 2020)

According to the Solar tree's design, when solar radiation levels fall below a particular threshold after sunset, the LED lights automatically turn on to conserve energy. When solar trees are planted in spirals, they may rotate to face the sun and produce the most energy possible. This approach is known as spiralling phyllataxy. The use of this technology allows even the smallest photovoltaic (PV) modules to create solar electricity. Solar trees may be designed in a variety of ways, depending on a number of different criteria. Using solar trees, for example, can assist to satisfy the country's energy demands while also lowering land use (Dey and Pesala, 2020).

The solar tree is supported on the ground by a vertical pole that supports the PV cells in a structure that resembles the branches and leaves of a real tree, making it a more efficient alternative to typical solar PV systems. It is possible to maximise solar power absorption by producing the greatest amount of solar surface on the least amount of land available for development. The solar tree has the potential to power anything from street lights to small electrical devices, cell phones, and PCs. There is nothing quite like the solar tree in terms of innovation, aesthetics, or an attempt to harness solar energy, to name a few characteristics. A three-dimensional structure of photovoltaic modules is used to enhance the overall solar energy capture surface and to convert solar energy into electricity more efficiently in low-light settings (Gangwar et al, 2019).

II. OBJECTIVES OF SOLAR TREE

The following are the primary goals of the solar tree concept:

- To reduce the amount of land or area needed for solar energy harvesting.
- To improve the public's impression of photovoltaic (PV) technology by making it visually appealing.
- A 3D structure that mimics a real tree can help enhance the overall efficiency of PV systems.
- To educate the public on the importance of renewable energy in promoting environmental sustainability.
- To transform every city into a smart, eco-friendly metropolis.
- As a means of providing power where the grid supply is unavailable or where individuals are unable to access it.
- To maximise the use of solar energy in order to meet the global public's need for power.

III. COMPONENTS OF SOLAR TREE

It's important to get the most out of the day's worth of sunshine using a solar PV tree. A solar tree has a basic structure and components as follows:

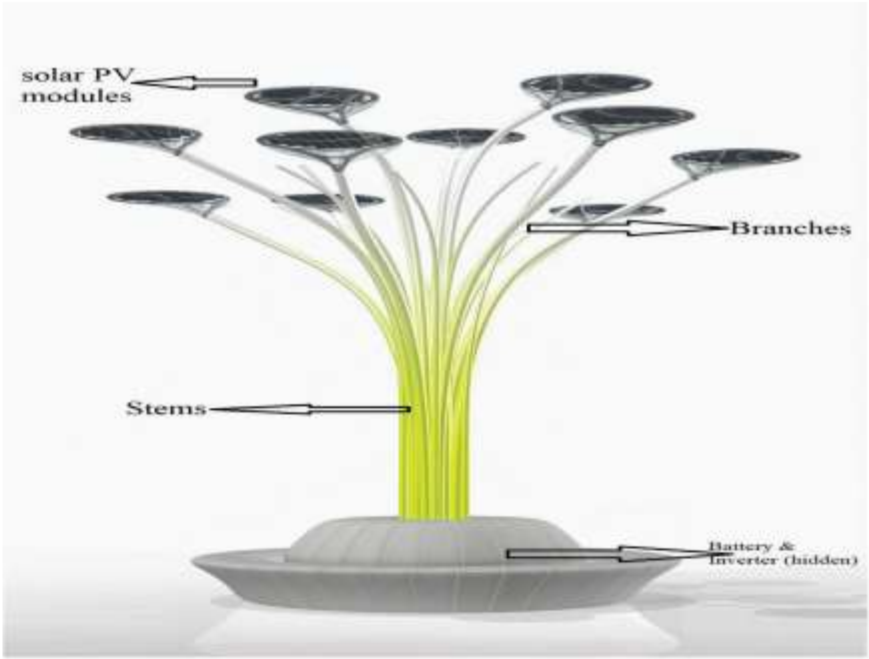

Figure 2: Primary Structure of a Solar Tree

(Source: Shukla et al, 2016)

Solar PV modules: The most widely used PV material, crystalline silicon (c-Si), was utilised to create the world's first viable solar cell in the early 1900s. It has been estimated that silicon is utilised in more than 95 percent of all photovoltaic cells produced across the world (Si). The usage of silicon solar cells in commercial and residential applications has been proved to provide the best potential efficiency. The development of solar cell technology has taken place in three stages: PV cells are classified into three generations: the first generation uses silicon wafers, which account for 85 percent of the market and includes single- or multi-crystalline solar cells; the second generation uses thin films of materials such as amorphous silicon, nanocrystalline silicon, copper indium selenide, and quantum dots; and the third generation uses copper zinc tin sulphide, organic, polymer, and dye-sensitive solar cells, as well as quantum dots (Sugatha et al, 2015).

Steel structure: Solar tree structures built of steel look amazing and take up less space, while also protecting the leaves and PV modules from the shadowing effects of other structures on their surroundings. One of Ross Lovegrove's most popular ideas for solar trees is seen in Figure 1. In order to keep the solar PV modules in place in the solar tree's stems and branches, a steel structure must be installed.

Cables: Cables will be required in order to connect the solar panels together. When it comes to mechanical and thermal needs, cables with high mechanical strength, as well as weather and UV resistance, are required to meet those expectations.

Inverter: Solar panels provide direct current voltage, which is then converted to alternating current by an inverter to power a home or business. The capacity to effectively convert and optimise power is the fundamental characteristic that distinguishes an inverter from other types of power converters. Each solar panel in the solar tree has a separate set of I–V and P–V characteristics, resulting in significant conversion losses for each panel (Shukla et al, 2016).

Batteries: Extra power may be stored in a variety of different types of batteries, each of which has its own characteristics. Batteries can help to solve the problem of PV intermittency by storing energy. Batteries of many sorts, including lead-acid, lithium-ion, nickel-cadmium, lithium-ion polymer, and others, are used in solar photovoltaic (PV) systems (Gurung et al. 2018).

IV. APPLICATIONS OF SOLAR TREE

According to Cuce et al (2022), the following are a few possible applications for solar tree systems:

Urban area:

In order to cover a household's daily electrical needs, less space is needed, which is a big help in metropolitan areas where land is scarce. This is backed by SPVT.

Remote islands and mountains:

To meet the needs of homes in remote and hilly sections of the country (off-grid locations). SPVTs can be deployed on aircraft and on muddy, steep terrain that is otherwise inaccessible to land-based SPV.

Rural area and agriculture:

Many rural and agricultural homes are still unable to meet their daily electrical needs since they are not linked to the main grid. Additionally, an SPVT can be used to power the farming tools, such as e-tractors and e-power tillers as well as water pumps and irrigation systems.

Resorts and golf courses:

To power the golf carts, fountains, small-sized lawn cutters, and other amenities. SPVT may also enhance the resort's overall aesthetic if it is well-designed.

Streetlights (highway and localities):

As a result of a lack of visibility for drivers, many accidents occur on the highways and in the surrounding areas. As a result, SPVT is the greatest alternative for preventing traffic accidents by illuminating the medians of roads and the surrounding areas with streetlights, unless the governments of different countries have to pay a large sum of money on grid power for the same.

Public parks and gardens:

Providing power in public parks and gardens to avoid the dangers of snakes, muddy surfaces, and other mishaps is a must. High-voltage power from the grid might cause avoidable deaths owing to inadequate maintenance of park light poles. SPVT, on the other hand, does not pose a significant risk.

Airports:

There is already a lot of area taken up by airports' running tracks, thus airports need electricity to power their running tracks. A SPVT uses less land to produce power.

Worship places:

Providing power at religious locations is important since many religious sites continue to be used well into the night in their devotion to God. Small parks are also available for visitors to enjoy in these locations. SPVT, on the other hand, is a viable choice for many locations throughout the world.

Vehicle's parking units:

The provision of energy for the lighting of parking spaces is another viable solution. Hybrid vehicles and security guards' flashlights may also be charged using this power.

Universities and institutions:

Campuses of colleges and universities: a large number of students from hostels remain active in the fields. As a green tree on campus, SPVT is the finest choice to power parking lots, an indoor games hall, an open auditorium, and other facilities.

Charging electric vehicles and gadgets:

SPVT's power may be used to charge electric or hybrid automobiles and electronic devices. A clean and green environment and transportation is encouraged as a result.

Information board:

Digital display boards and water coolers are powered by electricity in places like train stations, bus terminals, and shopping malls.

Sea shore and bank of the rivers:

To illuminate the sea beach and the banks of the rivers so that water, dirt, and aquatic species may be clearly seen.

Smart cities and localities:

Well-designed SPVT illuminates the surrounding environment and enhances the aesthetic appeal of the city as a whole as well as its neighbourhoods. In such a setting, everyone will have a good night's sleep.

V. PERFORMANCE ANALYSIS OF SOLAR TREES

A novel technique to catching sunlight is to use solar PV trees. The land footprint of the PV system is reduced thanks to the solar tree, which uses PV panels as leaves and is installed on a tree-like framework. Farming and solar electricity would be handled by the land simultaneously. Rural and urban places may equally benefit from new ideas. PV trees have more sunlight and generate 10% to 15% more electricity than flat PV panels since the panels are situated at a higher altitude. PV tree occupies around 1% of the land area compared to flat solar PV type (Maity 2013). The same amount of electricity can be generated with a solar tree on a 1-square-meter basement space, but a 100-square-meter basement area is needed for flat solar PV to provide the same amount of power. Temperature and irradiance affect the performance of solar PV trees in different regions.

One- and two-stage FPMs outperformed standard PV modules by 70 and 140 percent, respectively, according to Yuji and Yachi's (2010) computer simulations.

Bernardi et al (2012) showed that power generated in the same environment by 3DPV solar tree and the conventional module was 2.25Wh (2.27Wh in simulation) and 1.22Wh (1.01Wh in simulation), respectively.

Bosnia-solar Herzegovina's tree intends to encourage the adoption of energy efficiency and the use of renewable energy, as stated by Avdic et al (2013). The solar tree generated roughly 1943kWh/year of electricity, and the monthly required power on the solar tree was 77.3kWh/month and 927.6kWh/year, respectively. So, over the course of a year, 1015.4kWh of electricity might be sold.

A man's actions in the world decide whether or not "growth" will be seen positively or negatively by society as a whole. In addition to saving money and helping the environment, the solar tree is a practical and aesthetically pleasing solution that can be implemented in any location that receives ample amounts of free solar energy.

According to Dimitrokali et al (2015), the aesthetics of solar trees vary and are created to provide varied power sources for different urban and developed surroundings. Vehicles, buildings and streetlights are all included in this category (one or one PVTrees forest). In light of the biophilia idea, it may be projected that most people will benefit from visual (or aural) cues or the relationship itself. In urban locations, these solar tree constructions can offer a functional part of the environment and utilise natural elements to provide favourable subjective experiences that can influence health and well-being.

According to Srinivas (2016), solar tree has a 45.4 percent efficiency and 55.1 watt-hours of storage electricity. Using two 5 watt CFL bulbs for 2.5 hours or one 5 watt CFL bulb for 5 hours will keep a battery going for a long time. It's a good way to fulfil the world's energy needs and maximise the utilisation of a certain area. The solar tree saves space while increasing power production by a factor of ten or more.

To reduce the total cost of the household solar tree, Patil and Madiwal (2016) recommend using locally accessible materials. The design of a tree structure should be basic and imaginative in order to reduce expenditures. Payback time is expected to be 10 years for the Solar Tree's total cost of Rs.60000/-. Using solar trees to fulfil growing energy demand and save property is a great idea that should be implemented in India to lessen the country's reliance on the grid.

According to Mafimidiwo and Saha (2016), power generated by three-dimensional photovoltaics rose by 16%. The three-dimensional photovoltaic structure produced significantly more energy than two-dimensional planar ones, according to the findings. Installing PV panels on a tall structure, on the other hand, is both time-consuming and expensive. Depending on the price of the land, it may be more cost-effective to place the solar panels on an elevated building.

Takahashi and Yachi (2017) proposed the concept of power generation forest based on the design of Fibonacci sequence PV modules. In the power generation forest study, they investigated the effect of shadow on the power generation of three-dimensional Fibonacci numbers PV modules (FPMs). The researchers designed their model using 1/3 phyllotaxy pattern-based two-stage FPMs. The researchers also confirmed a variation in generated power because of a change in the arrangement pattern of multiple FPMs. Their results showed that honeycomb structure based FPMs generated the maximum amount of power in all seasons. It was found that the solar tree generated 1.5 times as much power as the usual approach.

Duque et al (2017) found that 876Wh of energy savings may be achieved in a year of operation. Create a solar-powered fake tree for charging mobile devices in open urban settings in Medellin City. It is projected that the monthly average usage of solar trees saves 81645.78 gr of CO_2 emissions, or the equivalent of planting 2.085 trees, in a year.

Yadav (2017) claims that flat solar panels yield 100% of their energy, but trees in the Fibonacci sequence create 120% more energy and need 50% less time to construct. Flat panels only produce 2.31 watts, compared to 8.28 kWh from the solar tree. We require 10–12 acres of land to generate 2 MW of electricity from an array of solar panels, while just 0.10–0.12 acres of land is needed for a solar tree, which is better for the future. In addition to being pollution-free, the solar tree also eliminates harmful pollutants like carbon dioxide (CO_2) from the air.

According to Ayneendra et al. (2018), the solar tree design produced 50% more electricity and collected 50% more sunshine. All sorts of land may be used to cultivate the solar tree, but it is most effective in locations that are both geographically isolated and socially marginalised because of the lack of access to power. It is good for the environment, saves money, and is simple to use in any household. It's handy for everyday living and the greater good.

Dey et al (2018) proposed the proper orientation of solar panels used in a solar tree for maximum power generation based on locations and applications. Firstly, the researchers studied the orientation of single panel optimization and experimented at 15 different locations that covered an extensive range of latitudes. Optimized solar trees in San Francisco and Paris increases in power generation of 2.04% and 7.38 percent in relation to latitude tilt, respectively. Compared to horizontal solar panels for San Francisco and Paris, the standard deviation of the energy curve in the solar tree is 21.5 percent and 3.35 percent lower. In contrast to the solar panels positioned at Tilt latitude, the construction of the solar tree may be employed on the ground.

VI. CHALLENGES OF SOLAR TREES

According to Hyder et al (2018), the solar tree is an innovative and energising idea, yet it has the following challenges:

- In terms of capital costs, the solar tree is the most difficult to implement. Since solar trees are built with metals, their capital costs are significant. Wooden pieces with a plastic abutment or a basic design with less metal components can help keep the solar tree's startup costs down.
- In a solar tree, the irradiance received by each solar panel is not equal because of the varied angles and orientations of the panels. As a result, the P-V and I-V characteristics of the solar tree vary, increasing inverter losses and decreasing conversion efficiency. Because of these inverter losses, we are unable to directly connect the solar tree to the utility grid. Batteries should be used to store energy and provide steady power to the grid in order to address these issues.
- There is a possibility of a shadow effect because solar trees have numerous phases. Upper solar panels might cast a shadow on lower solar panels. To avoid the shadow effect, we should choose designs that minimise shadows.
- Researchers are working to enhance the solar tree designs now available for low-power applications, but they're also looking at ways to make them more powerful.

- Birds' lives can be endangered by the heat dissipation from solar panels in solar trees. To ensure the safety of the birds, we should then apply bug repellents.

VII. CONCLUSION

To generate power, the notion of a solar tree is advantageous since it requires just 1% of the land space of a normal solar module. An increasing number of people are adopting the solar tree concept as a way to produce more energy per square foot of land. Urban locations with little open space may benefit from the PV tree idea. The goal of this research is to examine the many PV tree design options available to solar power plant owners. In comparison to typical PV modules, the solar panels on solar PV trees are angled in different directions, increasing the amount of solar irradiation that can be collected. The solar tree design idea has the potential to be the most promising "green" energy source. The varied solar tree design structures may be utilised for a variety of purposes, including street lighting, charging, and more. Mobile and laptop charging, street lighting, residential and industrial supplies, charging of electric cars and surplus energy delivery to the grid are some of the uses for which it may be applied.

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