Solar Trees: Harnessing Renewable Energy for Portable Charging of Low-Capacity Devices

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Abstract

A solar tree is a structure that incorporates solar energy technology, like the branches of a tree. Solar trees aim to highlight the vision of solar energy technology, and the main objective of the project is to draw attention to the possibility of exploiting clean energy, which is one of the important aspects of our daily lives, as phones have become an indispensable element, so charging them is of the same importance. Given how quickly smartphone batteries run out, the charger has become one of the most essential items in our bags. We travel with it everywhere and can't live without it, but it always puts us in a difficult situation when we are somewhere without access to electricity or are on a long trip and don't have time to find a place to charge. We had to devise ways to charge the phone and run low-capacity devices because of the phone and the deteriorating energy problem. This was no longer limited to thinking but rather came into effect. Because of the current era's emphasis on artistic and technological aspects, the shape of the solar tree was specifically chosen. The concept came about because trees can use sunlight to perform a process known as "photosynthesis," which helps to maintain the ecosystem. With solar cells affixed to the branches in a manner that allows them to be adjusted in different directions based on the angle at which the sun's rays are incident, the construction was modeled after tree branches, an inverter that changes the cell output voltage to the amount required by the batteries to be charged. To keep these pieces in the proper shape, they were positioned inside a box representing the tree's roots. Because of this, we have a portable charger that can run on clean, renewable energy at any time of day. Additionally, this tree is positioned as close to the window as possible to receive as much sunshine as possible. The design can be implemented in the form of a large tree on the roads and public areas that add an aesthetic view—phones, laptops, and operating low-capacity devices.

Keywords

Solar Energy Technology, Renewable Energy Charging Stations, Solar Tree Design, Sustainable Power Solutions, Portable Solar Chargers.

1. Introduction

Smart devices, such as mobile phones, always switch on, consuming their batteries wherever they are [1, 2, 3, 4, 5, 6, 7]. Mobile phone recharging requires a specific time and location and energy is always needing less consumption [8, 9]. Phones, along with satellites, are being used in a heavy manner for the applications of communication and other purposes [10, 11, 12, 13]. The abrupt shutdown of cell phones owing to low battery power prohibits individuals from hurrying to their place of employment, market, school, college, office, train, bus, etc. The use of renewable energies are arising in many different applications [14, 15, 16, 17, 18]. It would be crucial if we could give these individuals the ability to use renewable energy sources whenever they need it, on the road, to instantly charge smart devices [19]. Numerous studies have been conducted thus far to address the issue of offering smart device charging capabilities. A common characteristic of these advances is that they all rely totally or partially on renewable energy sources, such as solar, wind, etc., for their power generation [20, 21]. Some of these developments are portable, while others are big, stable charging stations. While the majority of them are meant for personal use, some may also have commercial uses in mind.

Due to the ongoing power outages and the rising cost of oil extraction, solar energy has emerged as the most popular energy source [22, 23, 24, 25, 26]. Anyone may use solar chargers because they are easy to use, portable,

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and readily available, especially in remote places. Fuel reliance is an issue that can be resolved with the usage of solar energy [27, 28]. Especially for charging the phone and operating low-power devices. The "Solar PV Tree" idea combines art and technology in a novel way to create solar PV. This novel concept was regarded as an attempt to combine artistic beauty with cutting-edge solar energy technology. In essence, the solar tree is a decorative method of generating clean energy. It features a structure shaped like a tree with panels placed like leaves on a power tree's limbs. A solar tree is a structure that has solar panels covering it to capture solar radiation and use it to power laptops, cell phones, and other tiny electrical devices. The solar PV tree can capture incident sunlight throughout the day, regardless of the sun's location, because the panels are set at different angles [29, 30, 31, 32].

The goal of this paper is to create a mobile solar charger that can be used anywhere. Simply put, a solar-powered mobile phone charger is an electronic energy device that uses solar radiation to create electrical current, which can then be used to power low-power gadgets and recharge mobile phone batteries. There will be a thorough and in-depth discussion of a few experiments that were utilized in the various solar tree designs. Although there have been technologies employed in the past, they are very different from the technology utilized in this research. There are other approaches and concepts for creating the solar tree, and we were unable to locate any that were comparable to the research that is currently in use.

Atique Sheikh's research focuses on installing solar PV modules on a pole and attaching branches to tilt them at a 40-45 angle for better sunlight [33]. Six branches with solar panels and a pole with one rotating panel provide power for small households. The solar tree, with seven panels, produces 25 volts and 1.71 amps, making it ideal for parks and schools. The system is rotated using a DC motor. Moreover, K. Ramesh Kumar and his group [34], designed a tree structure based on a natural tree, with a sturdy base and solar panels positioned at 30° and 45° tilt angles. The structure maximizes sunshine production while preventing panel shadows. The tree's branches must be sturdy enough to support the weight of the panels, ensuring stability and capturing more sunlight. This design is effective in conserving land and generating electricity.

Solar PV modules are installed on a 12-foot high, 3-inch diameter pole made of galvanized iron pipe [35]. The tree features eleven square branches angled between 40-45 degrees for more sunlight. A tilt mechanism allows the single solar panel to be angled at different times of the day. According to Ayneendra B1 and his group made a design that benefits the environment, saves money, and is inexpensive for homes, increasing power by 50% and extending sunlight collection time by up to 50% [35].

2. Experimental Approach

2.1. Experimental Parts

2.1.1. Photovoltaic modules

Silicon solar cells have recorded maximum efficiencies for home and commercial use, and it is estimated that 80% of all solar panels sold worldwide are made of silicon [36]. The first generation of solar cell technology included monocrystalline and polycrystalline solar cells, while the second generation consisted of amorphous silicon and thin film technologies. The third generation introduces some new and exciting solar PV module technologies like copper, zinc, and tin sulphide (CZTS) solar cells, dye solar cells, organic solar cells, polymer solar cells, quantum dot solar cells, etc. though modern technologies are being developed Silicon continues to be the most widely used solar cell technology.

2.1.2. Cables for connecting modules

PV modules are subject to atmospheric conditions such as rainfall, snow accumulation, solar radiation, and high temperatures. For secure connections between modules, cables with excellent mechanical strength are needed for use in conditions of high mechanical stress, dry and humid conditions, high-temperature conditions, and high solar insolation.

2.1.3. Inverter

The main use of an inverter is to convert direct current to alternating current for the solar panel. Efficiency is also the most important for energy optimization.

2.1.4. Batteries

Deep-cycle batteries have been used in renewable and sustainable energy applications around the world for decades. Some commonly used batteries in solar PV system applications are: lead acid batteries, lithium-ion batteries, lithium-ion polymer batteries, and nickel-cadmium batteries.

2.1.5. Structure

There is no standard structure for a solar tree, it can be designed creatively to make it look appealing to the eye and consume less space while avoiding the shading effect on the leaves/panels.

2.2. Detailed components of the solar tree designed and manufactured:

1. Solar cells and the dimensions of the solar cell (45 mm x 45 mm) as in Figure (1).

Figure 1: Solar cell

2. A solar controller (Mppt solar controller) to receive the voltage from the solar cells and convert it to charge the battery at a more appropriate level, as in Figure (2).

Figure 2: Solar controller

3. 2S Battery monitoring system to collect and display useful data such as battery voltage, power consumption, estimated remaining operating time, current consumption, battery temperature, and more as in Figure (3).

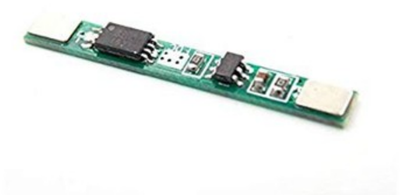

Figure 3: 2S battery monitoring system

4. 7805 Regulator to convert the fluctuating voltages of the voltage source into fixed and stable voltages as in Figure (4).

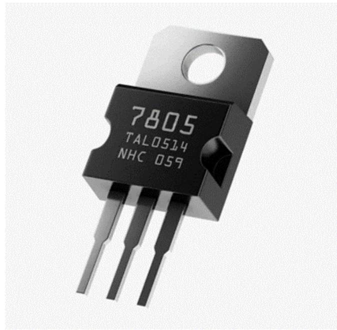

Figure 4: Regulator 7805

5. Dual USB port (5 volts, 1 amp) as in Figure (5).

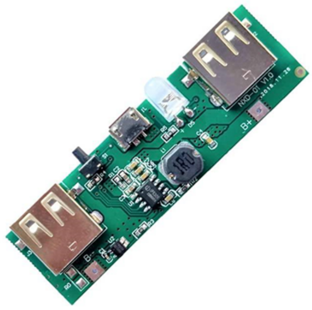

Figure 5: Dual USB port

6. Lithium battery (3.7 V, 10,000 mAh) as in Figure (6).

Figure 6: Lithium battery

7. Pinned wires, as in Figure (7).

Figure 7: Striped wires

8. Solar tree structure the structure is made of tree-shaped strings to achieve an artistic and modern look. This structure was first formulated using finite element approaches and then printed using 3D printers [37, 38]. This structure consists of a pole with 12 branches similar to the shape of tree branches. Each branch is connected to a frame that holds the cell by a ball joint. This ball joint provides the possibility of directing the cell at different angles according to solar radiation. The structure is installed over a box designed to hide the previously mentioned parts, as in Figure (8).

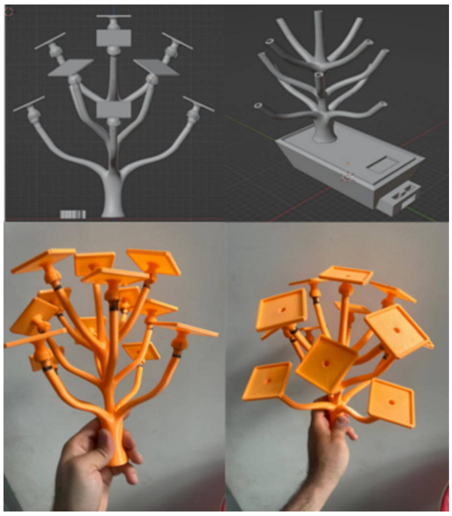

Figure 8: Structure of the solar tree

3. Calculations and Theoretical Work

The terms are explained in Table (1):

Table 1
Terminology

Symbol	Description
V	Voltages
I	The current
P	Ability
E	Intensity of solar radiation
η	Efficiency
D.O.D	Depth of discharge (DoD) refers to the percentage of the battery that has been discharged relative to the total capacity of the battery.
A	The angle of incidence of sunlight

3.1. Data Visualization and Experimental Results

A. Solar cell characteristics:

Using the PV analyzer, we found:

V_{open}= 2.11 v

I_{short}= 80.1 mA

I_{max}= 79.1 mA

B. Power of one cell:

Using a photoelectric analyzer, we found:

P= I*V

at an optimum angle (Angle = 90°)

solar radiation = 963 Wh/m²

P= 0.079 * 2.11= 0.1659W

η_{cell} 15.65 %

C. Average solar radiation:

The Baghdad region enjoys more than 3,000 hours of bright sunlight throughout the year and receives more than 5 kW/m2 of solar radiation on average per year.

D. The capacity of the used battery:

Characteristics of the battery used:

i. D.O.D = 40%

ii. Battery voltage = 3.7V

iii. η = 95%

Using (2) 3.7V, 10000mAh lithium batteries and connecting them in parallel we get a total capacity of 20000mAh

In parallel:

VT = V1 = V2

IT = I1 + I2

VT = 3.7 V

However, the power is capacity x voltage, so it is (20,000 mA x 3.7 V) / 1,000 = 74 watt

E. Charging rate:

We used 12 cells, connected every 6 cells in series, and merged them in parallel:

The total voltage is 12.6 v

And current 160.2 mA

Charging rate = 2.016 w

F. Battery charge time:

• Battery power: 74Wh

• Charging rate: 2.016W

Charging time = (battery power × D.O.D) / (charging rate× battery efficiency)

(74Wh×40%) ÷ (2.016×95%) = 15hr 45min

The connection was made as in Figure (9), which shows the electronic circuit diagram.

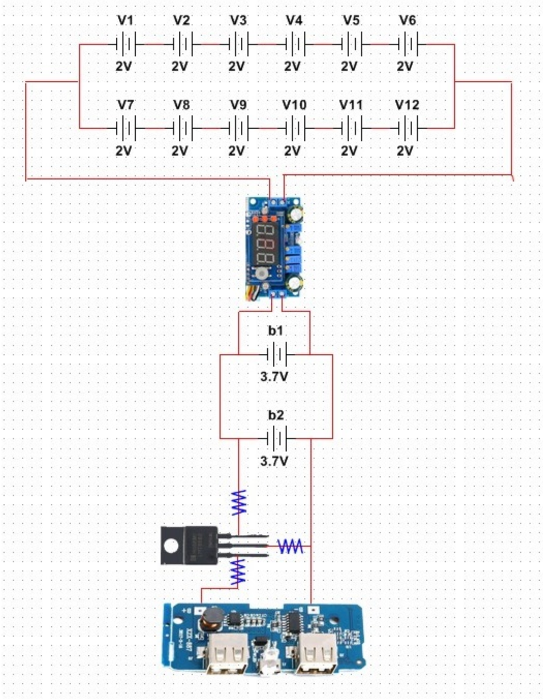

Figure 9: Electronic circuit diagram

The final appearance of the solar tree is as in Figure (10), Figure (11), and Figure (12) shows how to charge the phone using the solar tree.

Figure 10: The final form of the solar tree

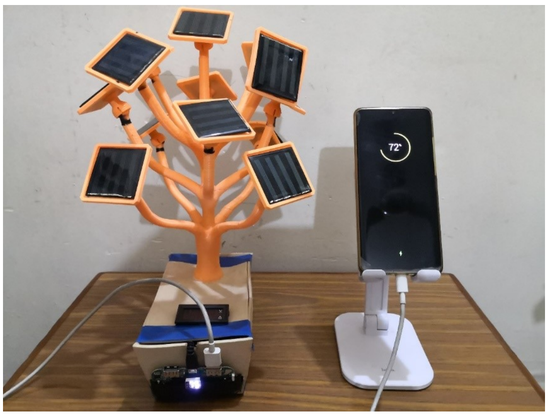

Figure 11: Charging the phone using the solar tree

4. Methodology Implementation

4.1. Applications

An indoor solar tree designed to charge low-power devices has a wide range of potential applications within a residential or indoor environment. Here are some applications where this device can be used effectively:

1. Home charging: The basic application is a dedicated charging within the home. Users can easily charge their low-power devices such as smartphones, tablets, smartwatches, and wireless headphones.

2. Office and Workplace: The indoor solar tree can be placed in offices, workplaces, or home offices to provide a sustainable charging solution for electronic devices used while working.

Figure 12: Powering the Light Pad using the solar tree

3. Schools and educational institutions: These solar trees can be installed in schools and libraries, allowing students to charge their devices such as laptops and tablets while studying or researching.
4. Public spaces: In indoor public spaces such as malls, airports, and libraries, these solar-powered trees can provide a convenient charging option for visitors and travelers.
5. Hotels and Hospitality: Luxury hotels can use these trees in their lobby areas or guest rooms to provide guests with a unique and environmentally friendly shipping experience.
6. Restaurants and cafes: Placing indoor solar trees in dining areas allows customers to charge their devices while enjoying a meal or coffee.
7. Conferences and Trade Shows: Organizers can use these trees to provide charging solutions at conferences, trade shows, and exhibitions where attendees often need to recharge their devices.
8. Exhibits and museums: In cultural institutions, solar-powered trees can provide a way for visitors to charge smartphones used in guided tours and interactive exhibits.
9. Residential complexes: Residential complexes, condominiums, and apartment buildings can install indoor solar trees in common areas so that residents can charge their devices.
10. Environmental education: Educational institutions and environmentally concerned organizations can use the solar tree as an educational tool to demonstrate the benefits of renewable energy and sustainable technology.
11. Emergency charging: During a power outage or emergency, a solar-powered tree can serve as a reliable source of power for essential appliances such as flashlights, radios, and emergency phones.
12. Sustainable technology exhibitions: Companies specializing in renewable energy and sustainable technology can use the solar tree as a display piece in their showrooms or at trade shows.

4.2. Features

1- Integrating highly efficient solar panels into the design to capture and convert light into electricity.
2- It includes a built-in battery storage system to store excess power generated during the day, ensuring continuous charging of the device during low light conditions or at night.
3- Install a variety of charging ports to accommodate different types of devices, such as USB-A, USB-C, wireless charging pads, and even traditional power outlets for versatility.
4- Implement an easy-to-use interface with indicators, touch screens, or LEDs to display battery status, available charging slots, and power generation data.
5- The tree is designed with movable and rotatable solar panels so that we can move it towards internal lighting sources to obtain maximum energy capture.
6- Safety features such as surge protection, over-current protection, and temperature monitoring to ensure safe charging.
7- Create an attractive and decorative design that complements the interior spaces, incorporating elements such as branches, leaves, and aesthetic finishes.
8- Improving the energy efficiency of the system to reduce energy loss during charging and storage.
9- Use durable materials that can withstand indoor conditions and provide a long-lasting charging solution.

10- Provides users with insights into their energy consumption and the environmental impact of using the solar tree.
11- The possibility of exploiting clean energy is one of the important aspects of our daily life, as phones have become indispensable items, and therefore charging them is of the same importance.
12- Choosing the shape of the solar tree in particular due to the importance of the artistic aspect as much as the technological aspect in the current era. The idea was inspired by the ability of trees to carry out the process of "photosynthesis" using sunlight, which would contribute to preserving the environment.
13- Light-weight and small-sized batteries were used, which allows the solar tree to be transported to any place to store solar energy and benefit from it at times of weak sunlight, in addition to the inverter that converts the voltage coming out of the cells into the value that the batteries need for charging. By incorporating these features into our solar-powered indoor tree, we can create an easy-to-use and efficient device that not only charges low-power devices but also promotes sustainability and environmental awareness indoors.

5. Results and Discussion

Readings of both solar radiation intensity, current, and voltage were taken using a solar irradiator and multimeter to calculate the output power of the system and the time it takes to charge the battery, which indicates the effect of the solar controller on the system and the results obtained will be discussed.

We took readings in two cases to show the effect of the solar controller

Case (1) Table (2) below represents the values of (E, I, V, P) Before connecting the solar controller to the system, the maximum voltage in this case (12.5) must be reduced to the battery voltage. For this reason, the solar energy controller must be used as in Table (2).

Case (2) Table (3) When the solar controller is connected, the maximum voltage will be reduced to (4.5) and the current will decrease despite the lower voltage, resulting in the voltage and current being regulated at the same time as in Table (3).

The relationship between solar radiation intensity and energy, as shown in Figures (13) and (14), can be explained by considering the basic principles of physics and the nature of electromagnetic radiation.

Solar radiation emitted by the Sun consists of electromagnetic waves that carry energy. Solar radiation intensity refers to the amount of energy carried by radiation per unit area per unit time, usually measured in watts per square meter (W/m²). It represents the flow of energy at the surface.

Table 2
Values of (E, I, V, P) before connecting the solar controller to the system

E (w/m)	I (A)	V (v)	P (w)	$\alpha(^\circ)$
208	0	2.3	0	90
281	0	3.4	0	90
362	0.01	5.3	0.053	90
572	0.08	9.2	0.736	90
709	0.12	12.1	1.45	90
890	0.14	12.5	1.75	90

Table 3
Values of (E, I, V, P) when connecting the solar controller

E (w/m)	I (A)	V (v)	P (W)	$\alpha(^\circ)$
248	0	0	0	90
276	0	1.3	0	90
373	0.01	3.4	0.034	90
642	0.06	3.7	0.22	90
780	0.082	4.3	0.35	90
932	0.091	4.5	0.4	90

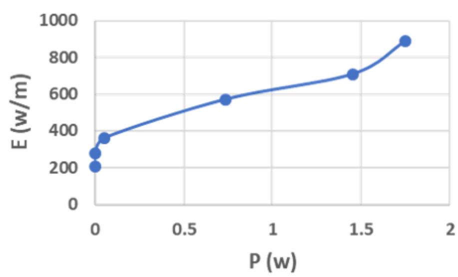

Figure 13: The relationship between solar radiation intensity and energy before connecting the solar controller to the system

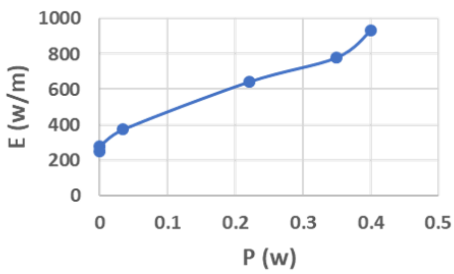

Figure 14: The relationship between the intensity of solar radiation and energy when connecting the solar controller

On the other hand, energy is the rate at which energy is transferred or delivered per unit of time. In the context of solar radiation, power is often referred to as solar radiation and is also measured in watts per square meter

(W/m²).

The relationship between power and force is direct and proportional. Mathematically, it can be expressed as follows:

Force = Intensity x Area

where:

Power: represents the total amount of power received per unit time (watts).

Intensity: Density represents the amount of energy per unit area per unit time (watts per square meter).

Area: The area represents the surface area over which radiation is received (in square meters).

This relationship shows that the energy received from solar radiation depends on the intensity of the radiation and the size of the surface area that intercepts the radiation. If the intensity of solar radiation doubles while the area remains the same, the energy received will also double.

It is important to note that this relationship assumes that the receiving surface is perpendicular to the incoming radiation and that there are no losses or interactions between the radiation and the receiving surface.

In short, the energy received from solar radiation is directly proportional to the radiation intensity and the size of the receiving surface area.

The graphs show the relationship between power and solar radiation intensity in each case, and we can see in case (1) the power is higher than in case (2) due to the lower voltage and current after connecting the solar controller.

The time to obtain a fully charged battery depends on the intensity of solar radiation, which varies depending on the time of the day. Table (4), will show the time required to obtain a full charge (6) time within one day.

The average time needed to get a full battery charge is (17 hours), when compared to theoretical calculations, it takes an additional 1 hour and 15 minutes for an actual full charge which causes the battery efficiency to not be ideal (η = 95%). Case (2) Table (3) When the solar controller is connected, the maximum voltage will be reduced to (4.5) and the current will decrease despite the lower voltage, resulting in the voltage and current being regulated at the same time as in Table (3).

Table 4
Time required to charge the battery

Time measurement	Time required to charge the battery
8 am	2 hours. 8 min. 32 sec.
11 am	1 hour. 15 min. 45 sec.
12 am	1 hour. 2 min. 16 sec.
2 pm	30 min. 12 sec.
4:30 pm	1 hour. 35 min. 3 sec.
6:30 pm	2 hours. 10 min. 15 sec.

6. Conclusions

This study successfully designed and implemented a solar tree that integrates aesthetic and functional elements to provide a renewable energy solution for charging low-power devices such as smartphones and laptops. The innovative design, inspired by the natural process of photosynthesis, employs strategically placed solar panels on branch-like structures to maximize sunlight capture throughout the day. Through rigorous testing, the system demonstrated the ability to maintain continuous power supply as it effectively managed solar energy capture and storage. Key findings included the solar tree's capacity to adjust panel angles dynamically for optimal sun exposure with a noted significant enhancement in the charging efficiency. The study also confirmed the practicality of the solar tree in various indoor settings, showcasing its potential to blend into urban environments while offering substantial power output.

Future research should focus on improving the efficiency and scalability of the solar tree design to further its application in diverse environments. Exploring advanced materials for solar panels and battery storage could enhance the system's performance and durability. Additionally, the integration of smart technology to track sun movement and optimize panel angles automatically could increase the energy efficiency and user convenience of the solar tree. Considering the rapid advancement in photovoltaic technology, subsequent studies might also evaluate the integration of newer solar cell types that could offer higher efficiencies or better aesthetic integration. Lastly, expanding the scope to include outdoor applications could help in understanding the environmental impacts and benefits of deploying solar trees in larger public spaces.

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