# BLOCKCHAIN TECHNOLOGY FOR IoT AND WIRELESS COMMUNICATIONS

Edited by
Gajula Ramesh, Budati Anil Kumar,
Praveen Jugge, Kolalapudi Lakshmi Prasad,
and Mohammad Kamrul Hasan

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# 4

# IoT-BASED CONCENTRATED PHOTOVOLTAIC SOLAR SYSTEM

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## 4.1 Introduction

Solar cells are referred to as photovoltaic (PV) cells by scientists because they transform sunlight immediately into electrical energy. The PV effect is the procedure of transforming sunlight (photons) to electricity, and it is called voltage [1]. Bell Telephone scientists discovered the PV effect in 1954 when they realised that

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**Figure 4.1** A big silicon solar array on the roof of a business.

when silicon (a sand-like material) was subjected to sunlight, it created an electric charge. Solar cells were quickly being used to power spaceships and tiny electrical devices like calculators and watches (Figure 4.1).

Thousands of houses and businesses are powered by individual solar PV systems. PV technology is also being used in major power plants by utility corporations. Solar panels for homes and businesses typically consist of 40 solar cells grouped together in modules [2–3]. A typical home is powered by solar panels ranging from 10 to 20. The panels can look toward the south at a permanent angle or on a tracking system that follows the sun to catch as much light as possible. A solar array is a collection of solar panels that works together to create a complete system (Figure 4.2).

Hundreds of solar arrays are linked together to form a large utility-scale PV system for use by a big power utility or industry. Traditional solar cells are constructed of silicon, have flat plates, and are the most efficient [4,5]. Second-generation solar cells made of amorphous silicon or non-silicon materials like cadmium telluride are known as thin-film solar cells. Thin-film solar cells make use of semiconductor layers that are only a few micrometres thick. Because of its adaptability, thin-film solar cells can be utilised as roof shingles and tiles, building facades, or skylight glass (Figure 4.3).

**Figure 4.2** Ground-mounted solar array in the fields.

**Figure 4.3** A home's roof using thin-film solar tiles.

Solar inks, solar dyes, and conductive polymers are among the novel materials being utilised to manufacture third-generation solar cells utilising classic printing press technology [6,7]. Some modern solar cells utilise plastic lenses or mirrors to focus sunlight onto a very small piece of high-efficiency PV material. The PV material is more costly, but because these systems consume so little energy, utilities and industry are finding them to be more cost-effective. Concentrating collectors, on the other hand, are only utilised in the country's sunniest places since the lenses must be directed toward the sun.

### *4.1.1 Photovoltaic (PV) Technology Types*

Solar radiation may be converted into electricity in two ways:

a. Photovoltaics (PV): Absorbed light is immediately transformed to electricity in some materials (photo effect).
b. Concentrated Solar Thermal (CST): To heat a liquid, direct light is focused into a single spot. The heat is then used to power a generator, much like in a traditional power plant (Figure 4.4).

### *4.1.2 Principle of Operation*

The layers of a solar module are shown (Figure 4.5).

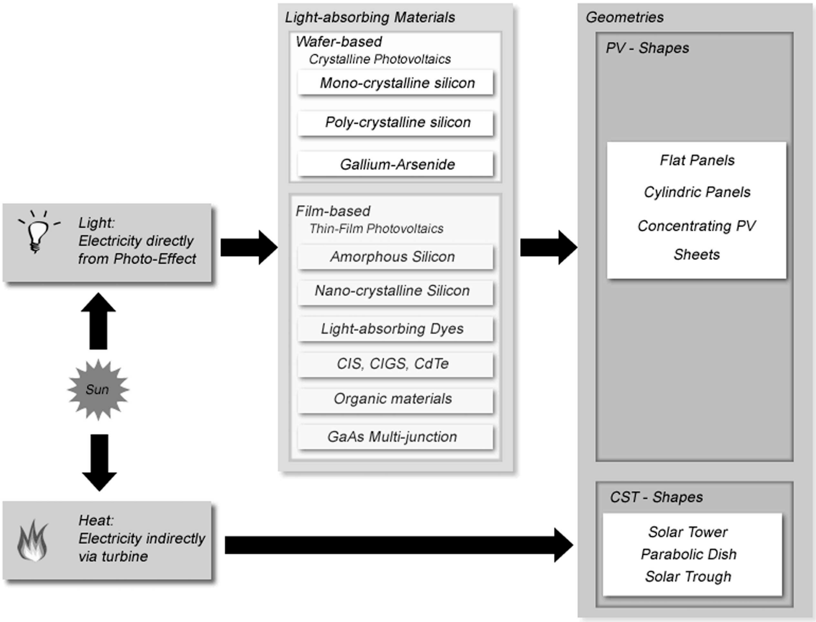


**Figure 4.4** Photovoltaic (PV) technology types.

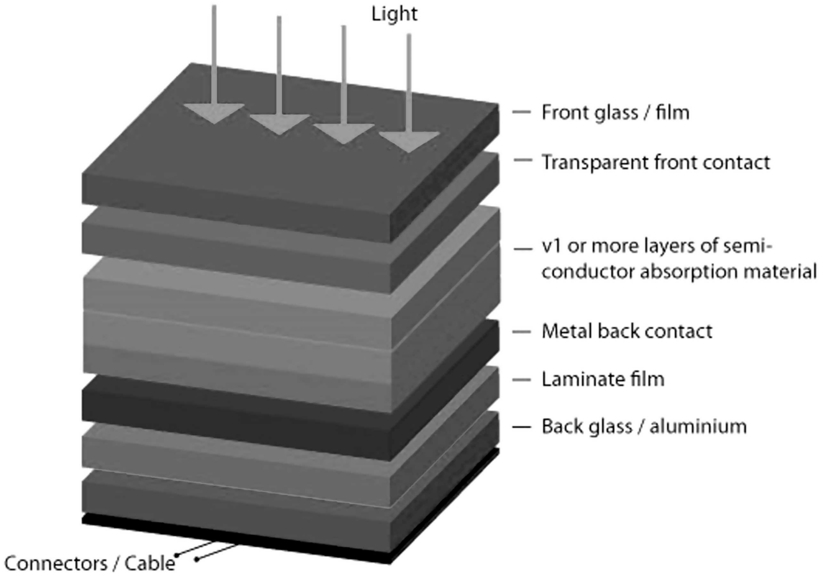


**Figure 4.5** Solar module layers.

From the light-facing side to the back, all PV modules have a number of layers [8]:

a. Protection Layer: Glass is commonly used; however, transparent material can also be used in thin-film modules.
b. Front Contact: The front electric contact must be clear, or light will not be able to enter the cell.
c. Absorption Material: The layer where light is absorbed and transformed into electric current is the module's heart. All of the materials utilised in this project are semiconductors. In many cells, there is only one substance, which is usually silicon. However, many layers of various materials may be used to increase performance. Furthermore, all layers will be doped. In other words, each layer is subdivided into an n-doped and a p-doped zone. For additional information about doping, see the sections below.
d. Metal Back Contact: The electric circuitry is completed by a conductor at the rear.
e. Laminate Film: The construction is waterproof and heat-insulated thanks to the lamination.

f. Back Glass: On the rear side of the module, this layer provides protection. It might be constructed of glass, but it could also be made of metal or plastic.
g. Connectors: Finally, the module has connections and wires that allow it to be connected.

### 4.2 Concentrated PV Systems

A concentrated photovoltaic (CPV) system converts light energy into electrical energy in the same way as standard PV technology does. The difference between the two methods is the optical system that concentrates a large quantity of sunlight onto each cell. CPV has been a well-established science since the 1970s, but it is just now becoming practical. It is the most current solar industry invention.

Concentrator-based PV systems use less solar cell material than other PV systems. PV cells are the most costly component of a PV system per square metre. Using relatively affordable materials like plastic lenses and metal housings, a concentrator collects solar energy shining on a large area and concentrates it into a smaller region—the solar cell. One approach to evaluate the efficacy of this strategy is to look at the concentration ratio, or how much concentration the cell gets.

Compared to concentrator PV systems, flat-plate PV systems provide a number of benefits. For starters, concentrator systems reduce the number of cells needed, allowing for the use of more expensive semiconductor materials that would otherwise be prohibitively expensive in some designs. Second, when exposed to concentrated light, the efficiency of a solar cell improves. The design of the solar cell and the substance used to make it affect how much efficiency increases. Third, a concentrator can be made from tiny cells. Because large-area, high-efficiency solar cells are more difficult to manufacture than small-area cells, this is favourable.

Concentrators, on the other hand, face difficulties. To begin with, the focusing optics required are far more expensive than the simple covers required for flat-plate solar systems, and most concentrators require continuous monitoring of the sun throughout the day and year to be successful. As a result, reaching larger concentration ratios necessitates the use of both costly tracking methods and more precise controls. To concentrate light, both reflectors and lenses have been utilised.

The Fresnel lens, which focuses incoming light using a narrow saw tooth structure, is the most promising lens for PV applications. When the teeth are aligned in straight rows, the lenses serve as line-focusing concentrators. When the teeth are placed in concentric rings, light is focused at a central point. However, no lens can transmit 100% of the incoming light. Although lenses have a maximum light transmission of 90%–95%, most lenses transmit less. Additionally, concentrators are incapable of focusing diffuse sunlight, which makes up around 30% of the solar energy available on a clear day (Figure 4.6).

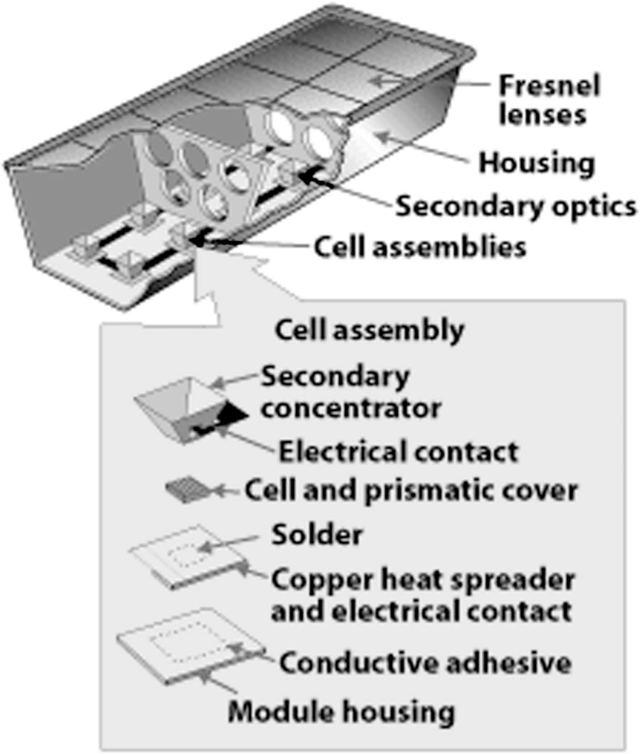


**Figure 4.6** Arrangement of concentrators.

A typical concentrator unit consists of a lens that concentrates light, a cell assembly, a housing element, a secondary concentrator that reflects off-centre light rays onto the cell, a mechanism to dissipate excess heat created by concentrated sunlight, and various connections and adhesives. Heat is also a concern with high concentration ratios when photovoltaic (PV) systems utilise sun radiation. In addition, the quantity of heat produced is focused. As temperatures rise, cell efficiencies fall, and rising temperatures put solar cells' long-term durability at jeopardy. As a result, in a concentrator system, the solar cells must be kept cool, necessitating advanced heat sync cooling solutions.

One of the most significant design goals of concentrator systems is to minimise electrical resistance where the cell's electrical connections carry off the current generated by the cell. Fingers, or wide grid lines in the contacting grid on top of the cell, are helpful for low resistance, but their shadow blocks too much light from reaching the cell. Resistance and shadowing difficulties can be solved by prismatic coatings. These coverings work as a prism, directing incoming light to areas of the cell's surface that lie between the metal fingers of the electrical contact grid. Another alternative is a rear-contact cell, which differs from regular cells by having both positive and negative electrical connections on the back. All electrical connections are located on the back of the cell, which decreases power losses due to shadowing but also mandates the use of extremely high-quality silicon (Figure 4.7).

### *4.2.1 CPV Operating Principle*

In concentrating photovoltaics, a large area of sunlight is focused onto the solar cell using an optical device (CPV). Because it focuses sunlight onto a small area, this technique offers three competitive advantages. Due to the lower area requirements, it is more cost-effective to utilise high-efficiency but more costly multi-junction cells to collect the same amount of sunlight as non-concentrating PV. The optical system is made up of conventional materials that were produced using tried-and-true techniques. As a result, the fledgling

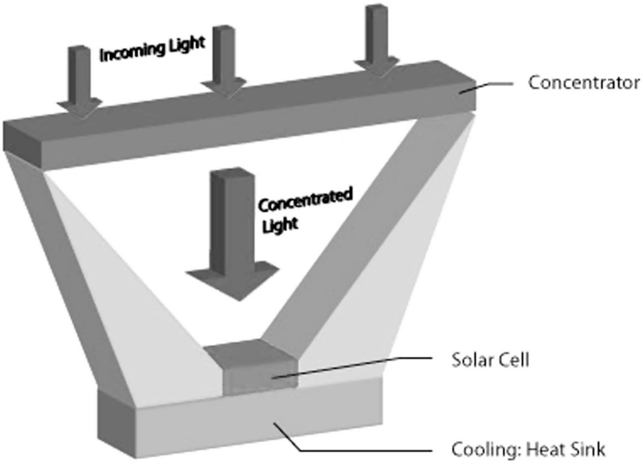


**Figure 4.7** CPV operating principle.

silicon supply chain is less reliant on it. Additionally, optics are less costly than cells [9].

This strategy is confined to clear, bright situations because focusing light requires direct sunlight rather than diffuse light. It also means that in the great majority of circumstances, tracking is required. Despite the fact that it has been investigated since the 1970s, it is just now becoming a viable solar energy option. Because this is a novel technology, there is no single dominating design.

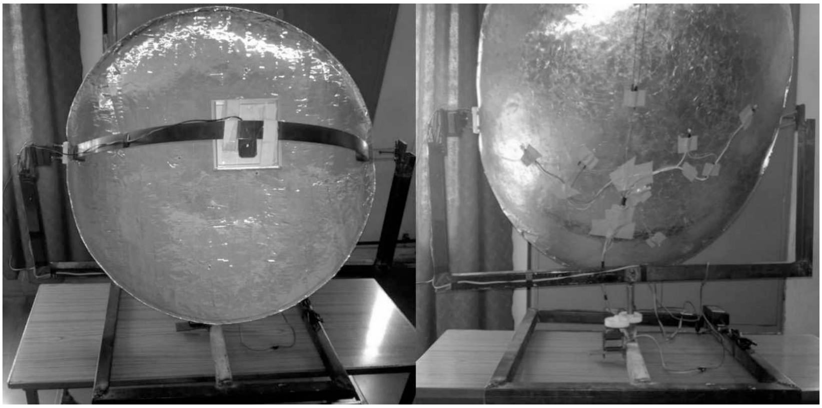
## 4.3 Construction and Operation of IoT-Based CPV

After the successful implementation of an incubated idea on a prototype, a CPV solar system with a dual axis solar tracking system was built for further enhancement of the efficiency. A concentrator can be rotated in Azimuth and elevation directions [10].

### *4.3.1 Mechanical Construction*

This construction has mainly had three basic physical parts. They are

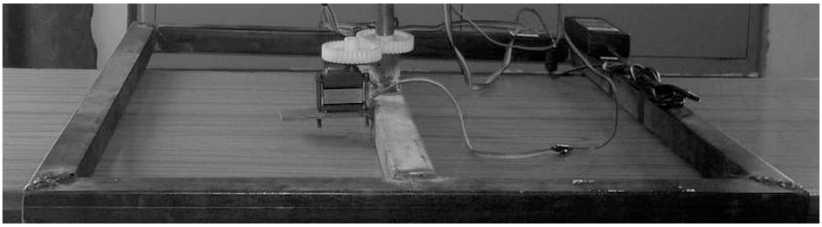
i. The base part and electrical connections
ii. The movable 'U'-shaped frame
iii. The concentrator and iron strip



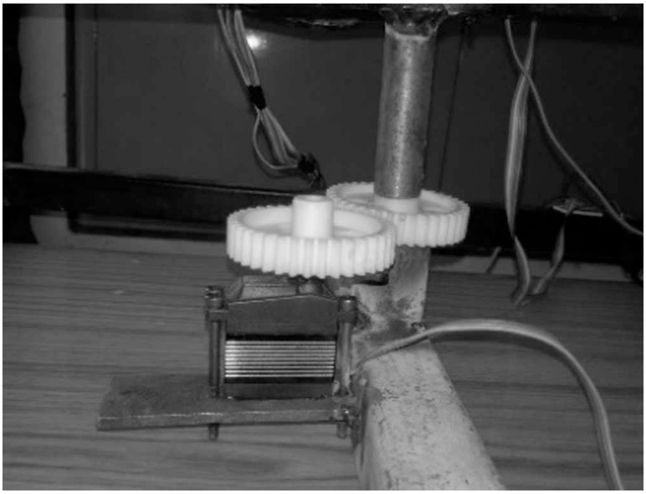
Concentrated solar tracker (front and back).

Mechanical construction and electrical connections are described below.

*4.3.1.1 The Base Part and Electrical Connections* The base part is built in the form of square shape, and a rod is placed at the centre of the square parallel to its sides. A servo motor is placed just adjacent to the middle rod to make the gear interlocking for vertical axis rotation. Arduino Nano 33 IoT and the supply adaptor are placed on the edge side of the rod after soldering all the required connections, which is shown below.

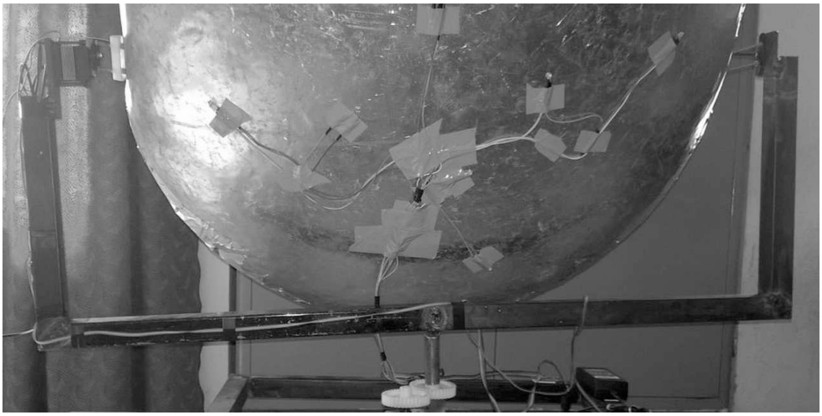


The base part with the vertical axis rotation gear system with servo motor.

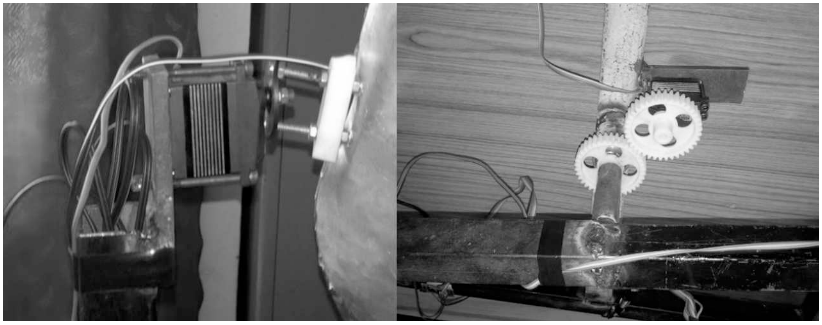


Gear system and Arduino Nano 33 IoT connections.

*4.3.1.2 The Movable 'U'-Shaped Frame* This is exactly a square-shaped 'U' frame to hold the parabolic dish with the help of screws on both sides. On one side, it has the servo motor with screws for horizontal rotation of the dish. This complete 'U' frame is placed on the middle rod of the base into one of the gears for movement.

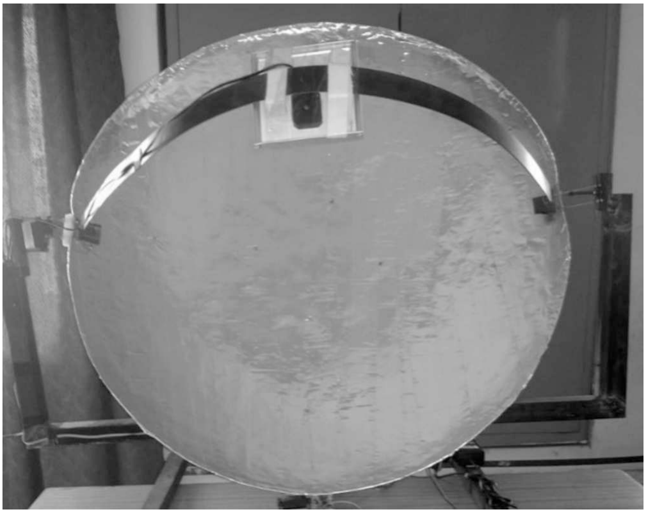


The movable 'U'-shaped frame mounted on the base.



Servo motor and mounted part on the gear.

*4.3.1.3 The Concentrator and Iron Strip* The concentrator has the eight light-dependent resistors placed on the diameters. Each perpendicular diametrical line on a parabolic dish has four sensors except at the centre. An iron strip is welded on both sides to the screws to support the PV panel. PV panel is placed on the inner side of the strip at the centre to absorb complete reflected light.



Concentrator and PV cell.

### *4.3.2 The Workings of IoT-Based CPV*

- Initially, when the sunlight falls on the collector, the sun rays are reflected to the focused point where the solar panel is placed. If the panel is not placed at the proper place, it can be adjusted by the handle provided, along with the collector to hold the solar panel.

- When the sun rays are made to fall on the solar panel, the multi-junction solar panel has high efficiency compared to normal PV panels producing electricity.
- The LDRs placed on the collector for tracking the sunlight increase efficiency to a considerable value.
- Now the produced electricity is collected into a 12-volt battery, or it can be made to run a load since the voltage obtained is of DC from the multi-junction PV cells.
- There is an LCD display to show the amount of voltage produced by the multi-junction PV cells.
- We have a 12-volt, 5-watt solar module.

| TECHNOLOGY | VOLTAGE (VOLTS) | CURRENT (AMP) |
|---|---|---|
| Concentrated solar power | 20 | 0.326 |
| Solar panel under sunlight | 18.40 | 0.335 |
| Solar panel under illumination | 16.20 | 0.306 |

From the above experimental data, it is clearly seen that the voltage produced by the solar panel is more than the expected value when compared to the normal solar panel under sunlight.

## 4.4 Results and Discussion

The efficiency of the existing system is further improved by using dual-axis tracking and using the energy wasted in the form of heat in multi-junction PV cells for heating water. Instead of manual operation, tracking is done in a digital way by using Arduino Nano 33 IoT. Arduino Nano 33 IoT is used to collect the data from various light sensors attached to the panel and identifies the optimal location for irradiation, i.e., it tries to keep the collector at right angles to the sun rays. This will enhance the performance of the system. At the same time, the Nano will send the generation data to the cloud using the available Wi-Fi. This will enable the operator to monitor the performance of the entire system from a remote location.

### *4.4.1 Model Calculations Are Given Below*

The solar panel ratings:

Max power output = 1 watt;
Max output voltage Vdc = 6 volts
$I_{mp}$ = 167 milliamps.
Open circuit voltage = 7.2 volts;
Short circuit current = 183 milliamps
Power = Vmp*Imp = 6*.167 = 1 watt;
Energy = Power* Time
The typical voltage generated by panel when concentrated = 5.2 volts

The typical voltage generated by panel when diffused sunlight falls on panel = 4.5 volts

No. of units generated by the panel for five peak hours with focused sunlight (Vf)

= 5.2*.167*5 = 4.342 watt-hours/day.

No. of units generated by the panel for five peak hours with diffused sunlight (Vd)

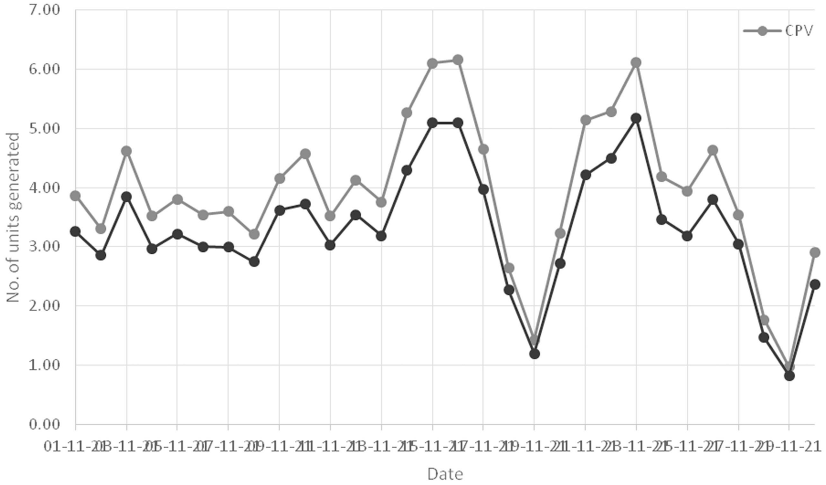
= 4.5*.167*5 = 3.757 watt-hours/day.

Increase in efficiency = (Vf − Vd)/Vd × 100 = (4.342 − 3.757)/3.757 × 100
= 16.36%

It is clear that a concentrated PV solar system with a dual-axis tracking system is more efficient than the conventional fixed solar PV system (Table 4.1).

**Table 4.1** CPV Solar System Performance Compared with Fixed-Tilt PV Solar System

| DATE | CPV | FIXED TILT | INCREASED EFFICIENCY |
|---|---|---|---|
| 01-11-21 | 3.87 | 3.26 | 15.85 |
| 02-11-21 | 3.30 | 2.86 | 13.40 |
| 03-11-21 | 4.62 | 3.85 | 16.70 |
| 04-11-21 | 3.52 | 2.97 | 15.64 |
| 05-11-21 | 3.80 | 3.22 | 15.28 |
| 06-11-21 | 3.54 | 3.00 | 15.23 |
| 07-11-21 | 3.60 | 2.99 | 16.82 |
| 08-11-21 | 3.22 | 2.75 | 14.48 |
| 09-11-21 | 4.15 | 3.62 | 12.86 |
| 10-11-21 | 4.58 | 3.72 | 18.79 |
| 11-11-21 | 3.52 | 3.04 | 13.77 |
| 12-11-21 | 4.13 | 3.54 | 14.26 |
| 13-11-21 | 3.76 | 3.19 | 15.17 |
| 14-11-21 | 5.26 | 4.29 | 18.51 |
| 15-11-21 | 6.10 | 5.09 | 16.56 |
| 16-11-21 | 6.1585 | 5.093 | 17.30129 |
| 17-11-21 | 4.6543 | 3.971 | 14.68105 |
| 18-11-21 | 2.6378 | 2.266 | 14.09508 |
| 19-11-21 | 1.4279 | 1.199 | 16.03053 |
| 20-11-21 | 3.2373 | 2.717 | 16.07204 |
| 21-11-21 | 5.1448 | 4.213 | 18.11149 |
| 22-11-21 | 5.2865 | 4.499 | 14.89643 |
| 23-11-21 | 6.1258 | 5.17 | 15.60286 |
| 24-11-21 | 4.1856 | 3.465 | 17.21617 |
| 25-11-21 | 3.9458 | 3.19 | 19.15454 |
| 26-11-21 | 4.6325 | 3.795 | 18.07879 |
| 27-11-21 | 3.5425 | 3.047 | 13.9873 |
| 28-11-21 | 1.7658 | 1.463 | 17.14803 |
| 29-11-21 | 0.9701 | 0.825 | 14.95722 |
| 30-11-21 | 2.8994 | 2.365 | 18.4314 |



Daywise generation comparision between CPV sytem and fixed-tilt PV solar system.

## 4.5 Conclusions

Solar energy is abundant in nature and is available free of cost. It emits light and heat energy. The main objective is to use this energy to produce electricity. In this project, a concentrated solar system using mirrors, concentrators, tubes (for fluid flow), and multi-junction PV cells are used to improve the efficiency of the system. Heat energy is concentrated; this concentrated heat energy is used to produce power. On the other hand, multi-junction photovoltaic cells directly produce power using light energy of the sun. This project is to combine both systems and get more efficiency. This way, the thermal and light energy present in the sun rays are harnessed to generate more electrical energy. The addition of an IoT system with a dual-axis tracking system has further improved the system efficiency and provided an advantage to monitor the system from anywhere, anytime.

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