Research Article

Performance Evaluation and Estimation of Energy Measures of Grid-Connected PV Module

R. Srimathi, 1 J. Meenakshi, 1 R. Vijayabhasker, 2 and Semagn Shifere Belay 3

1School of Electrical Engineering, Vellore Institute of Technology, Chennai, 600127 Tamil Nadu, India
2Department of Electronics and Communication Engineering, Regional Campus, Anna University, Coimbatore 641046, India
3School of Computing, Woldia Institute of Technology, Woldia University, Ethiopia

Correspondence should be addressed to Semagn Shifere Belay; semagn.s@wldu.edu.et

Received 5 July 2022; Revised 15 September 2022; Accepted 17 September 2022; Published 28 September 2022

Academic Editor: BR Ramesh Bapu

Copyright © 2022 R. Srimathi et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

In this paper, the effectiveness of two grid-connected photovoltaic (PV) techniques up of copper indium selenium (CIS) and monocrystalline silicon (m-Si) arrays has been examined. In order to determine whether the technology is suitable for the actual winter and summer climatic conditions in Thoothukudi, Tamil Nadu, the observed and calculated performances have been compared. The final yield, photovoltaic (PV) effectiveness, array yield, performance ratio, and capacity utilisation factor seem to be the variables used to evaluate performance. Using recorded meteorological data at the selected location, PVsyst software predicts both PV systems’ year-round performances. These predictions are then contrasted to the outcomes of the actual measurements. The outcome showed that with a maximal observed performance ratio, both PV systems function marginally better in the winters than those in the summers. The performance indicators of the PV mechanisms are contrary with those of other PV systems with comparable capacities that are located in different places.

1. Introduction

The quantities of energy utilized globally have substantially increased over the past few decades. It increases from 6131 TWh in 1973 to 23816 TWh in 2014, and it is predicted that this increase will improve quality of life by enabling advanced technology. By 2040, it is anticipated that 56 percent of the world’s energy would be consumed. Two significant obstacles stand in the way of the rising demand for electricity: the scarcity of common resources and the environmental issues brought on by emissions from the excessive usage of fossil fuels [1]. The rapid depletion of fossil fuel resources around the world increases the power price hikes, concerns about energy security, and environmental issues [2]. In all of these circumstances, one of the prospective power sources to substitute nonrenewable energy sources was environmentally friendly and sustainable energy sources, like solar energy [3].

India has a lot of potential for solar energy production. The geographical area, which experiences solar energy equivalent to 3000 hours of sunshine annually, is the explanation. This is more than 5000 quadrillion kWh hours. India almost universally receives 4–7 kilowatt hr of solar radiation per square metre. Under the National Solar Mission, India has the bold ambition to construct massive power grid connected solar power facilities designed to work in conjunction capacity of 20,000 MegaWatt by 2020. Understanding how well solar PV systems function under various climatic conditions is necessary for a successful deployment [4].

A significant sustainable energy source that generates electricity using photovoltaic (PV) power grids with no fossil fuel usage or emissions [5]. Semiconductor materials are used in photovoltaic cells or panels, which enable the direct conversion of solar energy to electrical energy. For a very long period, these modules can offer you a source of electricity that is secure, trustworthy, maintenance-free, and ecologically sustainable [6]. Although PV systems are more pricey than other alternatives for power generation, this technology has been encouraged because of its significant gains, which can be categorized into three: benefits for customers, benefits for electric utilities, and benefits for the environment [7]. When using PV modules in solar projects, it is important...
to understand how they operate and how they will behave in various climatic situations. The standard condition test (STC) is typically conducted indoors or in an air mass (AM) of 1.5, an intensity of 1 kilowatt/m², and a cell temperature of 25°C. Thus, it is essential to assess the actual efficiency of PV systems in outside conditions using trustworthy tools in predicting in a particular geographic area [8].

In the recent times, various studies have been carried out to enhance every aspect of photovoltaic (PV) systems. The behaviour of PVs in this environment, including temperature, irradiance, and cell temperature, must be taken into consideration while maximising production [9]. For academics, PV installers, and stakeholders, performance evaluations of various PV systems for a chosen site with its meteorological parameters are more straightforward to derive important conclusions. The outdoor performance of thin-film and monocrystalline (m-Si) photovoltaic systems that have been coupled to the grid was presented in this paper [2]. Solar panels made from monocrystalline silicon have cells that are each carved from a single ingot of monocrystalline silicon. Due to the fact that each cell is crafted from a singular piece of silicon, the composition of these cells is more refined. As a direct consequence of this, mono panels have a little higher efficiency level than poly panels.

The goal is to determine practical PV technology’s long- and short-term viability and effectiveness for places with comparable environmental circumstances. Under hot temperatures in south India, the real effectiveness of grid-connected PV modules with a copper indium selenium (CIS) PV array and monocrystalline (m-Si) system are contrasted. With specific input parameters relevant to the local latitude and longitude, the PVsyst software also predicts the performances of both PV systems. The proposal’s objective is to evaluate the energy efficiency of thin film PV technology and crystalline silicon in real-world climatic circumstances in Thoothukudi, Tamil Nadu, in southern India. A methodical process is developed to conduct the
analysis, and the approach used for this study is described below. They are shown in Figure 1.

2. Related Works

In this work, he presents a brand-new model design, simulation analysis, and test validation for the connected PV grid system. The simulation of a PV system has connected to a solar generator with a 3.2 Kwp rated power and a single stage integral Battery Storage systems [7]. Grid-connected photovoltaic (PV) system analysis, which may vary in terms of construction, technique, or location, is made easier by the use of relevant performance metrics. The four performance parameters that determine the overall system effectiveness regarding energy output, solar service, and the overall impact of system loss are reference yield, performance rating, final PV system yield, and PVUSA rating. These frameworks are examined for their capacity to offer the required insights into the development of the PV system and performance testing. They are replicated in a wide range of technologies, styles, and spatial situations. Also presented are techniques for calculating the system's AC power measurements during the design stage utilising multiples created from the performance metrics that were actually measured. It has been found that using the led to the reduction factor as a whole produces results that are

Renewable energy sources are increasingly being used in energy systems. The distribution of decision makers for photovoltaic (PV) decisions is becoming more and more dependent on economic analysis. Energy production and heat data from PV systems installed in Istanbul, Turkey in 2009 were analysed to determine the potential for solar power generation. Along with measurement, commercial factors were used. This study takes into account a number of taxes, including utility and supply taxes. The necessity for economic analysis to inform decision makers’ choices about photovoltaic (PV) distribution is growing. The PV systems that will be implemented in Istanbul, Turkey, are examined in this article. Tests were conducted using signals like power interruptions that were gathered in PV modules and tiny stations as part of an ongoing experiment. The consequences of employing photovoltaic systems on annual expenses as well as other taxes, including utility and food taxes, were taken into account. According to the findings, users can install solar PV systems to cut the electricity costs by more than 40%. Although solar PV systems have substantial up-front costs, subsequent price drops in PV modules and cost savings measures all help to bring down energy bills. Additionally, the price of electricity per kW-hour is less than the Turkish solar energy industry’s guaranteed price. The solar PV system’s capacity to fulfill summer’s increased demand is one of its advantages. The utilisation of a PV system will be even more profitable if a utility company utilises a taxation system with seasonal operation intervals. This is because the efficiency of the PV system will be increased. The scope of the study is going to be expanded so that it can monitor the production of solar energy. This is because having reliable information about expected solar production is necessary in order to regulate the demand side. Solar forecasting is essentially a method that gives grid operators with a technique to predict and balance the amount of energy generation and consumption. Assuming the grid operator has access to a variety of generating assets, reliable solar forecasting enables the grid operator to optimise the method in which they deploy their controllable units in the most effective manner possible. Future initiatives will also address difficulties with power system implementation and quality enhancement, like cost reduction through the use of PV

### Table 1: PV systems’ technical specifications.

| Parameter                | CIS     | m-Si    |
|--------------------------|---------|---------|
| MNM (watt)               | 180     | 210     |
| Vmp (V)                  | 88.5    | 39.62   |
| Imp (A)                  | 2.4     | 6.8     |
| Voc (V)                  | 115     | 48.15   |
| TCOP (%/K)               | -0.35   | -0.41   |
| Voc (A)                  | 2.45    | 5.65    |
| Inverter (kVA)           | 1.7     | 1.4     |
| Rated power (kWP)        | 1.62    | 1.3     |
| NMS                      | 4       | 1       |
| Azimuth angle (degree)   | 180     | 180     |
| NM                       | 10      | 5       |
| Module tilt (degree)     | 10      | 10      |

Note: MNM: module nominal Power, Vmp: module voltage at maximum power, Imp: module open circuit voltage, TCOP: temperature coefficient of power, Voc: module short current voltage, NMS: number of module string, NM: number of modules.

### Table 2: Sensor’s technical specifications in weather station [15].

| Instrument                  | Accuracy | Range          |
|-----------------------------|----------|----------------|
| WSS WS120                   | ±4%      | 0-75 m/s       |
| SRS (PYRA 300 V2)           | ±6%      | 0-1800 W/m²    |
| MTS(RTD Pt1000Ω)            | ±0.6°C   | 0-100°C        |
| WDS                         | ±4°      | 0-360°         |
| ATS (RTD Pt1000Ω class A)  | ±0.4°C   | 0-100°C        |

Note: WSS: wind speed sensor, SRS: solar radiation sensor, MTS: module temperature sensor, WDS: wind direction sensor, ATS: ambient temperature sensor.
more similar to those of the PVUSA technique; however, a greater knowledge of the issues and reduce factor can give rise to tighter agreement and reveal opportunities for improving system performance [11]. To adjust for lower output in actual operating conditions contrasted to the conditions in which the PV panel was rated, a scaling factor known as the photovoltaic (PV) derating factor is applied to the power output of the PV array.

The issue of electrical security has become more pressing due to rising electricity consumption in developing nations. To make use of the unused energy from renewable resources, this has become required. Due to their grid connectivity, PV systems have emerged as the most effective source of renewable energy on a broad scale. The design, operation, and integration of new grid-connected systems can be aided by performance analysis of these plants that are connected to the power. One of the largest auxiliary solar power plants, a 10 MW photovoltaic power grid attached to Ramagundam, receives a fair quantity of 4.97 kiloWatt hr/m2/day per year and the mean temperature is about 27.3 degrees centigrade. The business is geared for seasonal activities. This study goes into detail into the characteristics of solar PV architecture and its annual performance. Performance rating is determined by measuring various power losses (such as those caused by temperature, internal networks, electronics power, associated grids, etc.). The findings of plant performance tests are also contrasted with simulation results from PV system and PV-GIS software. The crop’s final yield ranges from 1.96 to 5.07 hours each day, with a yearly performance rate of 86.12 percent. It generates 15,798,192 MWh or 17.68 percent of CUF power annually. Monitoring data and operating details for a Photovoltaic system can be used for significant initiatives in the future [4].

It is necessary to perform research to meet the load rather than the effects of the distributed generation (DG) grid as a result of the Net Plus-energy Buildings (NPEB) plan. This document is an imitation of the EnergyPlus software application, which is based on NPEB and works with four Brazilian city areas. Analysis covers grid interaction, loads matching indications, and photovoltaic (PV) efficiency limits (LMGI). There are new grid effect indicators available to research how DG affects the electrical grid. The investigation of economic elements is done in the second phase with the aid of net metering. The years are displayed in the

| Sl. No | Parameters | Symbol | Equation | Eqn. No |
|-------|------------|--------|----------|---------|
| 1.    | Final yield | \(Y_F\) | \(\frac{E_{AC}}{P_{PV,rated}}\) | (1) |
| 2.    | Monthly energy output | \(E_{AC,M}\) | \(\sum_{d=1}^{n} E_{AC,d}\) | (2) |
| 3.    | Efficiency of PV module | \(\eta_{PV}\) | \(\frac{E_{DC,d}}{A_aH_l}\) | (3) |
| 4.    | Array yield | \(Y_A\) | \(E_{DC}\) | (4) |
| 5.    | System efficiency | \(\eta_Y\) | \(\left(\frac{E_{AC,d}}{A_aH_l}\right) \times 100\%\) | (5) |
| 6.    | Capacity utilization factor | CUF | \(\frac{E_{AC}}{8760 \times P_{PV,rated}}\) | (6) |
| 7.    | System loss | \(L_S\) | \(Y_A - Y_F\) | (7) |
| 8.    | Reference yield | \(Y_R\) | \(H_l\) | (8) |
| 9.    | Temperature loss | \(L_T\) | \(E_{DC} \times \left(\frac{(25 - T_M)\gamma}{1 + \gamma(T_M - 25)}\right)\) | (9) |
| 10.   | Performance ratio | PR | \(\frac{Y_F}{Y_R} \times 100\%\) | (10) |
| 11.   | Array capture loss | \(L_{ACap}\) | \(Y_R - Y_A\) | (11) |

Symbols definition: \(n\): number of days in a month; \(P_{PV,rated}\): PV array’s nominal power (kWp); \(E_{AC,d}\): energy output of daily DC from the array (kWh/kWp); \(E_{AC}\): energy output of daily AC (kWh/kWp); \(\gamma\): module’s temperature coefficient of power; \(H_l\): global-in-plane solar irradiation (kWh/m²/day); \(A_a\): array area of PV (m²); \(T_M\): temperature of PV module (°C); \(H_r\): in-plane reference irradiation of array (kWh/m²/day).

| Sl. No | EM | Eqn. | Eqn. No | Unit |
|-------|----|------|---------|------|
| 1.    | LCCE | \(\frac{(T_L \times E_{out}) - E_{in}}{T_L \times E_{sol}}\) | (12) | Years |
| 2.    | EPF | \(T_L \times \left(\frac{E_{out}}{E_{in}}\right)\) | (13) | — |
| 3.    | EPBT | \(\frac{E_{in}}{E_{out}}\) | (14) | % |
The yearly electricity supply loads vary from 20 to 36 percent depending on the climatic variables of the photovoltaic load relative and power generation levels exported to Brazil’s high grid by yearly basis power peak position around 0.7 but it can exceed 0.8 in extremely sunny conditions. When PV production is high and temperature control capacity is high, solar energy can supply up to 51% of the electricity requirement. The building achieves grid equity between 6 and 18 percent of discount rates, according to the economy, and payment terms are offered under various conditions for investment expenses, discount rates, and power bills. Investment expenses and loan discount rates, among other non-technical and unpredictable factors, have a substantial effect. It is difficult to attain grid equity, thus political backing and financial incentives are still required. According to studies, local economic situations fluctuate based on the price of power and the real discount rates [12].

In this paper, analysis and modelling of a grid are presented to help evaluate the interaction behaviour of its nodes and to help control performance during system development (GCPS). Maintenance costs are low. Most of the power comes from the sun, therefore it helps save money on electricity. In addition, setting it up is a breeze. Grid-connected PV systems have a short gestation period. Its natural characteristics are easily imitated using basic specification data and a straightforward solar array circuit model. Comprehensive power control and GCPS security are provided by user-defined and constructed modules and power circuits to account for the passage of normal and defective situations, which are controlled by its dynamic power control. In PSCAD/EMTDC, a temporary power system software package, the model is referred to and used. To confirm that the suggested simulation model is successful in assessing the GCPS detection and protection performance in accordance with the temporary magnetic field analysis, comprehensive simulation results are provided and analysed. This approach may offer a practical tool for managing the creation and assessment of GCPS effectiveness [13].

There are numerous issues with integrated photovoltaic (PV) systems that result in an average loss of 20–25 percent in power production. There are many different factors, including temperature impacts, variances in the position and inclination of solar panels, partial loss, and partial shading, and due to production methods, PV module current-voltage (V) properties can vary. By employing the proper electrical systems, these losses can be minimised. The idea of a smart photovoltaic module, a low-cost dc-dc converter having high point-tracking capabilities (MPPT), a controller, and a power supply cable (PLC) are all introduced in this work. This study also looks at the intermediate, cable, and modular topologies for grid-connected PV system construction. The suggested system, a smart PV module, belongs to this last category. The boost dc-dc converter’s topology and operating principles are being examined. Additionally, MPPT approach comparisons are carried out, which

| Monitored period (month) | Beam radiation (kWh/m²/d) | Diffused radiation (kWh/m²/d) | Clearness index |
|-------------------------|--------------------------|-------------------------------|----------------|
| Jan                     | 4.5                      | 1.8                           | 0.6            |
| Feb                     | 5.2                      | 2.1                           | 0.5            |
| Mar                     | 4.3                      | 2.9                           | 0.42           |
| Apr                     | 4                        | 2                             | 0.5            |
| May                     | 3.8                      | 2.4                           | 0.4            |
| Jun                     | 3.2                      | 2.7                           | 0.3            |
| Jul                     | 3                        | 1.5                           | 0.5            |
| Aug                     | 3.4                      | 2.3                           | 0.35           |
| Sep                     | 3.9                      | 3.2                           | 0.43           |
| Oct                     | 3.21                     | 2.6                           | 0.55           |
| Nov                     | 3.5                      | 1.2                           | 0.6            |
| Dec                     | 3.7                      | 1                             | 0.52           |

Results. The yearly electricity supply loads vary from 20 to 36 percent depending on the climatic variables of the photovoltaic load relative and power generation levels exported to Brazil’s high grid by yearly basis power peak position around 0.7 but it can exceed 0.8 in extremely sunny conditions. When PV production is high and temperature control capacity is high, solar energy can supply up to 51% of the electricity requirement. The building achieves grid equity between 6 and 18 percent of discount rates, according to the economy, and payment terms are offered under various conditions for investment expenses, discount rates, and power bills. Investment expenses and loan discount rates, among other non-technical and unpredictable factors, have a substantial effect. It is difficult to attain grid equity, thus political backing and financial incentives are still required. According to studies, local economic situations fluctuate based on the price of power and the real discount rates [12].

In this paper, analysis and modelling of a grid are presented to help evaluate the interaction behaviour of its nodes and to help control performance during system development (GCPS). Maintenance costs are low. Most of the power comes from the sun, therefore it helps save money on electricity. In addition, setting it up is a breeze. Grid-connected PV systems have a short gestation period. Its natural characteristics are easily imitated using basic specification data and a straightforward solar array circuit model. Comprehensive power control and GCPS security are provided by user-defined and constructed modules and power circuits to account for the passage of normal and defective situations, which are controlled by its dynamic power control. In PSCAD/EMTDC, a temporary power system software package, the model is referred to and used. To confirm that the suggested simulation model is successful in assessing the GCPS detection and protection performance in accordance with the temporary magnetic field analysis, comprehensive simulation results are provided and analysed. This approach may offer a practical tool for managing the creation and assessment of GCPS effectiveness [13].

There are numerous issues with integrated photovoltaic (PV) systems that result in an average loss of 20–25 percent in power production. There are many different factors, including temperature impacts, variances in the position and inclination of solar panels, partial loss, and partial shading, and due to production methods, PV module current-voltage (V) properties can vary. By employing the proper electrical systems, these losses can be minimised. The idea of a smart photovoltaic module, a low-cost dc-dc converter having high point-tracking capabilities (MPPT), a controller, and a power supply cable (PLC) are all introduced in this work. This study also looks at the intermediate, cable, and modular topologies for grid-connected PV system construction. The suggested system, a smart PV module, belongs to this last category. The boost dc-dc converter’s topology and operating principles are being examined. Additionally, MPPT approach comparisons are carried out, which

Figure 3: Monthly meteorological data. (a) Clearness index and mean global solar-radiation and (b) variations in module temperature, wind velocity, and ambient temperature.
The proposed (PCGSS) with bidirectional flows would enable residual energy to be brought to the power system in whole or in part, depending on its requirements, while in a critical working environment, the grid would then demonstrate the greatest outcomes of the growing performance. The PLC in every photovoltaic modules and its capability for grid-connected PV power are taken into consideration and studied in this article with regard to communications. A smart PV module (with dc-dc converter) prototype has undergone testing utilising the PV system testing platform to confirm its full performance. This paper explains this extremely potent instrument created to test all types of PV systems. By implementing a smart failure detection system, users will be able to create PV plant repair procedures based on specific data [14].

The proposed (PCGSS) with bidirectional flows would enable residual energy to be brought to the power system in whole or in part, depending on its requirements, while in a critical working environment, the grid would then directly supply loads. A photovoltaic (PV) system’s charging time would be reduced as a result, increasing its viability for commercial use. A completely new management method is proposed to achieve this goal, improve the power produced, and allow the system to function as a scattered resource inside the utility grid. New alternatives are constrained: in the first, all of the power from the dispersed network is consumed by the grid, and in the second, power is added to the grid as needed. In order for the system to function according to the routes employing management algorithms with either Max Power Points (MPP) or Limited Power Points (LPP) applications, requirements must be met. The maximum power point, also known as the MPP, is the point on the current-voltage curve of an illuminated solar module that corresponds to the point at which the product of that module’s current and voltage is at its highest value. LPP is carried out using a modified Perturbation and Observation approach. For continued power delivery and to maintain system performance, the battery system has been connected to the PV system. There are limits to a system’s capacity to deliver the best loads. [1].

In accounting for differences, input variables and failure rates based on the state of vital components, including PV modules, inverters, and capacitors, this study offers a systematic approach for assessing the dependability of large-scale power systems connected to a solar grid (PV). In order to examine PV systems connected to the actual grid, state calculations are used. The key PV system components’ failure levels based on ambient conditions are constructed and taken into account in the reliability study. To gauge the dependability performance of PV systems, a number of indication of the strength are defined. Considering the state of critical components like inverters, PV modules, and capacitors, as well as input parameters and failures, this study offers a methodical approach for assessing the dependability of high-power applications connected to a solar grid (PV). In order to examine photovoltaic panels connected to the actual grid, state calculations are used. The key photovoltaic systems components’ failure levels based on ambient conditions are constructed and taken into account in the reliability study. To gauge the dependability performance of PV systems, a number of reliability indicators are defined [5].

In developed countries, the deployment of energy photovoltaic systems (GCPVS) in urban structures is very widespread. International multilateral projects are being developed by many nations to hasten the installation of photovoltaic as a significant, long-lasting source of renewable energy. The prior approach, which relies on sensory networks (ANNs), is made to function with PV module electrical properties. This technique might create PV modules with crystalline V-I curves of any temperature and irradiance. The outcomes showed that the suggested ANN provided a good, precise prediction of the functionality of the crystalized PV modules. This technology, which is based on ANNs, will now be used to determine the fair value of the power that is supplied for PV installations. It is essential to determine the greatest amount of energy that can be harvested from a photovoltaic panel in order to maximise the amount of power that can be generated by a solar

### Table 6: Variations in module temperature, wind velocity, and ambient temperature.

| Monitored period (month) | Wind velocity (m/s) | CIS-module temperature (°C) | AT (°C) | m-Si MT (°C) |
|-------------------------|--------------------|----------------------------|--------|--------------|
| Jan                     | 3.7                | 32                         | 27     | 37           |
| Feb                     | 3.4                | 34                         | 29     | 39           |
| Mar                     | 2.6                | 40                         | 30     | 42           |
| Apr                     | 2.2                | 37                         | 35     | 34.2         |
| May                     | 3.6                | 36.5                       | 27     | 35.7         |
| Jun                     | 5.1                | 35                         | 26     | 42.4         |
| Jul                     | 4.6                | 33                         | 29     | 44.5         |
| Aug                     | 4                  | 38                         | 26.5   | 37.4         |
| Sep                     | 3.2                | 36                         | 28.4   | 38.6         |
| Oct                     | 2.6                | 35                         | 25     | 37.5         |
| Nov                     | 3.1                | 32                         | 27     | 39           |
| Dec                     | 3.5                | 30                         | 28.4   | 42           |

Note: AT: ambient temperature, MT: module temperature.

### Figure 4: CIS and m-Si PV array’s predicted and measured array yield comparison.

![Figure 4: CIS and m-Si PV array's predicted and measured array yield comparison.](image-url)
photovoltaic system. A comparison is made between the performance of a conventional MPPT method and one that is based on an artificial neural network (ANN). Since the modules used in these functions are identical to those used in this solar generator, this method will be utilised in particular to determine the power supplied for a given installation, the “Unver Generator”. Prices for PV modules are not rated when being compared [6].

3. Methodology

The development’s goal is to evaluate the thin film photovoltaic (PV) systems and crystalline silicon’s energy efficiency in real-world climatic circumstances in Thoothukudi, Tamil Nadu, in Southern India. A methodical process is developed to conduct the assessment. In order to assess the effectiveness of colocated monocrystalline Silicon (m-Si) and copper indium selenium (CIS) PV systems, the PV plants were initially developed employing PVsyst software. Grid-tied PV systems and a remote monitoring technology were deployed on the rooftop to conduct the exploratory method. The meteorological station that was set up at the location provides data on the ambient temperatures, wind speed, and sun radiation over horizontal substrates. The measured variables, like PV array’s surface temperature, current, and output voltage, have been used to study the array yield, PV, energy output, final yield, and system efficiencies. This research looks at the PV technology’s capacity utilisation factor (CUF) and performance ratio (PR). The computed energy losses include system loss, temperature loss, and array capture loss. Moreover, with the simulated results calculated from the PVsyst optimization technique, the PV systems’ year-round performance is contrasted to and evaluated against the actual outside climatic constraints. In the end, energy measurements such as energy production factor (EPF), life cycle conversion efficiency (LCCE), and energy payback time (EPBT) have been assessed in order to estimate the whole energy performance of the PV systems.

3.1. PV System Description.

The rooftop has been installed with the grid-tied PV frameworks using p-Si and CIS technologies that were used for the performance evaluation. Tamil Nadu does have a tropical climate with small seasonal variations in winter and summer temperatures. The coldest season, which lasts from November to February, has an average temperature of 28°C while the warmest season, which lasts from March to June, has an average temperature that reaches 40°C. The PV plants are made up of 10 CIS modules and 5 m-Si modules, with operational capacities of 1.62 kWp, and 1.3 kWp, correspondingly. The PV modules’ north-south orientation faces directly south, and they are inclined at a 10° fixed angle.

Temperatures of the photovoltaic (PV) modules of the system as well as the ambient temperature, global radiation,
direction, wind speed, and diffused radiation are continuously measured by the Wattmon solar kit, which is a component of the weather station at the location. Wattmon is a web-based application that allows you to log data, monitor, and control the devices you use. The system’s Alternating Current (AC) power output is connected to the electric grid using PowerOne single phase 250 V solar inverters with 1.4 kW and 1.7 kW capacities for m-Si and CIS units, correspondingly. Every six minutes, a real-time gathering mechanism is set up using a PowerOne GPRS kit to monitor the AC and Direct Current (DC) outputs from the PV plants. The presented grid-connected PV module’s schematic diagram is depicted in Figure 2. The employed PV technologies detailed specifications are represented in Table 1 and the utilized sensor’s technical specifications in the meteorological/weather station are depicted in Table 2.

4. Performance Parameters

4.1. Analysing Performance Metrics. The PV systems’ performance is studied in this research using the effectiveness metrics established by the IEC standard 61724 [16] and International Energy Agency (IEA). Reference yield, system losses, final yield, array yield and array, system and PV efficiencies, PR, and CUF are some of the evaluation metrics, and they are all shown in Table 3. The exact energy yields from array could be standardised to the system’s regarded power (i.e., 1.3kWp) [17]. The applicability of these normalised performance measures offers a foundation for comparing PV installations under diverse operating environment. Losses that diminish the effectiveness of the system are caused by radiation and convection heat transfer, both of which are utilised in the generation of power in PV modules. Convective heat transfer occurs in photovoltaic modules as a result of the movement of air across the surface of the module. Radiation is the final means through which heat can be transferred from the PV module to the environment around it. The array capture loss, cell temperature loss, and system loss were the more noticeable losses [18]. Per degree Celsius increase in module temperature over typical test

| Monitored period (2020) | Ls | Ys | FS | LAcap | Ls | Ys | FS | LAcap |
|------------------------|----|----|----|-------|----|----|----|-------|
| Jan                    | 0.25 | 4.5 | 13 | 1.2   | 0.24 | 5.0 | 11.5 | 0.52 |
| Feb                    | 0.75 | 4.8 | 12.7 | 1.63 | 0.21 | 5.28 | 11.3 | 0.64 |
| Mar                    | 0.04 | 4.9 | 12 | 1.54 | 0.21 | 5.29 | 11.8 | 0.43 |
| Apr                    | 0.02 | 4.4 | 11.6 | 1.26 | 0.14 | 4.9 | 11.4 | 0.36 |
| May                    | 0.06 | 4.2 | 11.8 | 1.34 | 0.12 | 4.5 | 12.2 | 0.21 |
| Jun                    | 0.5 | 3.75 | 13.2 | 1.1 | 0.28 | 4.25 | 12.5 | 0.34 |
| Jul                    | 0.25 | 4.0 | 13.4 | 1.4 | 0.24 | 4.29 | 11.9 | 0.45 |
| Aug                    | 0.52 | 4.25 | 13 | 1.6 | 0.21 | 4.6 | 12.6 | 0.47 |
| Sep                    | 0.34 | 4.9 | 13.3 | 1.59 | 0.19 | 4.8 | 12.7 | 0.38 |
| Oct                    | 0.25 | 4.75 | 13.7 | 1.48 | 0.15 | 5.2 | 11.82 | 0.27 |
| Nov                    | 0.001 | 4.2 | 13.5 | 1.05 | 0.02 | 5.5 | 12.9 | 0.25 |
| Dec                    | 0.002 | 4.5 | 13.9 | 1.36 | 0.005 | 4.9 | 13.2 | 0.22 |
4.2. Energy Metrics and Embodied Energy. The overall amount of energy needed for all the steps in a producing process, such as installation, fabrication, raw materials, and maintenance, is known as embodied energy $E_{em}$. To evaluate whether the system either adds to or reduces global warming and also to ascertain the PV system’s performance, this assessment is crucial. Three fundamental energy measures are used to calculate a PV system’s performance. Table 4 shows their representations as energy production factor (EPF), life cycle conversion efficiency (LCCE), and energy payback time (EPBT). The embodied energy’s breakup for circumstances, the PV module’s energy production drops from 0.3 to 0.4 percent [19]. The temperature of the PV system relates to the temperature-related loss. A rise in the external temperature causes the panel temperature to rise, which reduces the amount of power produced.
the CSI and m-Si PV plants was evaluated as 1692.28 kWh and 6865.73 kWh, respectively. Where $E_{out}$ is PV system’s overall energy generation (kWh/year), $T_L$ is PV system’s overall lifetime (years), $E_{in}$ is total energy involved in PV system’s installation and fabrication (kWh), $E_{sol}$ is the input of annual solar radiation (kWh), and $EM$ is energy metrics.

5. Results and Discussion

5.1. Meteorological Database. From January to December 2020, the CIS and m-Si PV module’s efficiency has been assessed continuously. Figures 3(a) and 3(b) collect and graph the various variables, including diffused radiation, global radiation, wind velocity, clearness index, module surface temperature, and ambient temperature.

The beam radiation were ranges from 5.2 kWh/m$^2$/d to 3 kWh/m$^2$/d; the diffused radiation were ranges from 1 kWh/m$^2$/d to 3.2 kWh/m$^2$/d; and the clearness index from the months January to December ranges from 0.3 to 0.6. Moreover, the wind velocity were ranges from 2.2 m/s to 4.6 m/s for the monitored period 2020; the ambient temperature ranges from 25$^\circ$C to 35$^\circ$C; the m-Si module temperature ranges from 34.2$^\circ$C to 44.5$^\circ$C; and the CSI module temperature ranges from 30$^\circ$C to 40$^\circ$C. The solar insolation of the CIS and m-Si power plant has been represented in Table 5 and the variations in module temperature, wind velocity, and ambient temperature are depicted in Table 6.

5.2. Energy Yields Analysis. The test site’s CIS and m-Si PV plants’ evaluated output was contrasted with the findings of the PVsyst simulation, which are shown in Figure 4. In order to minimize the uncertainties, the simulations incorporate the test site’s latitude, longitude, and altitude as well as observed climate databases (ambient temperature, worldwide solar radiation, and wind speed). The graph demonstrates that the projected and observed array yields for CIS and m-Si PV technologies followed the similar pattern. It turns out that for both PV systems, the array yield anticipated by the algorithms and the actual observed values correspond very closely. Table 7 illustrates the measured and predicted final yield for CIS and m-Si PV modules.

However, because of the lower in-plane incoming radiation in December compared to the expected amount in August, the observed array yield for both CIS and m-Si PV systems was the lowest. Additionally, it has been found that in the majority of climatic situations, CIS technology outperformed m-Si technology. Furthermore, because the ambient temperature was relatively less during the summer season and the dispersed element of light was larger in incoming
radiation, the CIS technology had observed a substantial yield above the projected value.

5.3. System Efficiency, PV, and Energy Losses Analysis. System loss, array capture loss, and temperature loss seem to be the energy losses taken into account in this research and should be given the appropriate attention. The module temperature was recorded at 44°C and 40°C, correspondingly, which significantly reduces the DC energy yield. In April, temperature losses for CIS and m-Si PV modules were reported to be as 0.224 h/day and 0.236 h/day. The system temperatures’ monthly average takes into account daylight hours or from 6 a.m. to 7 p.m. The modules’ temperatures for m-Si and CIS PV modules were 39°C and 32°C, correspondingly, during the cold months of November through January because of the decreased temperature losses, which are measured as 0.121 h/day and 0.26 h/day in December. Despite the clear skies and greater mean incident solar insolation in March month, the array’s DC energy yield was found to be significantly higher despite high-temperature depreciation. Additionally, a modest increase in DC energy generation is seen from June to September, along with minor changes in temperature degradation for CIS and m-Si PV modules. In any case, India seems to be in a warm, humid region, and because the temperature changes are never negative, the PV array experiences no gains rather than losses. The effectiveness of a PV method is highly influenced by both the module and irradiance temperature. For CIS and m-Si technologies, the mean monthly PV performance ranges from a low of 12.56 percent and 12.32 percent in April to a high of 15.8 percent and 14.6 percent in January. Throughout the year, the CIS technology’s mean module temperature is 4°C less than the m-Si technique. The PV effectiveness for both techniques is significantly lower in the hot than it is in the cold leading to increased module temperatures. Month-wise comparison is shown in Table 8. Figures 5(a) and 5(b) shows the temperature loss and yield array for CIS and m-Si. Figures 6(a) and 6(b) shows the PV efficiency and temp module for CIS and m-Si.

However, due to massive wind velocities that lower the module temperatures, a modest gain in PV effectiveness is seen for both PV modules in June and July. Through the year, the effectiveness of CIS PV system is practically on par with that of m-Si innovation. It demonstrates that the CIS system is operating equally well in regards to energy production as that of the m-Si plant underneath the real warm and wet weather conditions of southern India. The m-Si and CIS systems show the greatest \( L_{Agp} \) values of 1.63 h/day and 1.05 h/day as well as the lowest values of 0.64 h/day and 0.25 h/day, respectively. Table 9 shows the system loss, final yield, system efficiency, and capture losses monthly variation for PV modules. Figures 7(a) and 7(b) show the final yield and system loss for CIS and m-Si. Figures 8(a) and 8(b) show the capture loss and system efficiency for CIS and m-Si.

5.4. Annual and Monthly Performance Variation. The measurement values at the location for a full year are typically used to comprehensively examine the solar PV installations energy performance. The monthly overall in-plane-solar radiation ranged from 136.25 kWh in December 2020 during cold months to 194.54 kWh in March 2020 while summer months, even during evaluation period (January-December 2020) in this research. The lowest and highest values for standardized monthly energy production for m-Si and CIS PV systems, correspondingly, were 104.15 kWh and 115.25 kWh in December and 148.42 kWh and 162.64 kWh in March, including both. According to the recorded monthly mean energy production for the CIS and m-Si silicon power plants, the three most important environmental elements that determine energy production are the irradiance of the sun, the velocity of the wind, and the temperature of the surrounding environment. Despite all of the advancements, the performance of solar cells is still affected by a wide variety of environmental parameters. Some of these factors include temperature, humidity, wind velocity, light intensity, altitude, and air pressure. The PV array’s discharge current gradually increases as the radiation frequency increases, as is obvious. The irradiance has a linear relationship with the DC power that the PV systems produce. However, because of the opposing influence of the system temperature, there is a drop in the effectiveness of solar PV modules.

5.5. CUF and System PR Analysis. The performance ratio (PR) was among the most important factors to consider when evaluating an SPV system’s effectiveness. Since PR is a measurement of a PV system’s efficiency regardless of where it is installed, it is also known as the “quality factor.” Figure 9 displays the simulation of observed PR that was attained during the observation time. It should be remembered that plants function slightly better in the cold than they do in the summertime. This is due to substantial energy inefficiencies in the summer caused by increasing PV module heating at comparatively small wind speeds. For the m-Si plant, the observed monthly PR values were nearly identical to those predicted by the software, however, for the CIS plant, the observed PR values are greater for the majority of the months in 2020.

This explains an improvement of roughly 8% in the CIS system’s yearly mean daily PR when contrasted to the m-Si plant. Although CIS technique has a lesser STC conversion effectiveness than m-Si modules, it offers greater performance all year long. Since dispersed light’s short waves fractions seem to be more concentrated in the spectrum’s ultraviolet and blue end, CIS technique is better able to transform these frequencies into useful energy than m-Si technologies.

There has been no absorbance loss for CIS in the wavelength’s lower wavelength region less than 520 nm, which led to an enhancement in the short-circuit power intensity. The solar PV system’s cell efficiency and GHI determine the specific location’s CUF for the deployed PV system. According to the system’s final yield, the CUF eventually fluctuates with the AC power produced. During the maximum summertime in March 2020, the monthly mean CUF is at its highest, reaching 20.16 percent for m-Si systems and 23.09 percent for CIS systems, correspondingly. Both
PV systems’ CUF is considerably lower than the mean CUF of the majority of rooftop SPV modules when compared. Moreover, the monthly mean CUF for measured period is shown in Figure 10. Moreover, the presented PV system comparison with other systems is shown in Table 10.

5.6. Analysis of Energy Metrics. For the PV system’s real outdoor effectiveness under study, the EPF, EPBT, and LCCE were estimated. Table 11 provides the calculated embodied energy for the PV modules. The m-Si and CIS PV devices’ corresponding total embodied energies are calculated to be 6762.73 kWh and 1952.71 kWh. Table 12 and Figure 11 provide information on the PV equipment’ energy metrics.

6. Conclusions
In the current study, two colocated smaller scale roof-top PV plants on the campus had their performance compared. The monocrystalline silicon (m-Si) and copper indium selenium (CIS) technology, with capacities of 1.3kWp and 1.62kWp, correspondingly, are the foundations of the grid-connected PV installations. The PV system’s behaviour in the winter and muggy climate of southern Tamil Nadu, India, has been represented by the external evaluation. The monthly and yearly performance metrics are evaluated and contrasted with predicted outcomes. The incident solar irradiation and ambient temperature have a significant impact on the module’s temperature, which in turn affects the output power. For practically identical incident solar irradiance on the early days used for the study in heat and cold, the CIS PV module produces more power than the m-Si technology. By using the observed site variables as inputs to the modelling programme, the year-round efficiency forecast of the CIS and m-Si PV technologies is in reasonable accordance with the annual energy’s observed values injected to the grid with an ambiguity.

Data Availability
The data used to support the findings of this study are included within the article.

Conflicts of Interest
The authors declare that there is no conflict of interest regarding the publication of this article.

Acknowledgments
The authors would like to express their gratitude towards Vellore Institute of Technology, Chennai for providing the necessary infrastructure to carry out this work successfully.

References
[1] A. Guichi, A. Talha, E. M. Berkouk, and S. Mekhilef, “Energy management and performance evaluation of grid connected PV-battery hybrid system with inherent control scheme,” Sustainable Cities and Society, vol. 41, pp. 490–504, 2018.
[2] F. Perera, “Pollution from Fossil-Fuel Combustion is the Leading Environmental Threat to Global Pediatric Health and Equity: Solutions Exist,” International Journal of Environmental Research and Public Health, vol. 15, no. 1, p. 16, 2017.
[3] F. Hussain, M. Y. H. Othman, K. Sopian, B. Yatim, H. Ruslan, and H. Othman, “Design development and performance evaluation of photovoltaic/thermal (PV/T) air base solar collector,” Renewable and Sustainable Energy Reviews, vol. 25, pp. 431–441, 2013.
[4] B. Shiva Kumar and K. Sudhakar, “Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India,” Energy Reports, vol. 1, pp. 184–192, 2015.
[5] S. Ramesh, J. Seetha, G. Ramkumar et al., “Optimization of solar hybrid power generation using conductance-fuzzy dual-mode control method,” International Journal of Photoenergy, vol. 2022, Article ID 7756261, 10 pages, 2022.
[6] F. Almonacid, C. Rus, P. J. Pérez, and L. Hontoria, “Estimation of the energy of a PV generator using artificial neural network,” Renewable Energy, vol. 34, no. 12, pp. 2743–2750, 2009.
[7] A. Batman, F. G. Bagriyanik, Z. E. Aygen, O. Gül, and M. Bagriyanik, “A feasibility study of grid - connected photovoltaic systems in Istanbul, Turkey,” Renewable and Sustainable Energy Reviews, vol. 16, no. 8, pp. 5678–5686, 2012.
[8] T. M. Amiríhalakshmi, P. Ramesh, R. Thandiaiah, G. Ramkumar, S. Sahoo, and P. Thomas, “A novel approach in hybrid energy storage system for maximizing solar PV energy penetration in microgrid,” International Journal of Photoenergy, vol. 2022, Article ID 3559837, 7 pages, 2022.
[9] A. El Mouatamid, R. Ouladsine, M. Bakhrouya et al., “Modeling and Performance Evaluation of Photovoltaic Systems,” in 2017 International renewable and sustainable energy conference (IRSEC), pp. 1–7, Tangier, 2017.
[10] A. Chouder, S. Silvestre, N. Sadaoui, and L. Rahmani, “Modeling and simulation of a grid connected PV system based on the evaluation of main PV module parameters,” Simulation Modelling Practice and Theory, vol. 20, no. 1, pp. 46–58, 2012.
[11] B. Marion, J. Adelstein, K. Boyle et al., “Performance parameters for grid-connected PV systems,” in Conference Record of the Thirty-first IEEE Photovoltaic Specialists Conference, 2005, pp. 1601–1606, Lake buena Vista, FL, USA, 2005.
[12] G. A. Dávi, E. Caamaño-Martín, R. Rüther, and J. Solano, “Energy performance evaluation of a net plus-energy residential building with grid-connected photovoltaic system in Brazil,” Energy and Buildings, vol. 120, pp. 19–29, 2016.
[13] S.-K. Kim, J.-H. Jeon, C.-H. Cho, E.-S. Kim, and J.-B. Ahn, “Modeling and simulation of a grid-connected PV generation system for electromagnetic transient analysis,” Solar Energy, vol. 83, no. 5, pp. 664–678, 2009.
[14] E. Roman, R. Alonso, P. Ibanez, S. Elorduizapatarietxe, and D. Goitia, “Intelligent PV module for grid-connected PV systems,” IEEE Transactions on Industrial Electronics, vol. 53, no. 4, pp. 1066–1073, 2006.
[15] R. P. Kalidasa, K. Murugavel, and A. Karthick, “Performance analysis and energy metrics of grid-connected photovoltaic systems,” Energy for Sustainable Development, vol. 52, pp. 104–115, 2019.
[16] I E Commission, Photovoltaic system performance monitoring-guidelines for measurement, data exchange and analysis, IEC 61724, 1998.
[17] V. Sharma, A. Kumar, O. S. Sastry, and S. S. Chandel, “Performance assessment of different solar photovoltaic technologies
under similar outdoor conditions,” *Energy*, vol. 58, pp. 511–518, 2013.

[18] S. K. Yadav and U. Bajpai, “Performance evaluation of a rooftop solar photovoltaic power plant in Northern India,” *Energy for Sustainable Development*, vol. 43, pp. 130–138, 2018.

[19] F. Tahri, A. Tahri, and T. Oozeki, “Performance evaluation of grid-connected photovoltaic systems based on two photovoltaic module technologies under tropical climate conditions,” *Energy Conversion and Management*, vol. 165, pp. 244–252, 2018.

[20] L. C. de Lima, L. de Araújo Ferreira, and F. H. B. de Lima Morais, “Performance analysis of a grid connected photovoltaic system in northeastern Brazil,” *Energy for Sustainable Development*, vol. 37, pp. 79–85, 2017.

[21] M. Emmanuel, D. Akinyele, and R. Rayudu, “Techno-economic analysis of a 10 kWp utility interactive photovoltaic system at Maungaraki school, Wellington, New Zealand,” *Energy*, vol. 120, pp. 573–583, 2017.

[22] A. De Miguel, J. Bilbao, J. Cazorro, and C. Martin, *Performance Analysis of a Grid-Connected PV System in a Rural Site in the Northwest of Spain*, Elsevier Science Ltd, 2002.

[23] K. Padmavathi and S. A. Daniel, “Performance analysis of a 3 MWp grid connected solar photovoltaic power plant in India,” *Energy for Sustainable Development*, vol. 17, no. 6, pp. 615–625, 2013.

[24] L. M. Ayompe, A. Duffy, S. J. McCormack, and M. Conlon, “Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland,” *Energy Conversion and Management*, vol. 52, no. 2, pp. 816–825, 2011.