Design and Development of a Biomimetic Solar Tree for Sustainable Cogeneration: An Energy and Exergy Assessment

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Abstract. Solar energy is becoming an increasingly popular and important source of renewable energy. Solar trees have emerged as a novel and innovative approach to harvesting solar energy. Solar trees are artificial structures that mimic the shape and function of trees, with branches or leaves that contain photovoltaic cells to convert sunlight into electricity. The solar tree generates both electrical and thermal energy from solar radiation. The present study tested the thermal (module temperature, heat loss coefficient), electrical (power output), and operating parameters of a solar tree at Universiti Malaysia Pahang, Pekan, Malaysia, on a typical sunny day. First-law analysis and second-law analysis were carried out to determine exergy losses during the photovoltaic conversion process of solar trees. The data obtained from the experiment is utilized to determine the energy and exergy efficiencies of the solar tree. The energy efficiency ranges from 16.8% to 8.3% throughout the day, displaying some variability. However, as for the exergy efficiency of the photovoltaic solar tree under consideration, it is observed to be lower, ranging from 16.1% to 6.6% for electricity generation. It is observed that the exergy losses increased with increasing module temperature and a drop in exergy efficiency.

1 Introduction

The concentration of greenhouse gases in the atmosphere is heightened due to the growing reliance on traditional energy sources [1,2]. Renewable energy sources are gaining significant global importance in this regard. Theoretically, harnessing just 1% of the sun's energy would meet the world's energy needs. By effectively utilizing solar energy, it is even possible to replace the dependence on fossil fuels. Solar energy is abundant, infinite, and universally accessible [3–5]. Therefore, the potential and significance of solar energy in the future are

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immense. Despite their significant potential, except for water heating applications, solar energy technologies are currently not widely used.

Conversely, Malaysia benefits from a good climate that presents a wealth of chances for utilizing solar energy. Solar cells, commonly known as photovoltaic cells, are solid-state semiconductor devices that harness both direct and indirect sunlight to generate direct current electricity [6,7]. Solar irradiance may be classified into two main types: direct beam and diffuse. Direct beam irradiance refers to the solar radiation that reaches the Earth's surface in a straight line without any scattering or reflection. On the other hand, diffuse irradiance is the solar radiation scattered by various atmospheric mechanisms before reaching the Earth's surface. The solid angle formed by the solar disc encompasses the radiation stream. In solar PV systems, the diffuse component is used less frequently, while beam irradiance is used more frequently. However, the diffuse irradiance can still make up to 20% of the irradiance, even on clear days [8]. The quantity of solar energy that reaches a surface perpendicular to the radiation's path is always the highest. Therefore, it is crucial to know the solar radiation blocked by the tilted surface and site-specific climatic data when building a solar PV system. Even though tracking systems are expensive, a fixed system frequently adjusts at the correct tilt angle (monthly, seasonally, or annually) to maximize solar light collection [9].

The solar PV efficiency assessment often relies on a solar panel's energy efficiency, quantifying the power production relative to the original energy input delivered to the panel. In contrast to utilizing the second Law of Thermodynamics for energy analysis, the predominant approach in evaluating solar photovoltaic (PV) efficiency is based on the first Law of Thermodynamics. Energy analysis only considers how much energy is used and how effectively energy is converted [10]. Consequently, energy analysis disregards the potential energy loss that could have been employed productively in other physical or chemical processes. However, in applications where the effectiveness of energy usage relies solely on energy quantities, energy analysis can provide valuable guidance for effective management.

The term "exergy" pertains to the theoretical upper limit of work that can be obtained from a specific quantity of energy [11,12]. Engineers generally agree that exergy analysis is a potent technique for evaluating the thermodynamic and financial performance of diverse thermodynamic systems [13]. Exergy analysis offers an alternative approach to assess and compare solar PV systems. The process entails quantifying considerable energy, commonly referred to as Exergy or availability, alongside the quantification of irreversibility, which denotes the fraction of energy that cannot be efficiently utilized [14]. The application of exergy analysis can determine the utilization efficiency of an energy conversion system. The approach is deemed valuable due to its emphasis on reducing irreversibility or optimizing exergy delivery. In recent decades, exergy analysis has experienced a surge in popularity owing to its inherent advantages compared to energy analysis. In order to perform energy and exergy assessments on solar photovoltaic (PV) systems, it is crucial to assess the energy and exergy input and output values.

1.1 Literature Review

Calculating a grid-connected PV system's energy yield on a daily, monthly, and annual basis, as well as its capacity utilization factor and performance rate, is part of evaluating its performance [15]. Although the characteristics above depend on electrical energy production, they do not provide definitive insights into the energy conversion process occurring within the solar module. Thermodynamic analysis provides greater clarity for a deeper understanding of PV system performance [11][16] that of a heat engine [17]. The evaluation of energy efficiency in photovoltaic (PV) systems is based on utilizing the fundamental principles of the first law of thermodynamics. This principle primarily considers the input energy and the resulting helpful output. Energy efficiency primarily concerns measuring energy quantity and does not directly address any modifications in the quality of radiative energy throughout the conversion process. Its main objective is to quantify efficiency rather than assess alterations in energy quality [18]. During the first law analysis, it is assumed that various forms of energy, including electric, mechanical, chemical, and thermal energy, are considered to possess an equal level of quality or grade [19]. For instance, converting electrical energy into thermal energy is straightforward, whereas reverse processes are more intricate [20]. In contrast, exergy analysis is a comprehensive approach that embraces the principles of the second law of thermodynamics. It encompasses several photovoltaic (PV) array factors, including climatic, geometric, and operational aspects, while considering its thermal and chemical properties [21].

The exergy output is inevitably lower than the exergy input due to the inherent destruction of a portion of the Exergy during actual processes [22]. Additionally, exergy analysis accurately measures how much a system approaches an ideal state [23]. Exergy analysis aids in the identification of thermodynamic losses and guides potential measures to mitigate these losses. [24] investigated two approaches, namely the parametric method and the photonic method, for calculating the energy and exergy efficiency of PV systems. The exergy efficiency of a pair of photovoltaic (PV) modules linked in series was assessed for a representative day, yielding a range of values from a minimum of 7.8% to a maximum of 13.8%. [25] investigated to assess the Exergy and power conversion efficiency variations of amorphous and polycrystalline photovoltaic (PV) modules throughout a designated sunny day. [26] performed an analysis on the energetic and energy performance of a building-integrated semi-transparent crystalline silicon PV (BISPV) module when it was deployed on both the roof and facade of an educational building. The evaluation encompassed the energetic study's daily, monthly, and yearly periods without considering exergy destruction. In analyzing a 36W PV module's exergetic and energetic performance during a typical hazy day, [27] found that the module temperature impacted the exergetic efficiency.

1.2 Novelty of the current Research

Despite the increasing interest in solar tree technology, the literature remains limited in providing detailed thermodynamic analyses. Consequently, a comprehensive understanding of the underlying processes and efficiency improvements is yet to be achieved. The lack of empirical data on the real-world performance of solar trees further exacerbates the situation, hindering the formulation of effective strategies for their optimization. Hence. This work is carried out as a case study to analyze the performance of the solar tree based on exergy analysis.

This study aims to bridge the existing knowledge gap and shed light on the performance of solar trees through exergy analysis. The objectives of this study are:

a) To design and develop a portable solar tree, assess the thermodynamic performance based on heat transfer, and identify exergy losses.
b) To suggest various methods to enhance the efficiency of solar trees.

An in-depth case study examines the system's overall efficiency and identifies areas for potential improvements. In this regard, on-site measurements are used to quantify the solar tree's energy efficiency, exergy efficiency, and thermal losses. Future work can benefit from the strategy outlined in this research.

2 Methodology

2.1 Development of Solar Tree

Firstly, a literature review of solar tree designs has been studied to identify the designs with better efficiency. Then, a 3D solar tree model was designed to visualize the prototype. This designing process was done using Solidworks. Materials were purchased after designing the 3D model, and prototype fabrication began. The prototype was tested after fabrication to ensure it was working and had no faults. After testing, performance analysis was done to ensure the prototype matched the cost, material, and performance criteria. If the prototype didn't fulfill one of the criteria, it was modified and tested again until it fulfilled the criteria. The methodology of the current investigation is depicted in Figure 1.

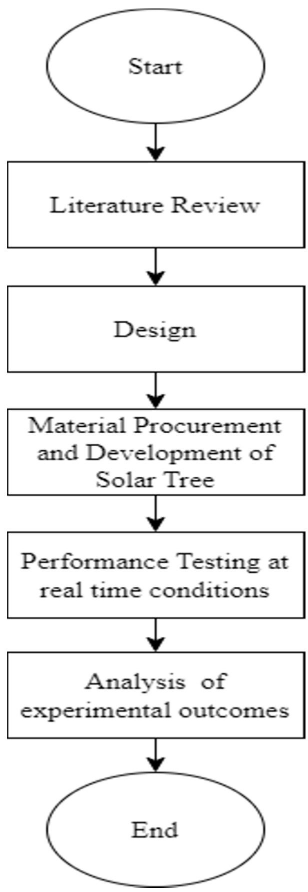

Fig. 1. Methodology of the current investigation.

2.2 Solar Tree Study and Site Condition

This analysis focuses on a 25Wp solar PV tree developed at Universiti Malaysia Pahang, located in Pekan, Malaysia. The prototype solar tree comprises five fixed tilted polycrystalline PV modules, each with a capacity of 5Wp. These modules are connected in series to form a string connection. The location's geographical coordinates are 3.5436° N latitude and 103.4289° E longitude. Throughout the year in Pekan, the ambient temperature ranges between 23.3 ºC and 32.2 ºC. Data such as Voc, Isc, wind velocity, solar irradiation, and ambient temperature were measured every 30 minutes between 9:00 am and 5:00 pm to evaluate the system's performance. The wind speed and surrounding temperature were determined using an anemometer and a temperature meter. A portable solar power meter was used to measure the strength of incident sun radiation.

2.3 Solar tree specifications

The input parameters and the specification of the PV module used in the current research are listed in Tables 1 and 2.

Table 1. Input parameter used for analysis.

Input parameter	Value
Nominal operating cell temperature (NOCT)	41 ºC
Stefan Boltzmann constant (σ)	5.67×10^{-8} W/m^2-K
The emissivity of the panel (ε)	0.9
Sun temperature	5780 K

Table 2. Specification of the PV module.

Model	HHGF10P(36)
Maximum power	5W
Open circuit voltage	21.24V
Short circuit current	0.63A
Maximum Voltage	17.50 V
Maximum Current	0.58 A
Dimensions	350×240×17 mm
Weight	1.1 kg
Fill factor	0.85

2.4 Energy and Exergy Analysis of Solar Tree

2.4.1 Energy Analysis of Solar Tree

The exergy equation for an open system, under steady-state circumstances and based on the first rule of thermodynamics, can be formulated in the following manner:

$$E_{in} = E_{out} \tag{1}$$

$$EX_{in} - E_{out} = E_{loss} \quad (2)$$

Equation (2) represents the general energy balance equation: Exout denotes the maximum energy extractable from a system supplied with Exin; minimizing energy usage results in reduced energy losses. The energy conversion efficiency of a solar cell refers to the ratio of absorbed light to converted energy that is successfully converted and collected as electrical energy when integrated into an electrical circuit. Conversely, energy efficiency is the ratio of a solar PV's power output to its energy input [28]. Nevertheless, the power output and energy efficiency of the photovoltaic (PV) system exhibit variability in response to changes in solar insolation and surface temperature conditions.

The energy conversion efficiency of solar photovoltaic (PV) systems, denoted as (η_{energy}), can be calculated using the following Equation [29]:

$$\eta_{energy} = \frac{V_{oc} \times I_{sc} \times FF}{A \times G} \quad (3)$$

The simplified Equation for its current-voltage characteristics represents the electrical behavior of a solar cell's circuit.

$$I = I_1 - I_2 \times exp^{\left[\frac{q \times (V - IR_S)}{A \times K \times T}\right]} \quad (4)$$

The electric power output of PV is:

$$P_{el} = I \times V \quad (5)$$

Furthermore, the maximum output power is expressed as:

$$P_{max} = V_{OC} \times I_{SC} \times FF = V_{mp} \times I_{mp} \quad (6)$$

The PV modules capture solar energy, transforming electric and thermal energy. However, some energy is lost through convection, conduction, and radiation. The architecture of the PV system plays a significant role in determining the heat transfer rate. It is essential to compute the operating temperature (TC) of a PV module, which, for simplicity, can be assumed to be uniform across the surface and influenced by the surrounding environment [30]. Elevated surface temperatures can lead to a decrease in PV efficiency. To counteract this, one approach is to artificially cool the cells by applying airflow or water spray on the backside, specifically targeting the heated region. In their dynamic thermal model, Duffie and Beekman incorporated a lump overall loss coefficient (UL) per unit area to consider these impacts effectively [31].

2.4.2 Exergy Analysis of Solar Tree

Exergy analysis involves considering energy quality or capability, which evaluates the most effective, not merely the most efficient, utilization of energy potential. The exergy balance equation for the solar photovoltaic (PV) system during a finite time interval in a steady-state flow process can be expressed as follows [32].

$$\text{Exergy Input} = \text{Exergy Output} + \text{Exergy Loss} + \text{Irreversibility} \quad (7)$$

The phenomenon of diminishing energy quality is commonly referred to as exergy loss, also known as availability loss. The term "exergy loss" is synonymous with the concept of irreversibility. Solar radiation emitted by solar cells can be converted into two forms: electrical energy and thermal energy. Using electrical energy is commonly referred to as "electrical energy." Thermal energy dissipation to the surrounding environment can be characterized as heat loss, destroying Exergy. The exergy efficiency of solar photovoltaics (PV) can be described as the quotient of the Exergy acquired by the system, also known as the exergy output, and the Exergy associated with the solar radiation received by the system referred to as the exergy input [33].

$$n_{ex} = \frac{E_x \ output}{E_x input} \quad (8)$$

The Exergy of an inlet in a photovoltaic (PV) system solely encompasses the Exergy associated with solar radiation intensity [34].

$$E_x \, in = AG\left[1 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4\right] \quad (9)$$

The outlet exergy for a PV system includes thermal Exergy and Electrical Exergy.

$$E_x out = E_x thermal + E_x electrical \quad (10)$$

Exergy of the Thermal Energy

$$E_X Thermal = Q\left[1 - \frac{T_a}{T_m}\right] \quad (11)$$

Where $Q = UA(T_m - T_a)$ (12)

A PV module's overall heat loss coefficient includes convection and radiation losses.

$$U = h_{conv} + h_{rad} \quad (13)$$

Convective heat transfer coefficient

$$h_{conv} = 2.8 + 3V_w \quad (14)$$

Radiative heat transfer coefficient between PV array surroundings

$$h_{rad} = \varepsilon\sigma\left(T_{sky} + T_m\right)\left(T_{sky}^{\ 2} + T_m^{\ 2}\right) \quad (15)$$

The effective temperature of the sky

$$T_{sky} = T_a - 6 \quad (16)$$

The module's temperature can be calculated based on the NOCT value.

$$T_m = T_a + (NOCT - 20).\frac{G}{800} \quad (17)$$

Electrical Exergy in the output electrical power of the PV module

$$E_x electrical = V_{oc} \times I_{sc} \times FF \quad (18)$$

A solar power plant's PV modules are positioned to receive the maximum sun insolation. The location, height, air conditions, and the solar path affect how much and what kind of sunlight is received [35]. The energy input of the system is calculated using the wattage formula and represents the solar power that is received by the module (En_{in}) [36]:

$$En_{in} = A_a \times S_t \quad (19)$$

Let A_a represent the surface area of the photovoltaic (PV) array in square meters, and S_t denotes the solar radiation incident on the array's plane in watts per square meter. The area of a photovoltaic (PV) array is determined by the number and size of PV modules it comprises.

$$A_a = N_m \times A_m \quad (20)$$

Let N_m represent the aggregate quantity of photovoltaic (PV) modules employed, and A_m denote the surface area of an individual PV module. According to the principle of energy conservation, energy is conserved and cannot be created or destroyed. The phenomenon of energy conversion involves transforming energy from one form to another. Solar energy is mainly transformed into electrical and thermal manifestations. The energy efficiency of the photovoltaic (PV) system can be quantified by calculating the ratio of the energy output (En_{out}) to the solar energy input (En_{in}) [37] and is given by;

$$\eta_{en} = \frac{En_{out}}{En_{in}} \quad (21)$$

The energy efficiency of a photovoltaic (PV) system is determined by its usable output. The expected outcome involves the production of electrical energy due to the incidence of solar energy. The energy efficiency measure is determined by the electrical power produced at a specific moment of solar irradiation, denoted as Po.

$$\eta_{en} = \frac{P_0}{En_{in}} \quad (22)$$

The determination of input exergy (Ex_{in}) in exergy efficiency calculations involves the utilization of Petela's relation, which quantifies the solar power received by the module [38]:

$$Ex_{in} = A_a \times S_t \left[1 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4\right] \quad (23)$$

In this context, the variable Aa symbolizes the surface area of the photovoltaic (PV) array, measured in square meters (m^2). At the same time, S_t represents the solar radiation incident on the array's plane, measured in watts per square meter (W/m^2). The variables "Ta" and "Ts" denote the ambient and solar temperatures, respectively. The sun's temperature is commonly regarded as 5777 Kelvin (K).

Two distinct categories of exergy losses are observed in internal and external photovoltaic (PV) systems [34]. External losses result from thermal energy being transferred from the surface of the photovoltaic (PV) system to the surrounding environment, leading to heat leakage. Internal exergy losses occur due to optical losses on the surface of the photovoltaic (PV) array, temperature disparities between the PV array and the surrounding environment, fluctuations in the PV array's temperature relative to the sun's temperature, and the destruction of electrical Exergy [39]. As mentioned above, the losses decrease electrical output, thereby reducing revenue generated by the power plant. The exergy destruction (CoEx) cost can be calculated using Equation (24).

$$\text{CoEx} = \text{electricity cost per unit} * \text{exergy destruction} \tag{24}$$

The PV module predominantly converts solar energy into electrical and thermal energy. Additionally, it should be noted that the efficiency of the photovoltaic (PV) module has an inverse relationship with the ambient temperature. Therefore, the impact of thermal losses on the performance of photovoltaic (PV) modules is substantial. In many instances, addressing internal losses can pose more challenges than external losses [40]. The current investigation focuses on the thermodynamic efficiency of a large-scale photovoltaic (PV) system, explicitly emphasizing the analysis of thermal losses and electrical output exclusively from the PV array. Thermal Exergy refers to the dissipation of heat from the surface of a solar system to the surrounding environment. The calculation of exergy thermal loss (Ex_{ther}) is possible.

$$Ex_{therm} = U \times A_a(T_a - T_m)\left(1 - \frac{T_a}{T_m}\right) \tag{25}$$

The Equation given in the context indicates the overall heat loss coefficient (U), the area of the photovoltaic (PV) array (Aa) in square meters, the ambient temperature (Ta), and the module temperature (Tm), all measured in Kelvin. The aggregate heat loss coefficient of the photovoltaic (PV) array is ascertained through the cumulative impact of convection (hc) and radiation losses (hr), which are combined. The acquisition of thermal Exergy by the solar photovoltaic (PV) system during its operational phase is deemed undesirable. As this results in thermal dissipation within the system, deducting its magnitude from the electrical energy generated is necessary. The electrical energy created, denoted as Po, can be characterized as the cumulative amount of alternating current (AC) power supplied to the grid over a given period, whether daily, monthly, or yearly. The algebraic sum of the electrical power output and the thermal losses determines the exergy output in the parametric approach. The exergy efficiency can be mathematically described as the quotient of the exergy output and the exergy input, typically given as a percentage.

$$Ex_{out} = P_o - Ex_{therm} \tag{26}$$

$$\Psi_{exer} = \frac{Ex_{out}}{Ex_{in}} \tag{27}$$

$$= \frac{(P_o - Ex_{therm})}{Ex_{in}}$$

3 Results and Discussion

3.1 Analysis of the Local Weather Conditions

The impact of ambient conditions on the module's performance was investigated by analyzing accurate data collected during a typical day in May in Pekan. This location's predominant weather season is called a warm and humid environment. Figure 2 depicts the Earth's radiation, temperature, and wind speed variations on the setup day. The conclusion is that solar irradiation peaks at 1.30 pm and reaches its lowest levels around 9 am. The amount of solar radiation has a significant impact on the input energy. Environmental conditions influence the solar tree's energy output. The minimum and maximum temperatures for the recorded day ranged from 29.9 to 39.3 degrees Celsius. Around 25 °C is the temperature at which the PV system performs at its best. It was discovered that the wind's velocity ranged from 1.05 to 3.2 m/sec. On average, this location has very little wind availability, less than 2 m/s. Therefore, it has a minimal impact on module temperature decrease. This fluctuation influences the convective heat transfer coefficient between the surface of the photovoltaic (PV) array and the surrounding air. The solar radiation intensity was discovered to vary between 1021 and 392.7 W/m2 at its maximum and minimum.

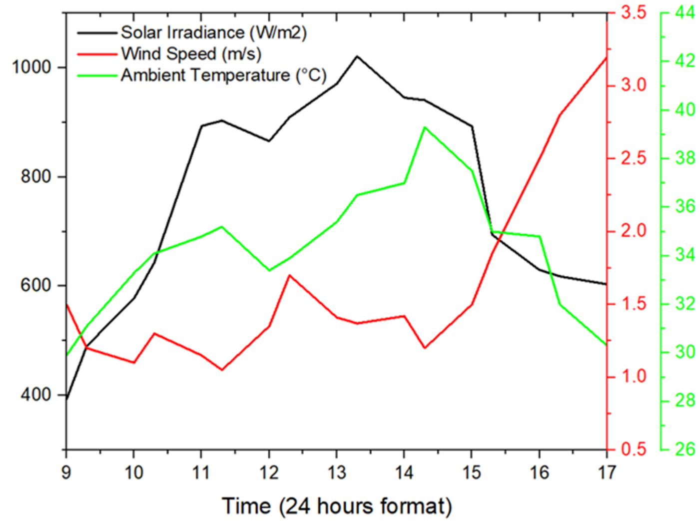

Fig. 2. Variations in global radiation, wind velocity and ambient temperature.

3.2 Exergy Parametric Analysis

Solar Exergy is exceptionally abundant owing to the elevated temperature of the sun, enabling it to be effectively harnessed for performing useful work. The input and electrical energies of the PV module are depicted in Figure 3. With changes in solar insolation, the input energy changes proportionally. Due to improved solar insolation, the most input energy is accessible during noon. During the day, there is less input energy. Exergy from the sun and electrical output are primarily influenced by sun insolation and solar tree area. Due to maximum sun insolation at noon, electrical energy is higher than, whereas it is lowest at 9 am. Seasonal temperature changes can be blamed for the variance in thermal Exergy.

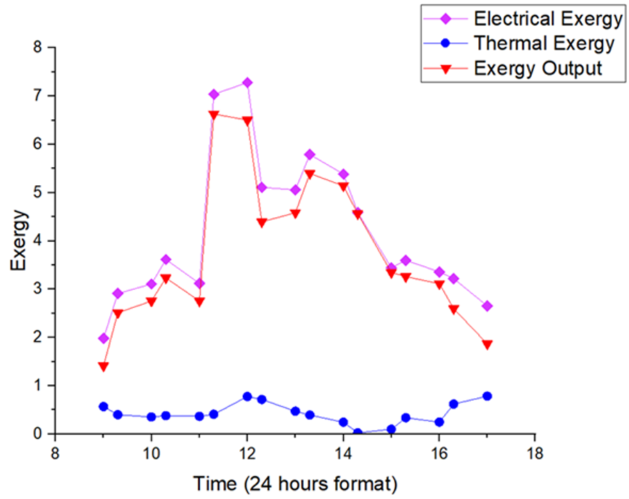

Fig. 3. Variations in electrical exergy, thermal exergy and exergy output of solar tree.

3.3 Heat Transfer Analysis

The correlation between the heat transfer coefficient and net heat transfer is evident in Figure 4. The net heat transfer peaked at 1200 and 1700 while the lowest was at 1500. This could be explained by the peak sun position and clear sky condition, which contributed to this output.

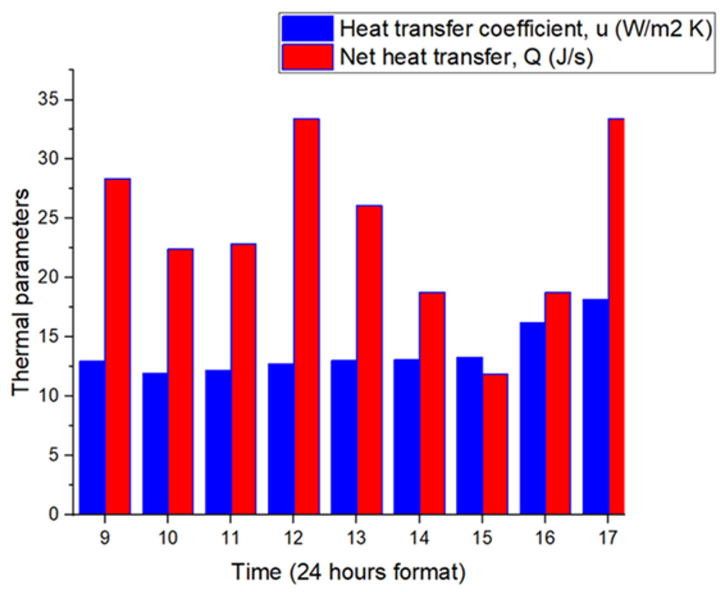

Fig. 4. Heat transfer coefficient and net heat transfer of solar tree.

3.4 Energy and Exergy Efficiency Analysis

The exergetic and energetic efficiencies, as determined by the comprehensive analysis, are reported to be 10.42% and 10.96%, respectively, as depicted in Figure 5. The solar tree exhibits low energy efficiency due to its inadequate output energy quality. Significant energy losses occur within the solar panel. The increased module temperatures have resulted in elevated energy losses, decreasing energy efficiency. The exergy efficiency, below 10.42%, results in a comparatively low output exergy value compared to the input. The solar tree with a power output 25Wp exhibits energy efficiency ranging from 8.33% to 16.82%, with an average efficiency of 10.96% (Figure 4).

Consequently, the level of efficiency is also considered to be ordinary. The hour with the highest electrical output exhibits more efficiency because the output exergy encompasses both the electrical output and thermal Exergy together. The variability in energy efficiency can be ascribed to the temporal fluctuations in ambient temperature. The summer months are characterized by increased temperatures, which exacerbate the loss of efficiency.

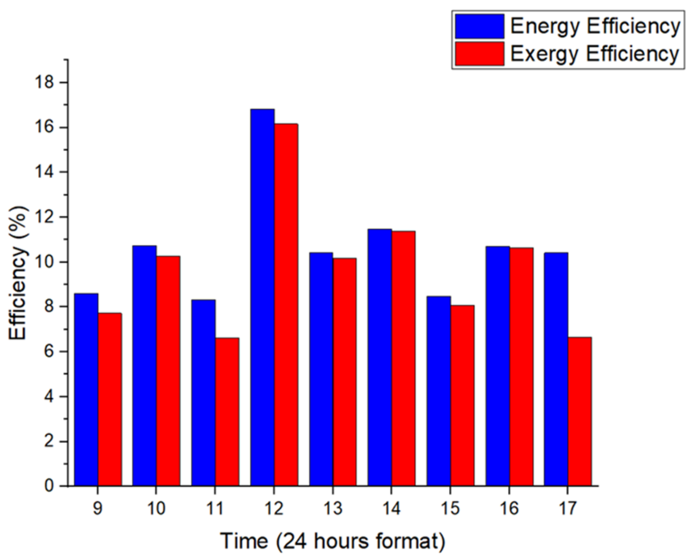

Fig. 5. Energy and Exergy efficiency of solar tree.

3.5 Exergy Loss Analysis

Figure 6 makes it abundantly evident that the solar tree's electrical Exergy is far less than what might be harvested due to significant exergy loss brought on by irreversibility. There is a good relationship between the exergy input and exergy loss graphs—the exergy input increases from 0900 until 1100. Then, exergy input and exergy loss fluctuation can be seen from 1100 to 1500 before the values decrease. As the conversion of PV energy is temperature-sensitive, higher temperatures result in increased losses. Exergy loss is amplified during the summer months due to elevated temperatures.

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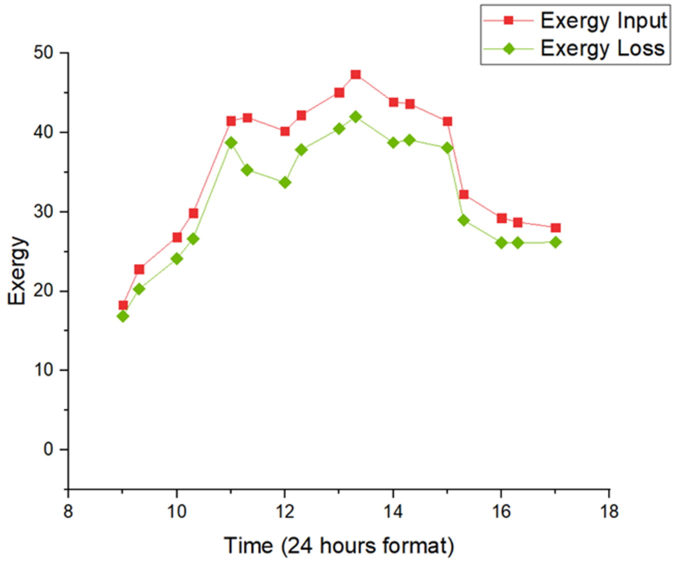

Fig. 6. Exergy input and Exergy loss of solar tree.

3.6 Electrical Efficiency Analysis

The average electrical efficiency is 16.15%, as shown in Figure 7. The efficiency is the lowest around 0900, which is around 6.76%. Electrical efficiency continues to increase until the peak hour, around 1200. At this time, the efficiency is at its highest, recorded at 29.12%. After 1200, there is a constant decrease in electrical efficiency until 1700, which is 12.56%. The drop in electrical efficiency from 1200 to 1700 is caused by clouds, which block the solar radiance, thus reducing the input received by the solar panels.

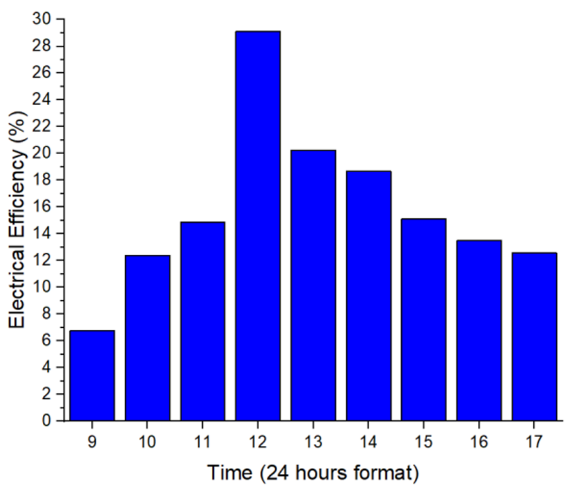

Fig. 7. Electrical efficiency of solar tree.

3.7 Discussion on the Impact of Various Parameters on the Performance of Solar Tree

Consequently, it can be deduced that the 25 Wp solar tree operates at a higher temperature, leading to thermal losses. The temperature of the photovoltaic (PV) module decreases due to convective heat transfer resulting from an elevated wind speed passing over it. Moreover, the convective heat transfer coefficient between the photovoltaic (PV) module and the ambient air in its vicinity is subject to the influence of wind velocity. There are the following factors which are responsible for the performance of a solar tree:

1. Partial shading on PV condition
2. Orientation of the panel
3. Temperature effect on panel

Shading on the PV board can occur due to various factors, such as the shade cast by tall trees positioned closely to the framework, shading from other adjacent panels, or even shade caused by birds perching on the board. Another significant factor that can negatively impact the board's performance is dust accumulation, which can degrade its efficiency.

As the temperature increases, the efficiency of the solar PV system tends to decrease.

$$E = A*r *H *PR \tag{28}$$

Small area/space requirement: It is the most favorable option for energy generation as it requires significantly less land than traditional PV structures. In recent times, land has become a precious resource due to the rapid growth of the population. To generate 2 MW of power using a PV module, an installation may require approximately 10-12 acres of land. However, a solar tree with only 0.10-0.12 acres of land can generate equivalent energy. Therefore, there is a need for a power generation plant that can maximize energy output while utilizing minimal land resources.

Productive energy production: Unlike the traditional structure, it may generate energy effectively. The spiraling phytotaxy technique helps the plant operate more effectively. It frequently finds application in modern power gracefully, street lighting frameworks, and other areas. It is undoubtedly more efficient and superior in area than the conventional solar PV system. Even if it is somewhat expensive, it is more cost-effective than all other expenses in the conventional structure.

Energy collection from wind: As the name implies, this device harnesses energy from the sun and incorporates an innovative component that captures energy from the wind. The stems are adaptable to move in any direction, and by shaking, they generate energy from the wind, similar to a distinctive tree. The unique mechanism has adjustable sheets attached to the stem that may be twisted in our desired direction. As a result, it may be possible for wind weight to adapt.

4 Conclusion

This study aims to conduct a detailed thermodynamic analysis of a solar tree to evaluate the performance of a solar photovoltaic panel. Meticulous measurements were conducted on a representative summer day To assess the energy losses incurred during the photovoltaic conversion process and afterward subjected to analysis. The examination of the thermodynamics of the solar tree is crucial in assessing its operating efficiency. The conclusions stated in this study are based on the findings.

- The solar tree's energy efficiency ranged from 8.33% to 16.82%, and its value is solely based on solar insolation and electrical energy output. The exergy research revealed that the existing configuration of the photovoltaic tree harnesses only a fraction of the available Exergy despite the significant exergy potential in solar radiation.
- The energy efficiency of the solar tree diminishes as solar radiation and ambient temperature increase due to elevated cell temperatures and the existence of irreversibilities.
- These empirical values are the foundation of exergy analysis, enabling a more accurate evaluation of the solar tree's effectiveness and inefficiencies.
- A solar tree must pay a very high price for energy destruction. Adding a PVT module to the solar tree system can reduce significant heat losses.
- It could be beneficial to research to increase the solar tree's effectiveness.
- The optimization of the design and utilization of the solar tree can be achieved by employing exergy analysis. It is imperative to optimize a solar tree's design and operating components to enhance efficiency. Future research should concentrate on simulating the solar tree's performance.
- The study provides valuable insights that can drive advancements in solar tree technology and further integration into sustainable energy systems.

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