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Economic Impacts of Solar Energy Systems on Regional Development in Africa

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Abstract

This study addresses the need for space-efficient, cost-effective residential renewable energy solutions in Nigeria by introducing and evaluating a 5 kW solar tree system tailored to Bauchi State's solar conditions. The research objective is to determine whether the proposed system can reliably meet a daily energy demand of 30,000 Wh while delivering high performance, durability, and economic benefits. Methodologically, the system is designed with photovoltaic modules, a charge controller, a battery bank, an inverter, and a steel support structure sized for the region's irradiance; performance, cost savings, and structural integrity are assessed using efficiency, annual bill reduction, and a calculated safety factor. Key findings show that the system achieves over 86% efficiency, saves US$1,415 annually on electricity bills, and attains a safety factor of 2.85, indicating robustness against wind and environmental loads; the configuration fulfills the targeted daily energy requirement. The study concludes that the solar tree provides a viable, space-efficient residential solution that reduces reliance on fossil fuels. The contribution and implication are a practically

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implementable design that can support household-level energy transition efforts and inform wider deployment of residential solar technologies in Nigeria.

Keywords: Solar Tree; Photovoltaic System; Residential Energy; Bauchi State, Nigeria; Energy Efficiency; Cost Savings; Structural Reliability; SAM; SOLIDWORKS

INTRODUCTION

Sustainable and renewable energy solutions are required due to the growing worldwide energy demand and the negative environmental effects of fossil fuels, particularly in developing nations like Nigeria. Power interruptions and reliance on pricey, environmentally harmful alternatives result from traditional energy infrastructures' inability to meet household demands. The perfect answer is solar energy, a plentiful, clean, and untapped resource. However, issues like inadequate roof space, improper panel alignment, and aesthetic problems make it difficult for rooftop solar systems to be used in Africa. In Nigeria and throughout Africa, the solar tree provides a visually appealing and space-efficient solution that promotes sustainable development goals and ensures energy security.

Solar trees are structures that mimic the shape of a natural tree, using photovoltaic panels to harness sunlight and convert it into electricity. Ideal for urban areas with limited land, they offer significant energy per square meter and promote sustainable energy. However, high initial costs and maintenance can hinder widespread adoption. Solar trees have a minimal land footprint but require substantial upfront investment and a long payback period, especially in regions with lower sunlight exposure.

METHODOLOGY

System Block Diagram

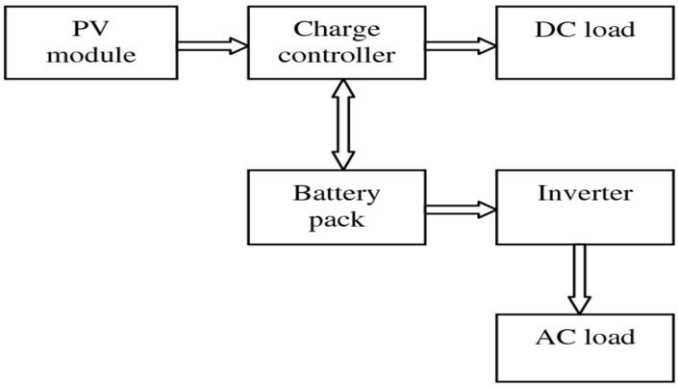


Figure 2: Block Diagram of Solar Tree PVs Generation and Usage

In this study, we have expressed our belief that the Solar Tree concept for home electrification is a significant step toward lowering electricity costs and reducing Nigeria's reliance on the unreliable grid power of today. In order to lessen global warming, it also offers sustainable energy sources. The tiny family's energy demand, or load, is taken into account while calculating the proposed system's capacity and the sizes of its parts. The average load history is taken into account based on how long a day's usage lasts. The electrical appliances listed below are predicted to be used for five hours.

RESULTS AND DISCUSSION

Table 1: Electrical design Results

S/N	Component	Quantity	Total
1	Series connection (2panels in series) for the combined output series string	2=48+48 96x6.25	96v 600w
2	Parallel connection (10 strings), Total power	10x6.25 96x62.5	62.5A 6000w
3	Battery Bank Sizing 30000wh/day x DOD Number of batteries chosen: 12v,300Ah	24000Ah 30000/3600	 8
4	Series and Parallel configuration 48/12=4, 8/4=2	4 x 2	8
5	Inverter Sizing	5000 x 1.25	6250w
6	Charge controller capacity	8 x 10=80A,25% margin	100A
7	Wiring size DC from the panel to the charge controller	80A	35mm²
8	Wire size from Inverter to DB	132A	50mm²

Table 2: Mechanical structural results

S/N	Component	Dimension/Quantity	Total
1	Total panel weight Force due to gravity	9 x 27 245 x 9.81	245kg 2404N
2	Steel Trunk and Branches	$\pi(0.3m)^2$-$(0.2m)^2$ x55m,each 1.5mlong; volume per branch $(0.1m)2$-$(0.097m)2$ x 1.5 $)2$ $0.0173m^3$x 9	$0.0628m^3$ $0.0173m^3$ $=0.1557m^3$
3	Total steel volume Steel density	0.0628+0.0173 $7850kg/m^3$	0.2184m
4	Steel weight Force due to gravity	7850 x0.2184 1744.44 x 9.81	1714.44kg 17,112.9564N
5	Combined Dead load Total weight	245kg+1714.44	1,959.44kg
6	Total force	17112.956+2404	19516.956N
7	Wind pressure	0.5 x $1.225kg/m^2$ x $(4.5m/s)^2$	$12.4N/m^2$
8	Area per panel Total area	2.4 x 1.5 9x3.12	$3.12m^2$ $28.08m^2$
9	Total wind force	$12.4N/m^2$x28..$8m^2$	348.192N
10	Base stability Overturning moment due to wind	5.5m+1.3m 348.102N x 6.8m	6.8m 2367.094Nm
11	Resisting moment by Base Resisting moment	1961.795kg × 9.81 m/s^2 19245.2080N × 0.35 m	19245.2080N 6735.8228Nm
12	Factor of safety	= 6735.8228 Nm / 2367.098 Nm	2.8456
13	Material stress and Bending moment	348.192N × 5.5m	1,915.056Nm
14	Section modulus for hollow cylinder	1,915.056 Nm / 1.54×10^{-4} m^3	12.4 MPa

AC Energy and Irradiance Data

The AC energy data from January to December. The data is expressed in kilowatt-hours (kWh), capturing the energy output across the year. The results are displayed in a bar chart alongside the corresponding global irradiance, direct irradiance, and beam irradiance levels, providing insights into their correlations and seasonal trends.

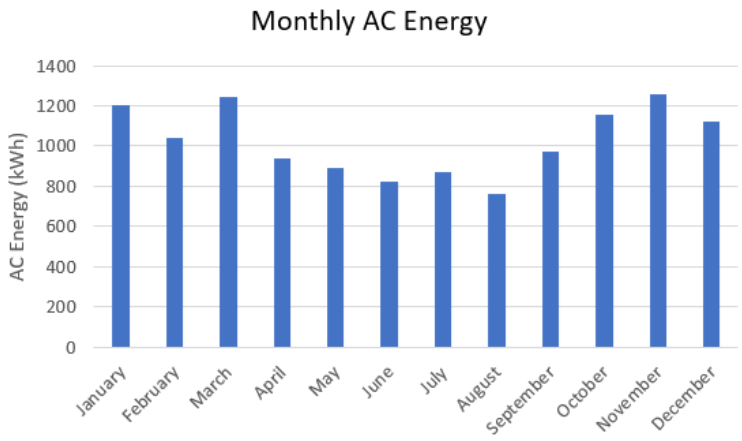


Figure 3: Monthly AC Energy Data

Table 3: General losses in conversion process

S/N	Type of Energy/Amount	Amount(kwh)	Energy loss	Efficiency
1	**Nominal POA (Plane of Array) Energy (kWh**	69,088 kWh		
2	**Nominal DC Energy (kWh)**	12,775 kWh	12,775−11,502 =1,273 kWh	11,502/12,775×100 ≈90%
3	**Net DC Energy (kWh)**	11,502 kWh		
4	**Gross AC Energy (kWh)**	11,090 kWh	_____	DC to AC Efficiency =(11,090/11,502)=96.4%
5	**Annual Net Energy Delivered (kWh)**	10,986 kWh	_____	_____

Nigerian State Locations

The approximate latitudes and longitudes for the state locations in Nigeria:

Kano State – 12.0022° N, 8.5914° E

Gombe State – 10.2897° N, 11.1712° E

Plateau (Jos) – 9.8965° N, 8.8583° E

Jigawa State – 12.2280° N, 9.5616° E

Kaduna State – 10.5105° N, 7.4165° E

Katsina State – 12.9855° N, 7.6171° E

Sokoto State – 13.0059° N, 5.2476° E

Lagos State – 6.5244° N, 3.3792° E

Rivers State (Port Harcourt) – 4.8242° N, 7.0336°

Yobe State – 12.0000° N, 11.5000° E

Sokoto, Jigawa, and Kaduna states are the highest power-producing locations, producing approximately 900kwh each. The peak energy production period is in May, with a peak load of 4.39kw in August. SAM software, an industry-standard tool for performance and financial analysis, supports various energy technologies, enabling informed decisions in renewable energy planning and management.

Table 6: Year 1 Monthly Electric Bill & Savings (USD)

Month	Without System	With System	Savings
Jan	117	21	96
Feb	102	19	83
Mar	108	13	94
Apr	129	52	77
May	183	60	122
Jun	267	89	178
Jul	315	98	217
Aug	289	181	108
Sep	231	109	122
Oct	189	57	132
Nov	105	18	86
Dec	115	21	94
Annual	2,158	743	1,414

The I-V Curve

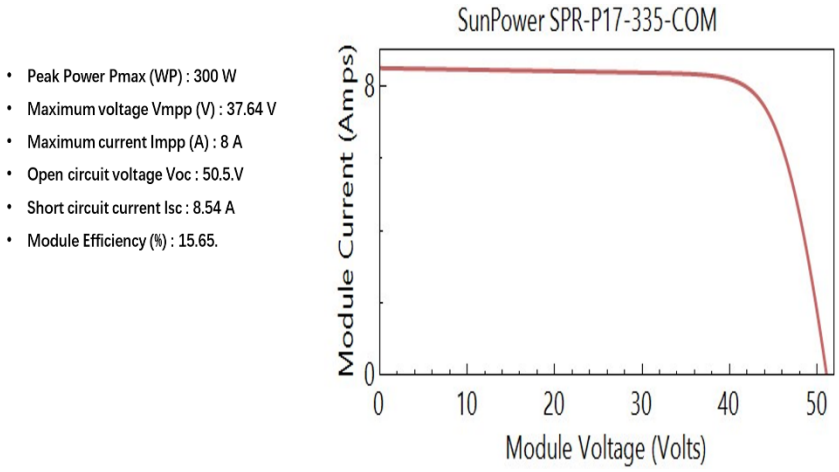


Figure 3: I_V curve(current/voltage)

I_V curve(current/voltage) module Short-Circuit Current (Isc) at V ≈ 0V

When the module is short-circuited (i.e., no load is connected), it delivers its maximum current (Isc). This is the top-left point of the curve.

For SPR-P17-335, Isc ≈ 6.3 - 6.6A .

Open-Circuit Voltage (Voc) at I ≈ 0A

When the module is not connected to a load, the voltage rises to its maximum open-circuit voltage (Voc).

This is the far-right point of the curve.

For SPR-P17-335, Voc ≈ 46 - 48V.

Maximum Power Point (MPP)

The point where the module delivers maximum power (Pmax = Vmp × Imp).

It is somewhere in the middle of the curve.

For SPR-P17-335:

Maximum Power (Pmax) ≈ 335W

Voltage at MPP (Vmp) ≈ 38V

Current at MPP (Imp) ≈ 6.1A

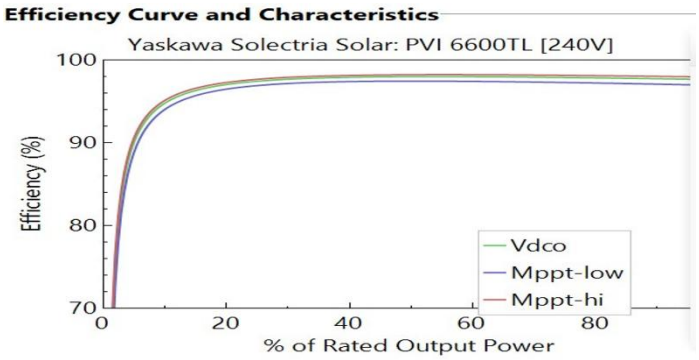


Figure 4: Inverter efficiency curve and characteristic

Inverter efficiency curve and characteristic

Efficiency curve for the Yaskawa Solectria Solar PVI 6600TL inverter.

The graph is an Efficiency vs. Output Power (%) curve, which shows how efficiently the inverter converts DC power (from solar panels) into AC power (for use in homes or the grid) at different levels of load.

Y-axis (Efficiency % from 70–100):

Represents the conversion efficiency of the inverter. Higher values mean less energy is lost during conversion.

Maximum efficiency for this inverter is usually ~97-98%.

X-axis (Output Power % from 0–80):

0% = No output power

100% = Full rated power (6600W)

Key Features of the Curve

MPPT-Hi (High MPPT Voltage)

This represents efficiency when the input DC voltage is high (close to the upper voltage range of the inverter's MPPT tracking).

Typically, this occurs in cool conditions or when panels are connected in a higher-voltage configuration.

Vdco (DC Operating Voltage)

Represents efficiency at a middle-range DC voltage.

This is the normal or nominal operating voltage of the inverter.

MPPT-Low (Low MPPT Voltage)

This shows efficiency when the input DC voltage is lower (closer to the lower MPPT voltage range).

This typically happens in hot weather (since solar panel voltage drops as temperature rises) or when fewer panels are in series.

Interpretation on how the Efficiency Curve Behaves

At Low Output Power (0–20%)

Efficiency is generally lower (~70–85%) because inverters have internal power losses (standby power, control circuits,

The inverter is not operating at its optimum load, so more energy is wasted.

At Medium Output Power (20–60%)

Efficiency improves rapidly, reaching around 95-97%.

The inverter is working in an optimal range.

MPPT-Hi vs. MPPT-Low:

MPPT-Hi curve is usually slightly more efficient than MPPT-Low because higher DC voltage results in lower current, reducing heat losses.

MPPT-Low curve shows slightly lower efficiency, as lower voltages mean higher currents, leading to more resistive losses.

Vdco Curve:

This represents a middle operating condition and is typically very close to the MPPT-Hi curve.

At High Output Power (60–100%)

Efficiency is at its peak (97-98%).

After reaching the peak, efficiency slightly decreases near 100% load due to heat dissipation and electrical losses.

Practical Takeaways

To maximize efficiency, the inverter should operate in the middle-to-high power range (40-100% of rated power). Higher input voltages tend to improve efficiency slightly. This suggests using a higher DC voltage configuration for better performance. Avoid very low power operation (0-20%), as efficiency drops significantly. In hot weather, efficiency might drop slightly due to lower MPPT voltage.

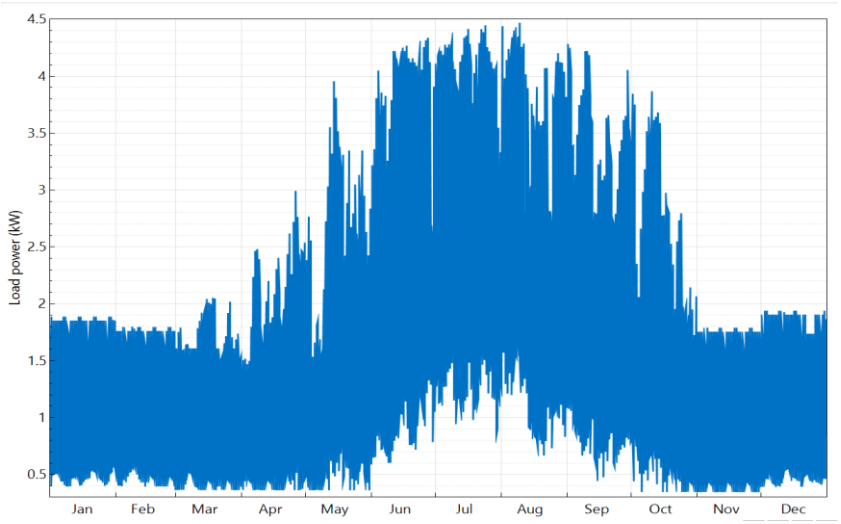


Figure 5: Hourly Load Power (kW)

Hourly load power: Graph shows the variation in electric load power over time. X-The x-axis represents the months of the year, from January to December, showing the load

changes throughout the year. The y-axis represents the load power in kilowatts (kW), ranging from 0.5 kW to 4.5 kW.

Winter Months (January to March & November to December):

The load power is relatively low and stable, mostly between 1.5 kW to 2.5 kW. There are minimal fluctuations during these periods.

Spring to Summer (April to September):

The load power starts increasing in April, reaching its peak levels in May, June, and July, where values consistently exceed 4 kW



Figure 6: Daily load power graph

Daily load power graph:

The graph starts low in Jan (around 0.8 kW) and rises toward 3 kW mid-year: Indicates increasing power usage—due to hotter weather (fans, ACs). Could peak in summer (e.g., May–July), when cooling appliances are heavily use If the graph dips in the middle (June–July) and rises again at the end:

Reflect seasonal usage, like higher demand during winter and summer, and lower in raining months. Certain loads like water heaters or air conditioners may drive this pattern. The graph is relatively flat around 2 kW:

Shows steady, consistent load demand throughout the year—typical for homes with no major seasonal load variation.

Possible Causes of Load Variation:

i. Climate: Heating in winter, cooling in summer.

ii. Occupancy: Higher load when more people are present (e.g., holidays, festivals).

iii. Solar power contribution (if hybrid system): Load might appear reduced when solar input is higher.

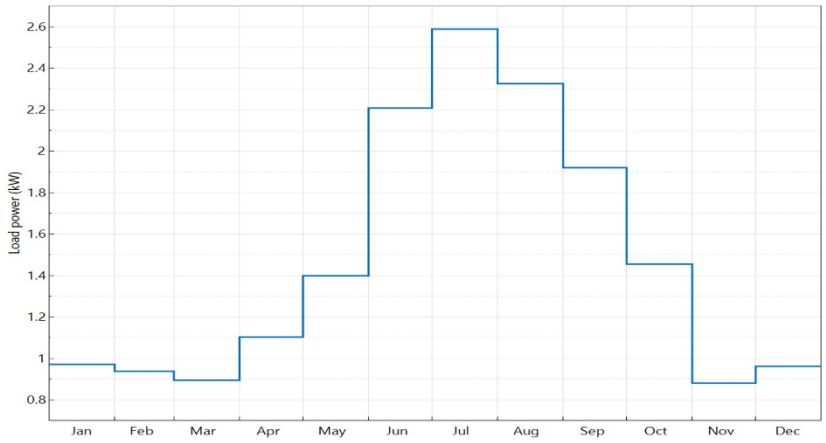


Figure 7: Monthly load power

Monthly load power

Figure 7 represents the monthly load power variation over a year. Power demand starts low in January-March due to reduced industrial activities and heating-dominated regions. The peak occurs in July-August, with a noticeable increase in power demand. Industries like irrigation may ramp up power usage during this period. After April, power load decreases due to reduced heating demand and moderate cooling needs. Factors influencing this trend include seasonal temperature changes, industrial and agricultural cycles, and human behavior, such as holidays, work schedules, and weather.

System Advisor Model (SAM) Report

The performance model evaluates system efficiency and productivity, including adjustment factors and annual results. The financial model assesses the project's financial viability, including cost, financing, tax, insurance rates, and incentives. The electricity demand and rate are evaluated, including energy usage patterns and seasonal variations. Summary results provide a concise summary of the system's performance and financial

outlook, including annual energy production, efficiency, and environmental benefits.

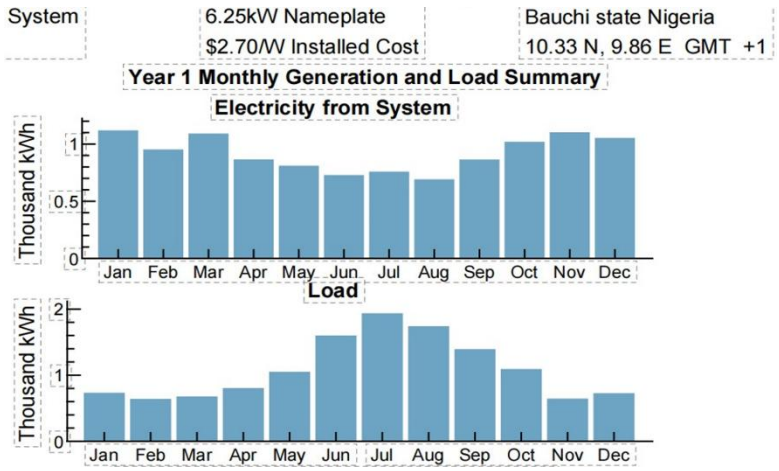


Figure 8: Year1 Monthly Generation and Load Summary

Monthly Generation/load Summary:

The solar tree project in Bauchi State, Nigeria, faces seasonal variations in its climate. The production graph shows a high, dip-to-medium level pattern, influenced by solar irradiance, with higher generation during sunny months and moderate declines during cloudy ones. The load graph has an inverse pattern, impacting the project's efficiency and sustainability. The tropical savanna environment influences the climate, with dry, hot, and rainy seasons impacting solar generation.

Table 7: Year 1 Monthly Electric Bill and Savings ($)

Month	Without System	With System	Savings
Jan	117	21	96
Feb	102	19	83
Maret	108	13	94
Apr	129	52	77
May	183	60	122
Jun	267	89	178
Jul	315	98	217
Aug	289	181	108
Sep	231	109	122
Oct	189	57	132
Nov	105	18	86

Month	Without System	With System	Savings
Dec	115	21	94
Annual	2,158	743	1,415

Electric bill and savings for the entire year:

Without System (2158 USD): This represents the amount paid for electricity without energy-saving system or solar panel system in place. Over the course of the year, there fore electric bill amounts to $2,158.

With System (743 USD): This is the amount paid for electricity after installing an energy-saving system, such as solar panels. The electric bill is reduced to $787.

Total Savings (1415USD): This represents the savings achieved by using the energy-saving system. The savings are the difference between the bill without the system and the bill with the system, which amounts to: Savings=2158−743=1415USD.

By installing an energy-saving system (likely solar panels the electric bill has been reduced by $1415 over the year. Initially, without the system, you would have paid $2,158 for electricity. After installing the system, your annual bill dropped to $743.

This means that, substantial amount of money have been saved throughout the year while reducing your electricity costs.

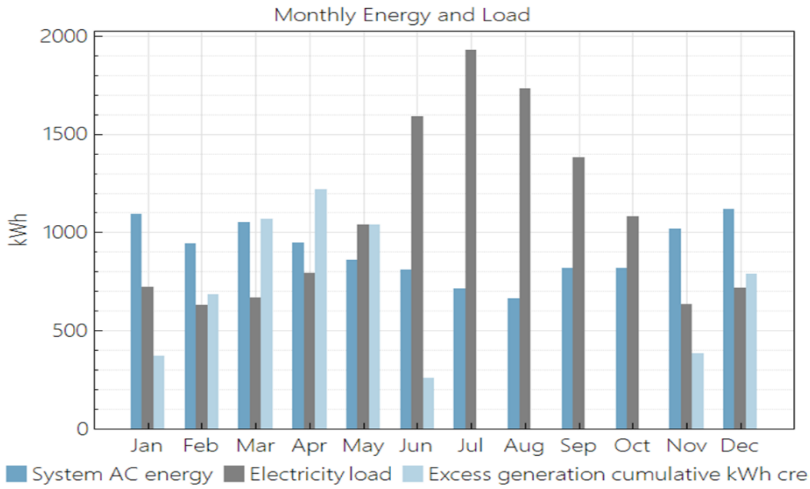


Figure 9: Monthly Energy and Load

Monthly Energy and Load

The graph shows three key metrics over the year (January to December) along the x-axis: Monthly Energy (light blue bars)

Excess Generation Cumulative kWh Credit (light gray bars). The y-axis represents the energy values in kilowatt-hours (kWh), ranging from 0 to 2,000 kWh.

Observations: Monthly Energy:

The light blue bars represent the total energy generated each month.

Energy production is higher during the winter months (January, February, March, April, October, November, December) and lower during raining season (June, July, August).

Electricity Load:

The dark gray bars show the electricity consumed each month.

The load remains relatively consistent throughout the year, but it is significantly lower than the monthly energy production.

Excess Generation Cumulative kWh Credit:

The cumulative credit for energy generated each month is represented by light gray bars, which steadily grow over the year, peaking in December. Most months have a surplus, with lower energy production contributing to the credit. By December, the credit reaches its maximum, reflecting the year's large surplus.

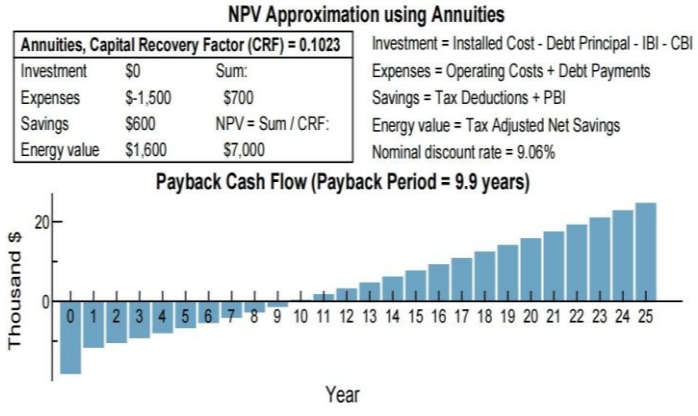


Figure 10: Payback cash flow (payback period=9.9 years)

Project After-Tax cash flow (payback cash flow)

A project's early years can be marked by negative cash flow due to high startup costs or operational inefficiencies. By about 10 years, it has broken even or started showing

modest profits, gradually moving from zero to a positive figure. As the project matures and becomes more efficient, cash flow continues to rise. By Year 25, the project is fully established and operational, yielding a positive after-tax cash flow.

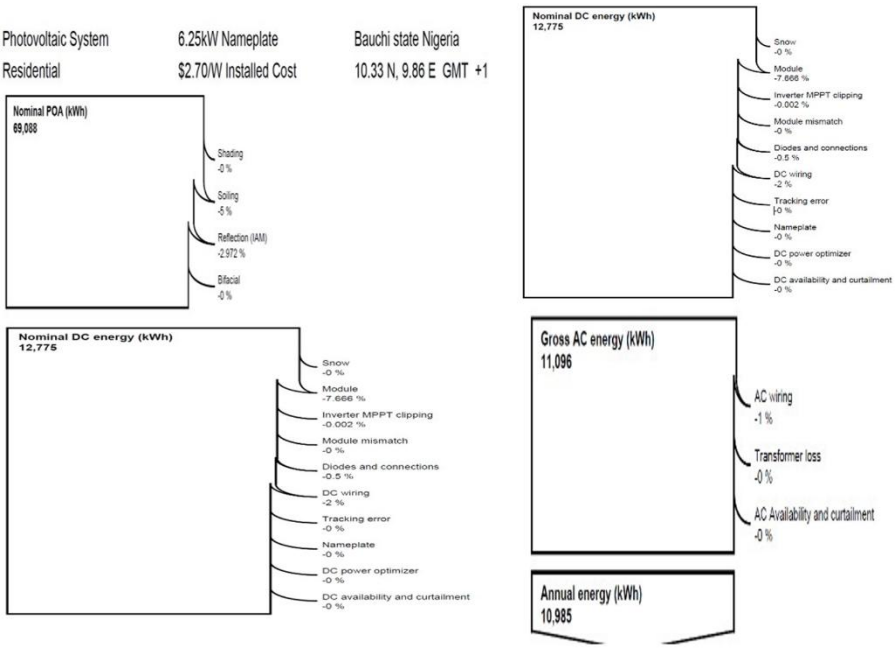


Figure 11: General losses in conversion process

General losses in conversion process

Nameplate Capacity: 6.25 kW

This is the maximum power output the system can theoretically produce under ideal conditions.

Inverter Capacity: 6.25 kW

The inverter is rated to handle up to 6.25 kW, matching the nameplate capacity. This ensures the system can efficiently convert the generated DC power to AC power without bottlenecks.

Performance Metrics:

Nominal POA (Plane of Array) Energy (kWh): 69,088 kWh

The estimated total solar energy incident on the array surface over the year. This is the potential solar energy available for conversion, assuming ideal conditions.

Nominal DC Energy (kWh): 12,775 kWh

The expected DC energy output from the system before real-world losses. This is what the system should theoretically generate in DC electricity.

Net DC Energy (kWh): 11,502 kWh

The actual DC energy output after accounting for system losses such as shading, soiling, and efficiency.

Difference from Nominal DC Energy: Losses=12,775−11,502=1,273 kWh Losses

Efficiency Rate: Efficiency=(11,502/12,775)×100≈90% Efficiency=(12,77511,502)×100≈90%This indicates the system is operating at about 90% of its nominal potential.

Gross AC Energy (kWh): 11,090 kWh

The total AC energy produced before any auxiliary consumption or internal inverter losses.

Conversion Efficiency: DC to AC Efficiency=(11,090/11,502)×100≈96.4%

Annual Net Definition: The energy actually delivered to the grid or consumed, accounting for inverter and other system losses.

Overall System Efficiency: Total Efficiency=(10,986/12,775)×100≈86%

This is the final performance metric, reflecting the real-world energy available for use from 6.25 kW system.

Total System Efficiency: Around 86%, indicating some losses due to conversion, shading, or other factors.

DC to AC Conversion Loss: Approximately 3.6% is lost during the DC to AC conversion process.

Difference Between Gross and Net Energy: Small, suggesting minimal auxiliary power usage or internal system consumption. It is recommended that regular maintenance (cleaning panels, inspecting wiring) could minimize efficiency losses.

Monitoring shading and panel alignment ensures optimal performance year-round.

This breakdown shows that the solar PV system is performing efficiently, with energy conversion losses within the expected range.

Energy Delivered (kWh): 10,986 kWh

The energy actually delivered to the grid or consumed, accounting for inverter

and other system losses.

Overall System Efficiency: Total Efficiency=(10,986/12,775)×100≈86%

This is the final performance metric, reflecting the real-world energy available for use from 6.25 kW system.

Total System Efficiency: Around 86%, indicating some losses due to conversion, shading, or other factors.

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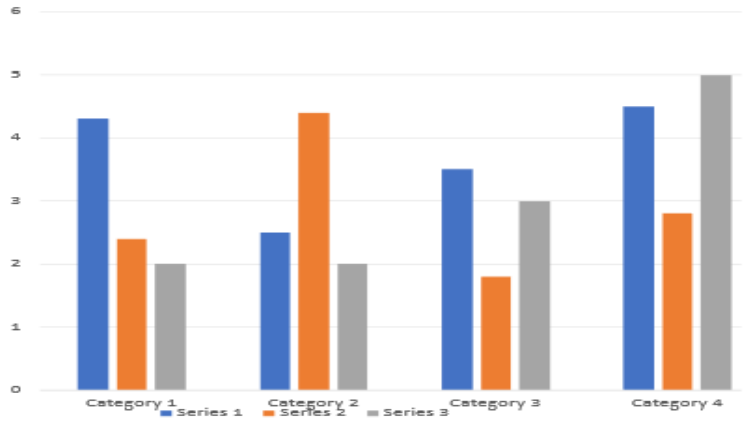


Figure 12: Global Irradiance: Direct/Beam irradiance, Direct irradiance and Diffuse irradiance

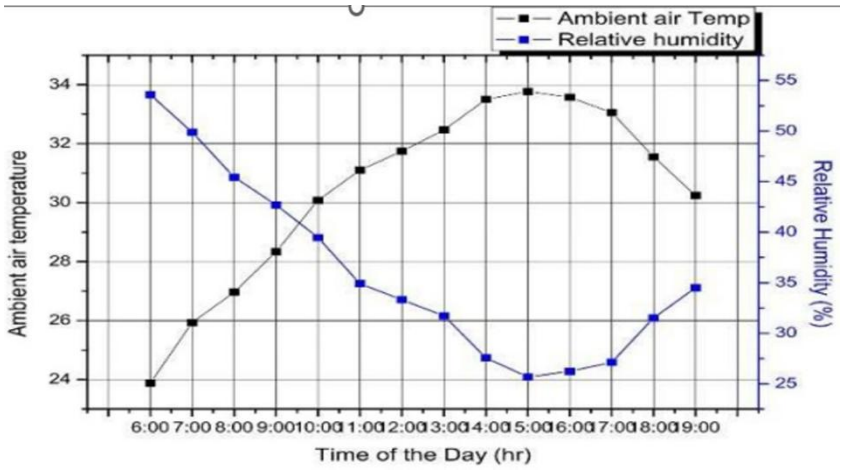


Figure 13: Hourly variation of the ambient air temperture

Global irradiance: Direct/Beam irradiance, Direct irradiance and Diffuse irradiance

Seasonal Variations:

The data shows that the highest energy outputs occur in November, March, and January, while the lowest are in August and June. These seasonal variations are influenced by solar irradiance, efficiency factors, and environmental factors. Maintenance schedules and panel alignment are crucial during high irradiance months. The deregulation environment is expected to lower electricity prices, benefiting consumers.

Hourly variation of the ambient air temperature and its relative humidity.

The X-axis represents time from 6 AM to 9 PM, indicating daily variations in ambient temperature and relative humidity. Ambient temperature starts at 24°C and increases by 2°C, peaking in the afternoon before declining in the evening. Relative humidity ranges from 25% to 35%, showing an inverse relationship with temperature. This information improves power system efficiency and electricity supply.

Expected Trends and Interpretation:

The report describes the weather patterns in the morning, afternoon, and evening. The morning temperature is low, with humidity around 35% due to cooler conditions and overnight condensation. The afternoon temperature rises, reaching a peak around 32°C-34°C, with relative humidity dropping to 25%-27%. The temperature gradually decreases as the sun sets, with the highest temperature occurring around midday to early afternoon and the lowest relative humidity around 25%. As the day progresses into the evening, temperature drops, leading to an increase in relative humidity.

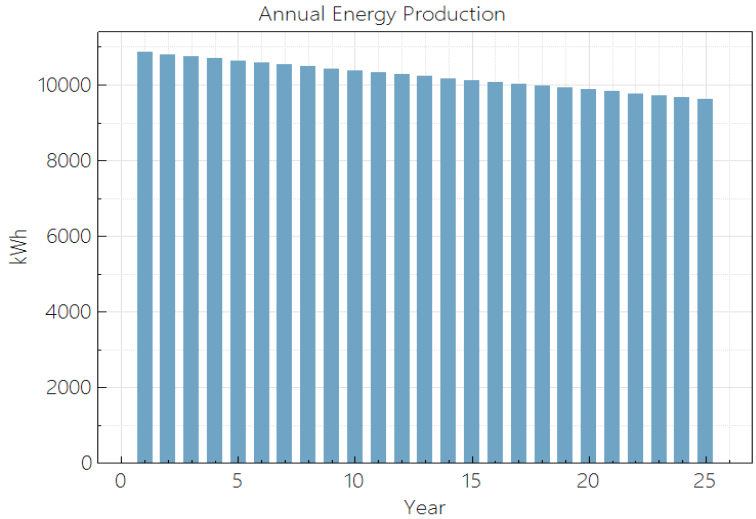


Figure 14: Annual Energy production

Power industries are reliable. It will happen in the future; power industries will have only one sole objective to provide utmost satisfaction to their customers all over the world.

Annual Energy Production.

(A)There are six data points over 25 years:

t=0,4.17,8.33,12.5,16.67,20.83,25t = 0, 4.17, 8.33, 12.5, 16.67, 20.83, 25t=0,4.17,8.33,12.5,16.67,20.83,25 years (with equal intervals).

Corresponding values: 0,1000,2000,300,4000,5000,6000, 7000, 8000, 9000, 10000.

These values increase linearly over time, that reflect cumulative performance, stress, or utilization

(B). The Scenarios for System Performance

(a) Positive Growth Scenario

If higher values mean better performance: The system is improving steadily over 25 years.

It reflects an increasing capacity, efficiency, or output due to enhancements or optimizations.

Example: A production system scaling up over time.

(b) Degradation or Stress Scenario: Higher values indicate wear, stress, or load:

The system is accumulating wear or degradation over time.

The linear trend suggested predictable wear under controlled conditions.

The end point (10000) represents a failure threshold or limit.

Example: Mechanical stress buildup in a structure.

(c Utilization or Resource Consumption: If the values track resource use or workload:

The system is consuming resources at a consistent rate.

Reaching 10000 indicate complete resource utilization or exhaustion.

Example: Energy consumption or budget utilization over time.

Insights for a Linear Trend:

Steady-State Conditions: The linear progression suggests stability in the factors driving the system.

Predictability: You can forecast future performance (if trends remain constant).

(C) Potential Actions or Considerations: Plan has to be made for how to sustain and optimize further improvements.

Degradation: Monitor critical thresholds to prevent failure (e.g., at or near 10000). Schedule maintenance or intervention as needed or necessary.

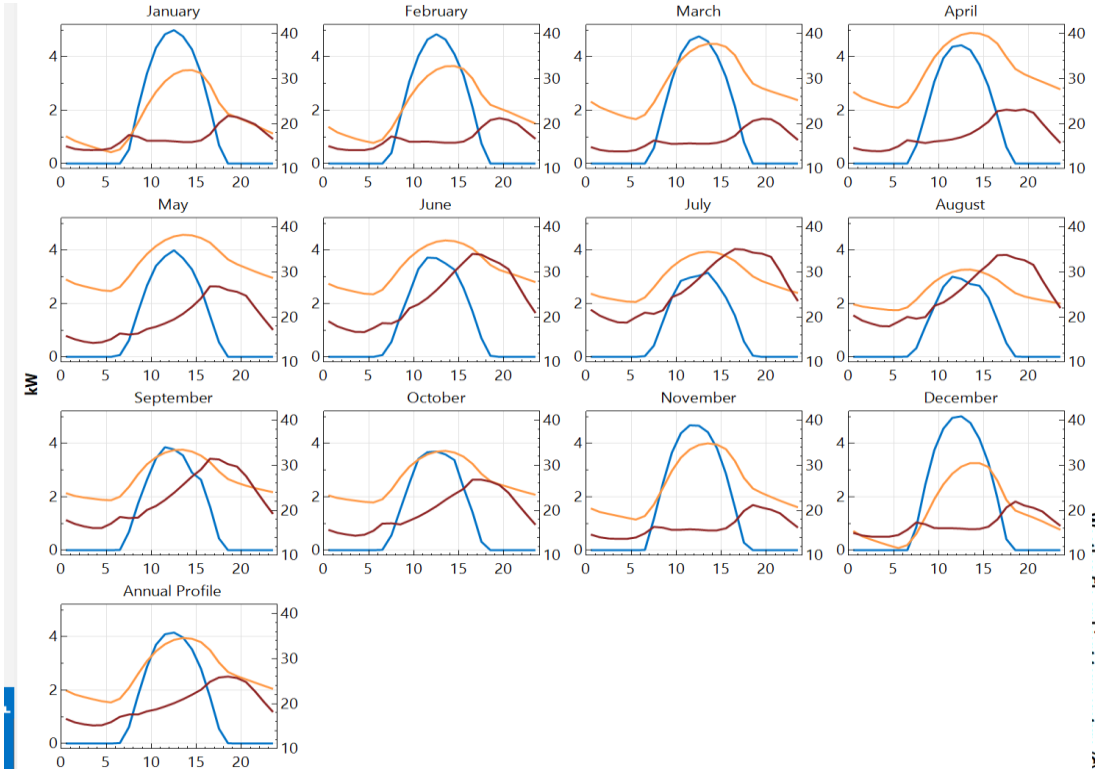


Figure 15: Electricity load year1(kw) (brown color), System power generated(kw)(blue color) and Weather file ambient temperature (yellow color)

Electricity load year1(kw) (brown color), System power generated(kw) (blue color) and Weather file ambient temperature (yellow color)

Y-Axis: The left-side y-axis (0,1,2,3,4) is measuring the Electricity load (kW).

The right -side y-axis (10,20,30,40,) is measuring the weather ambient temperature (deg), which tends to have a larger range than the electricity load or power generation.

X-Axis: The bottom x-axis (0, 5, 10, 15, 20) represents system power generated monthly, the 12 graphs, each represents a month (January–December).

Three distinct waveforms alternating across months represent the changes in electricity load, power generation, and weather ambient temperature over time. Electricity

load fluctuates hourly and seasonally due to natural variations, with peaks and troughs in the weather load waveform corresponding to daily and seasonal sunshine patterns.

System Power Generated (kw color blue):

Solar panels generate power based on available irradiance energy, increasing proportionally as irradiance increases. The three waveforms interact differently, with some months having higher ambient temperatures and power generation matching load well, while others may have mismatches and system inefficiencies, requiring grid support or lag slightly.

Weather file ambient temperature (deg color yellow):

This follows a usage pattern based on demand, which could be: Higher in the evening when people use more electricity. Seasonally variable, with peaks in winter (for heating) or raining season (for cooling).

If power generation is higher than load, excess energy could be stored or sent to the grid. If power generation is lower than load, additional electricity must come from the grid or batteries.

The System power generation and electric load align well, this indicate the system is well-sized.

The large gaps where power is too low, need battery storage or grid backup.

If System power is too high relative to load, energy storage or grid export options are in place.

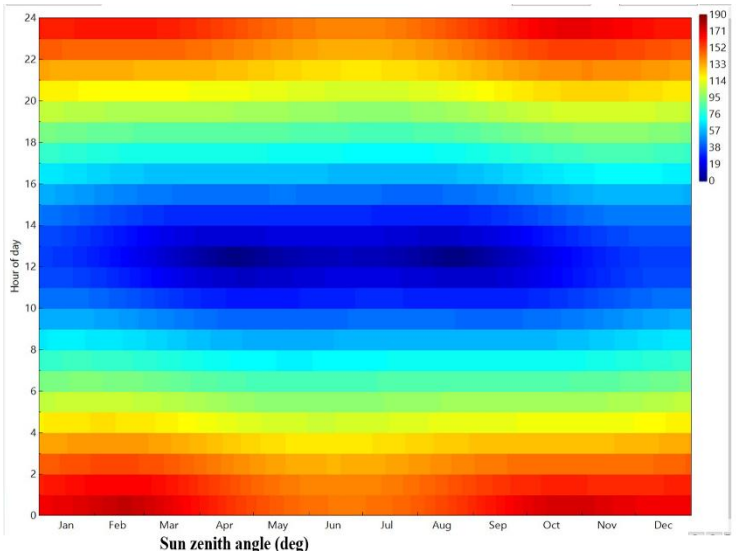


Figure 16: Sun Zenith/Hour of day

Sun Zenith Angle (SZA) gradient chart, are:

X-axis represents the months (January–December).

Y-axis represents the time of day (0–24 hours).

Color gradient corresponds to different Sun Zenith Angles (SZA), as indicated by the legend:

Blue (0–38°) → Sun is high in the sky (closer to the zenith).

Light blue (57–95°) → Sun is lower in the sky (closer to the horizon).

Yellow (114°) → Sun is very low, near sunrise/sunset.

Red (133–190°) → Sun is below the horizon (nighttime).

Daily Solar Cycle: The blue regions occur during daytime when the Sun is above the horizon.

Red regions dominate the nighttime when the Sun is below the horizon.

Yellow and light blue indicate transitions at sunrise and sunset.

Near raining season (June/July in Northern Hemisphere): The blue region extends for more hours, meaning longer daylight.

Near Winter (December/January in Northern Hemisphere): The red area is larger, indicating longer nights.

Equinoxes (March/September) have nearly equal day and night durations.

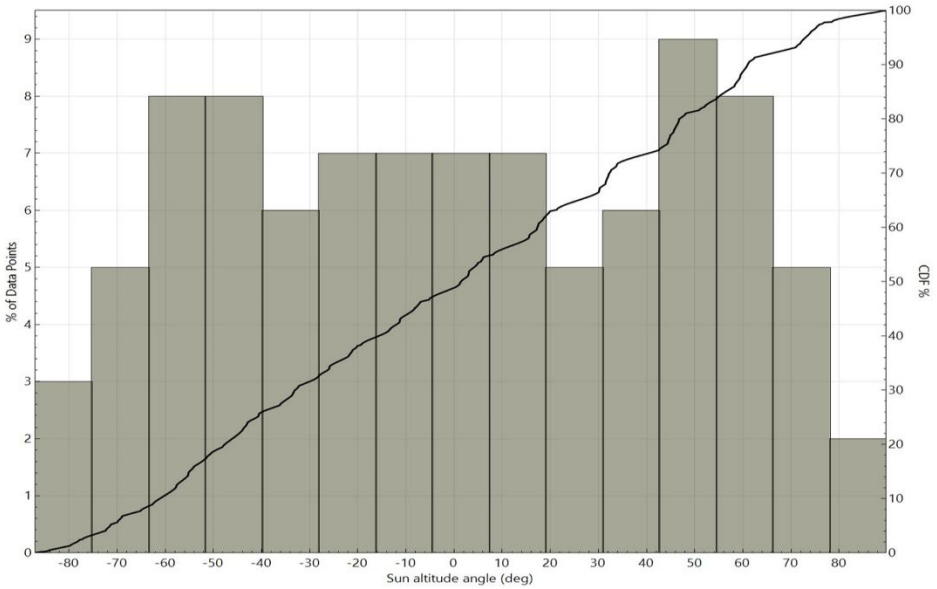


Figure 17: Cumulative Distribution Function/Sun altitude(deg)

Cumulative Distribution Function/Sun altitude(deg)

The bar chat graph at y-axis left 0=9 in step of 1 % of data points, at right side CDF% 0-100 in step of 10, x-axis -80 to 0 in step of -10 and 0-80 in step of 10 is the Sun altitude angle (deg).

The bar chart represents data related to the Sun's altitude angle (in degrees) on the x-axis, with two different y-axes:

Y-axis: A percentage scale ranging from 0% to 9% in steps of 1%, representing the frequency distribution of data points.

Right Y-axis: A Cumulative Distribution Function (CDF) scale from 0% to 100% in steps of 10%, showing the cumulative sum of the data.

X-axis: Represents the Sun altitude angle (in degrees) with values from -80 to 80:

Negative values (-80 to 0): The Sun is below the horizon (before sunrise or after sunset).

Positive values (0 to 80): The Sun is above the horizon (daytime).

The bar chart (left y-axis) shows the percentage of data points for each sun altitude bin, illustrating how frequently the Sun is at certain angles.

The CDF curve (right y-axis) accumulates these frequencies, reaching 100% at the last bin, showing the total distribution.

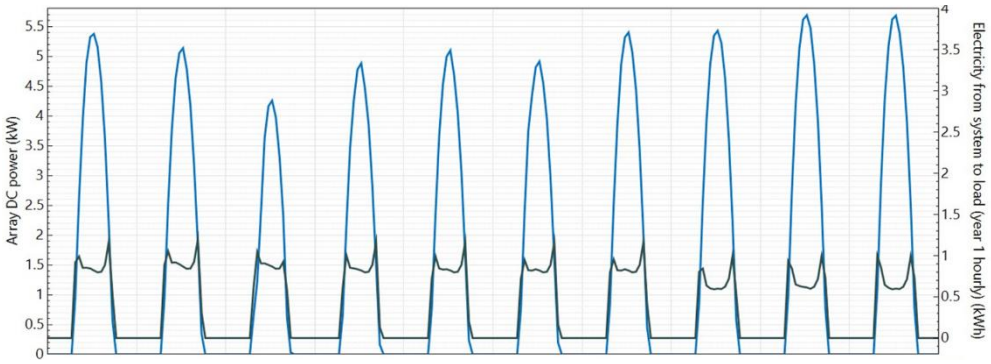


Figure 18: Array DC power(kw)/Electricity from system to load (year 1 hourly) (kwh)

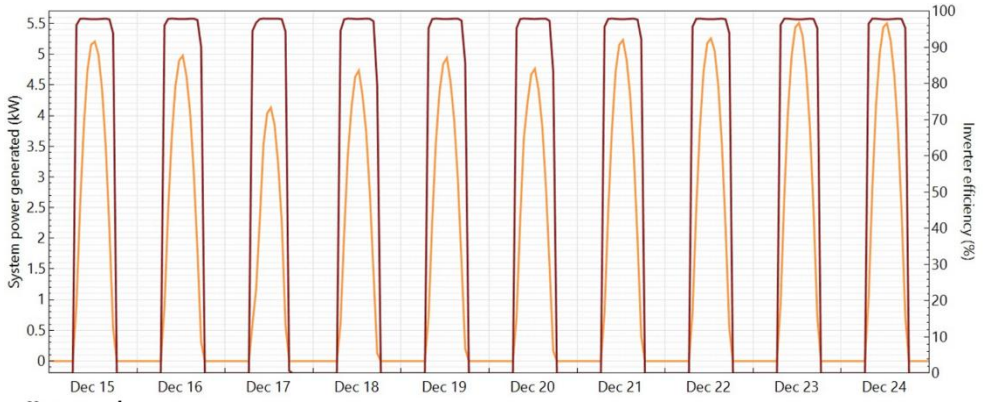


Figure 19: Inverter Efficiency/System Power Generated

Array DC power(kw)/Electricity from system to load (year 1 hourly) (kwh)

The graph of Array DC power(kw) on the y-axis 0-5.5 in step of 0.5 left, on the right-side electricity from system to load (year1 hourly) (kwh) 0-4 instep of 0.5

The graph shows two related datasets on a dual Y-axis plot:

Left Y-axis: Array DC Power (kW) ranging from 0 to 5.5 kW in 0.5 kW steps

Right Y-axis: Electricity from system to load (kWh) ranging from 0 to 4 kWh in 0.5 kWh steps

Interpretation of the Graph:

Solar Power Generation & Load Supply Relationship

The Array DC Power (left Y-axis) represents the instantaneous power output of the solar array.

The Electricity from system to load (right Y-axis) shows the energy supplied to the load in kWh (energy over time).

Daily Power Output Trends:

If the X-axis represents hourly data, the solar power will likely rise in the morning, peak around noon, and drop in the evening (a typical bell-shaped curve).

The electricity supplied to the load may follow a similar trend but depends on battery storage, inverter efficiency, and energy demand.

General Seasonal & Performance Trends:

If the graph covers a full year, expect higher power output in raining season and lower in winter due to seasonal variations in sunlight.

The electricity supplied to the load might not always match solar power generation exactly, due to factors like storage, grid export, or demand fluctuations.

Efficiency & System Behavior:

The graph demonstrates the relationship between system power generated and inverter efficiency. It shows that at low power generation (0-1 kW), inverter efficiency is usually lower. As system power increases, inverter efficiency typically rises, reaching its optimal range (~95-98%) at moderate power levels. However, at maximum power (~5.5 kW), efficiency might slightly drop due to thermal losses or overload conditions. The graph is a dual Y-axis plot, showing the relationship between system power generated and inverter efficiency.

Daily Trends (If X-axis is Time):

Inverter efficiency may start low in the morning (low power generation). It improves as solar output increases, peaking around midday. In the evening, efficiency drops again as solar power decreases.

If the inverter efficiency never reaches 90–98%, it may indicate system inefficiencies (e.g., undersized/oversized inverter, heat losses, or grid conditions). If efficiency fluctuates significantly, it could be due to shading, cloud cover, or inverter design limitations.

CONCLUSION

The design and implementation of a solar tree in Bauchi State, Nigeria, showcased its economic viability and environmental sustainability. The tree, estimated to cost $17,640, has a 9.9-year payback period. The project also aligns with global efforts to promote renewable energy solutions. The design was optimized using SAM software and SOLIDWORKS. The success of this project suggests the potential for wider solar tree adoption in regions with high energy potential. Future studies could focus on structural design optimization, energy storage integration, cost reduction strategies, and hybrid systems.

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