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Design and Performance analysis of a stand-alone PV system at Dantsoho Hospital using PVsyt

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ABSTRACT

Solar energy is rapidly emerging as a critical component of sustainable power systems, particularly in regions with unreliable grid infrastructure. In Nigeria, frequent power outages and escalating energy costs highlight the urgent need for dependable and autonomous energy solutions, especially for critical facilities such as hospitals where uninterrupted power supply is essential for life-saving operations and service continuity. This study presents a comprehensive design, simulation, and economic evaluation of a standalone photovoltaic (PV) system for the proposed Yusuf Dan Tsoho Memorial Hospital in Kaduna State, Nigeria. The system, with a nominal capacity of 73 kW, was designed using PVsyst software, incorporating detailed load assessment and optimal sizing of system components, including PV arrays, inverters, and battery storage. The integration of energy storage ensures continuous power availability, thereby enhancing system reliability and resilience against grid failures. The techno-economic analysis compares the standalone PV system with the conventional utility grid supply. Results indicate that the lifecycle cost of the PV system is estimated to be cheaper than the grid connection base. Despite the high initial capital investment, the standalone system demonstrates superior economic viability over time due to reduced operational costs and independence from grid instability. The study underscores the effectiveness of standalone PV systems in delivering reliable, cost-effective, and uninterrupted power for healthcare facilities in developing regions. The proposed design provides a scalable and practical framework for deploying off-grid renewable energy systems in critical infrastructure, contributing to improved energy security and sustainability.

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INTRODUCTION

The economic development of any nation is closely linked to the availability and reliability of its energy resources. With rapid globalization and industrialization, the depletion of non-renewable energy sources has become a major global concern. Consequently, countries around the world are increasingly exploring alternative and sustainable energy solutions, among which solar energy has emerged as a leading option. Driven by the urgent need for decarbonization and the ongoing global energy crisis, the transition toward clean and renewable energy systems has become imperative. Photovoltaic (PV) technology plays a vital role in mitigating climate change by reducing greenhouse gas emissions and supporting global sustainability goals (Iqbal & Tariq Iqbal, 2019).

Solar energy is abundant and possesses the potential to exceed current global energy consumption demands. It is a clean, renewable, and environmentally friendly resource

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that can significantly contribute to future energy needs. Photovoltaic systems enable the direct conversion of sunlight into electrical energy with increasing efficiency due to continuous technological advancements. In recent years, PV systems have gained widespread adoption as a reliable means of harnessing solar energy (Irshayyid & Chen, 2023). However, one of the key challenges in solar energy utilization is ensuring continuous power supply during periods of low solar irradiation. This challenge is effectively addressed through the integration of energy storage systems, which enhance system reliability and stability. Additionally, factors such as geographical location, weather conditions, and load demand significantly influence the performance and efficiency of PV systems(Anayochukwu Ani, 2024).

Photovoltaic systems can be broadly classified into grid-connected and standalone (off-grid) systems. Grid-connected systems operate in conjunction with the utility grid, supplying power when solar generation is insufficient and exporting excess energy when production exceeds demand. In contrast, standalone PV systems operate independently of the grid and are particularly suitable for areas with unreliable or no grid access (Mahmood et al., 2020). These systems provide a cost-effective and sustainable alternative to conventional energy sources such as diesel generators, kerosene, and biomass, which are associated with environmental pollution and health hazards.

In critical facilities such as hospitals, the availability of a reliable and uninterrupted power supply is essential for sustaining life-saving equipment, medical procedures, and overall healthcare delivery. In many parts of Nigeria, frequent grid power outages pose significant risks to patient safety and operational efficiency. Standalone PV systems, when integrated with battery storage, offer a dependable solution for ensuring continuous power supply and enhancing energy security in such environments (Mashaly et al., 2025).

A standalone PV system is therefore considered suitable for this project due to its economic viability, reliability, ease of installation, and low maintenance requirements. This study focuses on the design of a standalone solar PV system for the proposed Yusuf Dan Tsoho Memorial Hospital located in Kaduna State, Nigeria. The primary objective is to develop an alternative and reliable energy solution capable of meeting the hospital's electricity demand. The system design and sizing are carried out using PVsyst (Version 8.06), an industry-standard simulation tool, while analytical methods and findings from related studies are used to validate the results. In addition to meeting the energy requirements of the facility, this study also presents a comprehensive economic analysis of the proposed system to evaluate its feasibility in comparison with the conventional utility grid supply.

PROBLEM STATEMENT

The increasing dependence on electrical energy, particularly in critical sectors such as healthcare, requires a power supply that is both reliable and uninterrupted. However, in Nigeria, electricity supply is characterized by inadequacy, instability, and frequent outages, making it difficult to meet the continuous energy demands of essential facilities. This challenge is especially severe in hospitals, where uninterrupted power is vital for operating life-saving equipment, conducting medical procedures, preserving drugs and vaccines, and ensuring effective patient care. Power disruptions in such environments can lead to serious consequences, including loss of lives, equipment damage, and reduced quality of healthcare services.

Although alternative sources such as diesel generators are commonly used, they are costly to operate, environmentally unfriendly, and not sustainable over time. These challenges highlight the urgent need for a dependable and sustainable energy solution capable of providing continuous power supply. Therefore, this study focuses on the design of a standalone photovoltaic system for Yusuf Dan Tsoho Memorial Hospital in Kaduna State, aimed at ensuring a stable, reliable, and uninterrupted electricity supply for critical hospital operations.

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METHODOLOGY

Load Design

The first task for any photovoltaic system design is to determine the system load/demand. This load estimate is one of the key factors in the design and cost of the grid connected PV system. This is normally done by calculating the overall load of the building or reading the maximum demand load of the building from the meter (if any) or consulting their power provider (P.H.C.N or KEDCO).

Over Voltage Protection

The sources of over voltage can be lighting, atmosphere distribution or switching transient in power lines. The basic techniques in current used are;

1. Grounding PV array metal structure
2. Arresting over voltage by means of semi-conductor and other active devices like fuses, metal oxide arrestor, gas discharge devices, zener diodes.
3. Interception via air terminal; the air terminal located inside the array fields are special lighting protection strategy. Lighting mast is connected to the buried ground cables on roofed- mounted arrays. The air terminals are usually placed above the highest part of the building to attract the electric discharge (kumra et.al, 2012).

Sizing of the Solar Array

Before sizing the array, the total daily energy or demand in Watt-hours (E), the average sun hour per day T_{min}, and the dc-voltage of the system (V_{DC}) must be determined. Once these factors are made available we move to the sizing process. To avoid under sizing, losses must be considered by dividing the total power demand in $Wh.day^{-1}$ by the product of efficiencies of all components in the system to get the required energy E_r (Akinsade et al., 2025). Or multiplying by 1.3 (www.leonics.com)

$$E_r = \frac{E}{\eta_{overall}} \quad (1)$$

The peak power, the previous result is divided by the average sun hours per day for the geographical location T_{min}(Abu-Jaseer, 2010).

$$P_p = \frac{\text{Daily Energy requirement}}{\text{Minimum sun peak hours per day}} = \frac{E_r}{T_{min}} \quad (2)$$

The total current needed calculated by dividing the peak power by the DC- voltage of the system(Abu-Jaseer, 2010).

$$I_{dc} = \frac{\text{Peak Power}}{\text{System DC voltage}} \quad \frac{P_p}{V_{dc}} \quad (3)$$

Modules must be connected in series and parallel according to the need to meet the desired voltage and current in accordance with. First the number of series modules which equals the DC voltage of the system divided by the rated voltage of each module V_r. (Anayochukwu Ani, 2024).

$$N_s = \frac{\text{System DC Voltage}}{\text{Module rated voltage}} = \frac{Vdc}{V_r} \quad (4)$$

Second, the number of parallel modules which equals the whole modules current divided by the rated current of one module Ir. (Iqbal & Tariq Iqbal, 2019).

$$Np = \frac{\text{Whole Module current}}{\text{Rated current of one module}} = \frac{Idc}{Ir} \quad (5)$$

The total number of modules Nm equals the series modules multiplied by the parallel ones (Iqbal & Tariq Iqbal, 2019).

N_m=number of series modules X number of parallel module

$$Nm = Ns \times Np \quad (6)$$

Sizing of Battery Bank

The results from PVSYST simulation give 432 numbers of batteries for the system (8 in series x 54 in parallel) after the simulation. To avoid under-sizing, an analysis was conducted to confirm the result. The number of batteries can be obtain from:

$$= \frac{\text{Daily average energy demand X Days of autonomy}}{\text{Battery voltage X Battery capacity}} \quad (7)$$

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No. of Batteries = (277500 x 4)/ (12 x 258) = 434.64
Thus, 435 Batteries will be sufficient.

$$\text{No. of batteries in series} = \frac{\text{the system DC voltage}}{\text{Battery voltage}}$$

N_s= 96/12= 8 batteries.

Then number of parallel paths N_p is obtained by dividing the total number of batteries by the number of batteries connected in series:
$N_P = N_T / N_S$ = 435/8 = 54.4 approximately 55 batteries.

Sizing of the Voltage Regulator

A voltage regulator controls the flow of current. A good voltage regulator must be able to withstand the maximum current produced by the array as well as the maximum load current (Irshayyid & Chen, 2023). Sizing of the voltage regulator is obtained by multiplying the short circuit current of the modules connected in parallel by a safety factor F_{safe}. The result gives the rated current of the voltage regulator (Irshayyid & Chen, 2023).
I= parallel module short circuit current × safety factor

$$= N_p \times I_{sc} \times F_{safe} \quad (8)$$

The factor of safety is employed to make sure that the regulator handles maximum current produced by the array that could exceed the tabulated value. And to handle a load current more than that planned due to addition of equipment, for instance. In other words, this safety factor allows the system to expand slightly *Hameed et al 2020*.

Sizing of the PV Array

The results from PVSYST simulation gives 303 Number of 240Wp solar module for the system. To avoid under-sizing, an analysis was conducted to confirm the result.

$$I_{dc} = \frac{\text{Peak Power}}{\text{System DC voltage}} = \frac{P_p}{V_{dc}} \quad (9)$$

$$I_{dc} = \frac{49600}{96} = 516.8A$$

The number of modules in series is given by:

$$N_s = \frac{\text{System DC Voltage}}{\text{Module rated voltage}} = \frac{\text{Vdc}}{V_r} \quad (10)$$

$$N_s = \frac{96}{40} = 2.4$$

$$= \text{Approximately equal to } 3$$

Similarly the number of modules in parallel is

$$\text{Np} = \frac{\text{Whole Module current}}{\text{Rated current of one module}} = \frac{\text{Idc}}{\text{Ir}} \quad (11)$$

$$\text{Np} = \frac{517}{5.11} = 100.9$$

$$= \text{Approximately equal to } 101$$

PV Syst software tool

It aims to perform a thorough system design using detailed hourly simulations. Within the framework of a "project", the user can perform different system simulation runs and compare it.

Figure 1: PVsyst software tool

Sizing of the Inverter

To size the inverter, the total number of appliances with the likelihood of operating at the same time was taken from the load profile. At this stage the issue of diversity factor comes into play; the computation is detailed below.
P= 73000 x 0.6 = 43.8kW

The inverter must be able to handle this much power at $220V_{ac}$. Thus, two SatCon PVS-30kW inverters were used for the design. The reason for choosing this inverter is that: it offers

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market leading reliability, efficiency and ease of use for a standalone photovoltaic system.

SIMULATION RESULTS

Array Orientation and Optimum Tilt Angle

A prior requirement to the design of any solar based conversion system is the knowledge of optimum orientation and tilt surface at which peak solar energy can be collected`` (Mashaly et al., 2025). Fig 1 shows the PVSYST software tool's page where the geographical coordinates were inserted. The PVSYST was also used to obtain annual solar irradiance corresponding to different sloped surfaces for every month of the year, and this is shown in table 1. Fig .2 depicts a graph of Average solar irradiance kwh/m^2.day against tilt angles, and it is used to the optimum tilt angle for the design.

	horizon global KWh/m2.day	tilted global KWh/m2.day	tilted global KWh/m2.day	tilted global
month	0°	10°	15°	20°
January	5.8	6.3	6.5	6.7
February	5.8	6.2	6.3	6.4
March	6.3	6.4	6.5	6.4
April	6.3	6.2	6.1	5.9
May	5.9	5.7	5.5	5.2
June	5.4	5.1	4.9	4.7
July	4.9	4.6	4.5	4.3
August	4.5	4.3	4.2	4.1
September	5.1	5.1	5.1	5
October	5.6	5.9	5.9	5.9
November	6.1	6.6	6.8	7
December	5.8	6.4	6.7	6.9
Average	5.6	5.7	5.8	5.7

Table1:Annual solar Irradiance

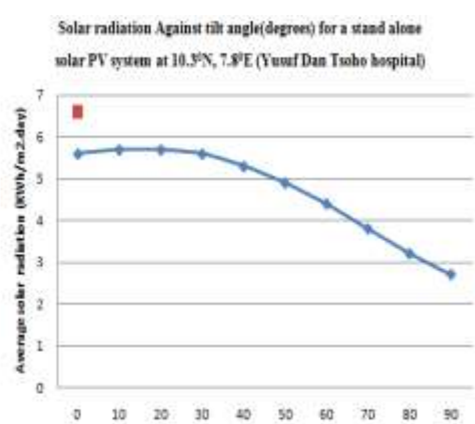

Figure 2: Optimal tilt angle orientation

From this Preliminary analysis, when the array is at an angle of 15º it receives the highest average value of the solar irradiance. Now, it is evident that the fixed tilt angle best suited for capturing solar irradiation over the whole year is 15°. Based on this, an array tilt of 15° to the horizontal was chosen as the optimal angle of inclination. It also (Fig 3) suggests that an azimuth of 0° is most suited for the location. Due to the location is close to the equator and the sun is mostly overhead all year round.

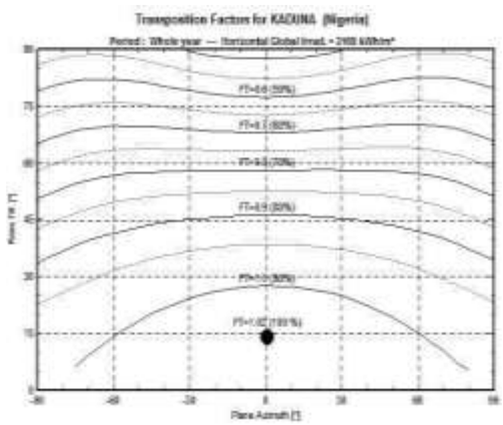

Fig 3: Transposition factor for Kaduna state (PVsyst, 2025).

Load Profile

The load profile obtained in this research illustrates the temporal variation of electrical energy demand over a 24-hour period, highlighting the presence of base, intermediate, and peak load conditions. The results indicate that energy consumption is not uniform throughout the day, with certain periods exhibiting higher demand due to increased activity, while a continuous base load persists around the clock (24 hours a day**).** This pattern is particularly important for photovoltaic (PV) system design, as it underscores the need for adequate energy generation during peak periods and sufficient energy storage to sustain supply during low or no solar generation intervals as shown in table 2. Consequently, the derived load profile provides a reliable basis for sizing system components to ensure efficient and uninterrupted operation.

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Table 2: Load profile

SUMMARY OF THE LOAD PROFILE (USER'S NEED) FOR THE HOSPITAL, KADUNA.					
S/N	APPLIANCES	QUANTITY	POWER	MEAN DAILY USE	DAILY ENERGY
1	FLOURESCENT	100	25W/lamp	7.0hrs/day	17500Wh
2	TV/MAGNETOSCOPE/PC	29	200W/app	.0hrs/day	23200Wh
3	DOMESTIC APPLIANCES	30	850W/app	2.5hrs/day	63750Wh
4	FRIDGE/DEEP FREEZER	11		0.8KWh/day	8800Wh
5	OTHER USES		38750W	3.0hrs/day	116250Wh
6	STAND-BY CONSUMER		2000W	24hrs/day	48000Wh
	TOTAL DAILY ENERGY TOTAL MONTHLY ENERGY				277500Wh/day 8325Kwh/day

Fig 4: Energy Needs Computed In PVsyst.

However, it can be noticed that in July and in August the global solar energy is inferior to the demand this is due to the days of Autonomy. Fig 3.9 shows the batteries average state of charge and the loss of load probability.

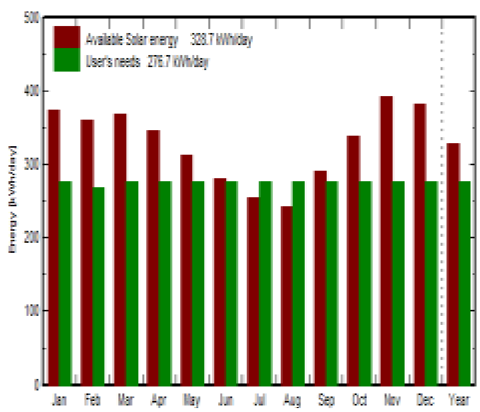

Fig 5: Resource Estimation (Preliminary Design).

The probability of loss of load is 4% over the year. However, the loss of load appears during winter months, especially in July and in August. In addition, the average battery state of charge is low during this period; this is also due to the days of Autonomy.

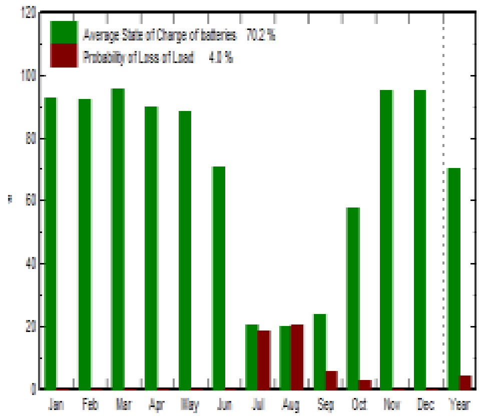

Fig 6: Batteries Average State of Charge and LOL (Preliminary Design).

Near Shading

In order to be sure that the different building and threes around the installation will not create any shadow which would make our photovoltaic system less efficient, all potential obstacles have been scale in PV syst. A preview of the shading scene is depicted in Fig 3.17 and Fig 3.18 shows the near shading result.

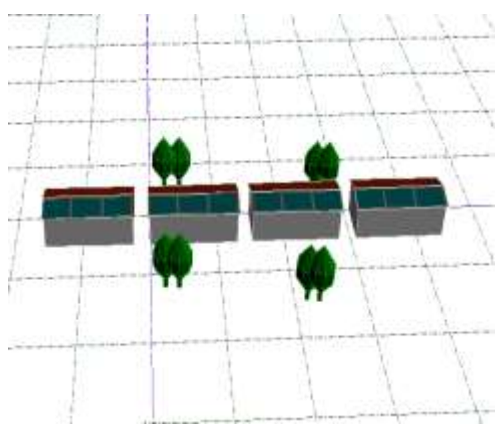

Figure 7a: Perspective View of the PV Field And Surrounding Shading Scene (PVsyst).

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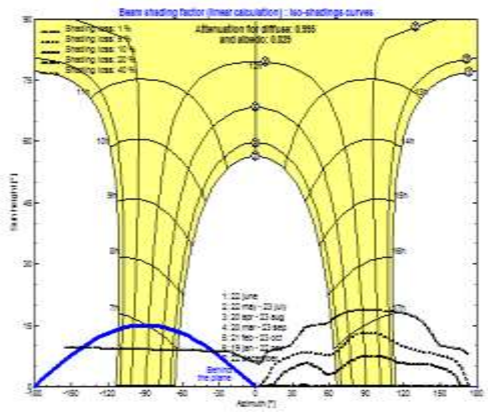
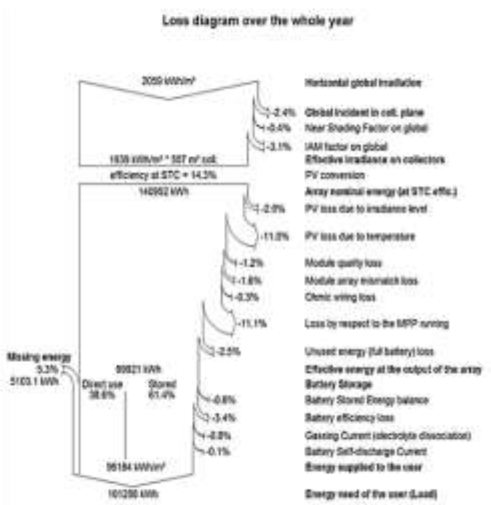


Fig 7b: Near Shading Result. (PVsyst,)
Battery Loss



CONCLUSION

This system design using PVSYST has helped us in determining the solar irradiance, the hospital loads, designing the solar module, batteries, inverter and the subsequent analysis (economic evaluation) has shown that solar photovoltaic is a viable alternative form of energy worth considering. This is especially true for countries where incentives for such systems exist as the user stands the chance of making a profit out of their own consumption of energy. The analysis shows that PVC is technically feasible and reliable, although the standalone solar PV system has a high initial cost but, on the run, it is cheaper due to almost zero maintenance cost. Over and under-sizing have also been avoided to ensure adequate, reliable, and economical system design.

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