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Development of an Optimal Poly-1-Order (OP-1) Model for Approximating Solar Photovoltaic (PV) Power Generation

Ene, I. P.

Department of Electrical/Electronic Engineering
Faculty of Engineering
University of Port Harcourt

Omorogiuwa, E.

Department of Electrical/Electronic Engineering
Faculty of Engineering
University of Port Harcourt

Abstract: This study was conducted to develop and evaluate the Optimal Poly-1-Order (OP-1) model for approximating solar photovoltaic (PV) power generation. Using a mixed research method, the study employed Ibrahim's simulation and prediction of grid-connected PV system theory with two objectives and their corresponding research questions. The study gathered primary and secondary data to approximate the implementation of a solar-PV system with an OP-1 model for generating electricity: optimizing energy production, load demands, and financial viability in the medical hostel facility of the University of Port Harcourt, Rivers State, Nigeria. With the use of simulation and descriptive methods of data analysis, results showed that the lighting system had 400 lights, each with 12W power. It operated for a total of 18 hours. Daily power consumption was 36,400 Wh. More so, it showed that 60 fans with 100W power were used during the same hours, resulting in a daily power usage of 108,000 Wh. Based on a comprehensive economic evaluation, the OP-1 solar-PV system was found to be economically viable for powering the medical hostel. The system met electricity demand, resulting in a remarkable 407% ROI and substantial savings for the grid, despite a lower optimized size of 193kW compared to the base peak generation of 383.90k. The study concluded and recommended that the proposed OP-1 Solar-PV power plant can meet the facility's electricity needs with a peak generation of 383.90kW and detailed energy analysis. Deploying this efficient solar-PV setup guarantees reliable and green electricity for the Medical Hostel, slashing the campus's carbon footprint and grid reliance.

Keywords: Optimal Poly-1-Order;OP-1 Solar-PV System; Grid-Connected PV System; Solar-PV Power Generation.

Nomenclature

Abbreviations	Descriptions
OP-1	Optimal Poly-1-Order
1S-PV	Solar Photovoltaic
W	Watts
1ROI	Return on Investment
11kW	Institute of Electrical and Electronics Engineers
UNIPORT	University of Port Harcourt
11 MAPE	Mean Absolute Percentage Error
1MATLAB	Matrix Laboratory
11NASA	National Aeronautics and Space Administration
11HOMER	Hybrid Optimization of Multiple Energy Resources
1RSOE	Randomized Sparse Outlier Eliminator
11MH	Medical Hostel
GPS	Global Positioning System
111DC	Direct Current
1111ORA	Outlier Rejection Analysis
kW	Kilowatt
1kWh	Kilowatt-hours
1O & M	Operations and Maintenance
11Wh	Watt-hour

111. Background to the Study

The rapid increase in energy consumption within hostel facilities at public higher institutions stands as a significant challenge nowadays. This issue is not unique to terti1ary institutions in Nigeria, as the number of students housed within these facilities continues to rise [3]. Consequently, the hostel facilities are confronted with a dilemma - the amount of energy consumed is of great concern. This, in turn, impacts the quality of the learning environment in tertiary institutions [17]. Given that electricity is indispensable in these facilities, with students relying on it for lighting, cooling, heating, and other electronic gadgets, it is crucial to have access to a sustainable energy source. However, Nigeria's hostel facilities have to depend on generators that run on fuel, making this energy source expensive and environmentally destructive [17]. Evidence suggests that there is an urgent need to switch to an alternative, reliable, and affordable energy source to run hostel facilities at public higher institutions[25]. This shift would ensure a stable energy supply, affordable energy cost, and most importantly, improve the quality of the learning environment [20]. A solution that has been proposed is the adoption of the OP-1 model as an approximation of solar PV power generation to help p111rovide a sustainable energy supply to the facility [7]. This model has been 1used in other establishments worldwide and has been proven to be effective in providing a sustainable energy supply through the effective installationof solar PV systems [10].

As UNIPORT has also faced similar issues, the adoption of this sustainable and affordable solution is crucial[16], considering the increasing number of students residing in these facilities [6]. The utilization of the OP-1 model has significantly propelled the solar PV power generation industry, promoting the cause of eco-friendly and sustainable energy sources. Education institutions can embrace this technology to facilitate a wholesome and environmentally friendly learning atmosphere. The cost-effective adoption of the OP-1 can help achieve this goal [19]. W1ith solar PV power generation, UNIPORT's hostel may cater to its energy requirements while promoting sustainability. Additionally, as highlighted by [1], stable and eco-friendly energy sources in higher educational institutions are crucial in fostering novel research and development. Hence, this research study sought to determine, measure, and evaluate the adoption and development of the OP-1 model for the approximation of solar PV power generation in the UNIPORT hostel facility.

1.1 Statement of the Problem

The vast potential of solar PV in generat11ing electricity at a large scale offers significant benefits for sustainability and profitability. However, this potential is often hindered by flawed power generation projections in the initial stages. Faulty assumptions or software discrepancie1s have led to instances where solar PV unintentionally disrupts power generation, impacting overall efficiency and coordination with other energy sources. Consequently, the focus at the UNIPORT hostel facility has shifted towards ensuring a stable and reliable power supply, prioritizing optimal energy management and economic considerations. To address this, researchers have undertaken the development and evaluation of the OP-1 Model, renowned for its effectiveness in different locations and utility applications, aligning with the UNIPORT hostel facility's specific attributes and energy requirements.

1.2 Aim and Objectives of the Study

This study was aimed at the development of an OP-1 model for approximating PV power generation in the MH facility of the UNIPORT, Rivers State, Nigeria. Specifically, the objectives were to:

1. Establish the energy consumption patterns and load profile demand of the MH facility using OP-1 model design solarPV.
2. Evaluate the viabilityof implementing anOP-1 model design solar-PV in generating electricity in the MH facility.11

1.3 Research Questions

1. What are the energy consumption patterns and load profile demands of the MH facility when utilizing the OP-1 model design solar-PV system?
2. How financially viable is the implementation of a solar-PV system with an OP-1 model design for generating electricity in theMH facility?

The paper is organized as follows: Section 2 covers the literature review. Section 3 details the Materials and Methodology, and 4 emphasizes the results. Section 5 mentions the discussion. Section 6 mentions the advantages and disadvantages of the proposed method. The conclusion is recapitulated in Section 6.

2. Literature Review

The OP-1 model is derived from the concept of system identification[11], which involves estimating the parameters of a mathematical model based on input-output data[18]. In this case, the model is a first-order polynomial [10], hence the name "Poly-1-Order." The term "optimal" refers to the fact that the model parameters are determined through an optimization process that minimizes the difference between the actual system response and the predicted response of the model [4]. Thus, the OP-1 model is a mathematical representation used in Electrical Engineering to describe the behavior of linear systems with a single input and a single output which is derived through an optimization process that minimizes the difference between the actual system response and the predicted response of the model[29]. The primary purpose of this study is to accurately predict the output of PV systems by considering various factors such as solar irradiance, temperature, and other environmental variables. The OP-1 model stands out due to its simplicity and efficiency in capturing the nonlinear behavior of PV systems. It achieves this by utilizing a first-order polynomial equation to effectively represent the relationship between the input variables and the output power generation. Extensive validation studies have proven the accuracy of the OP-1 model in different geographical locations. In a study conducted in different climes, researchers successfully employed the OP-1 model to forecast the power generation of solar PV panels[13][5] [2][33][9] [14]. The results obtained from this study demonstrated a high level of accuracy, providing valuable insights for grid integration and energy management systems. Another notable application of the OP-1 model was observed in other parts of Asia, where researchers utilized it to estimate the performance of a grid-connected PV system[26] [23] [31][27] [15] [32][34]. The model produced accurate predictions with a high coefficient of determination (R^2) value, signifying its reliability and effectiveness in approximating solar PV power generation. Similarly, in another research study conducted by [12] as well as[28], the OP-1 model proved to be a valuable tool for estimating the energy yield of a PV system. By utilizing this model, researchers were able to obtain reliable predictions, further emphasizing the OP-1 model's potential in various locations.

The OP-1 model has also been applied in other locations such as India, Australia, and Germany. In India, researchers such as [30][24] as well as [22]utilized the OP-1 model to estimate the energy yield of a PV system and discovered that it accurately predicted the power generation potential. Moving to Turkey, [8] applied the OP-1 model to evaluate the performance of a PV system. Their study concluded that the model consistently provided reliable predictions. Across the pond in Germany, [35] conducted a study to investigate the accuracy of the OP-1 model in estimating the energy yield of a PV system. By comparing the model's predictions with actual measurements, they found that the OP-1 model provided remarkably accurate estimations, underscoring its effectiveness in a European climate.

2.1 Theoretical Framework

The theory of simulation and prediction of residential grid-connected photovoltaic system performance explores the works of [12], as published in the International Journal of Power Electronics and Drive Systems. This study serves as a theoretical framework for the development of the OP-1 model for approximating PV power generation. The [12] study showed that with the right design, the OP-1 model can achieve high accuracy in predicting PV power generation, with a MAPE of less than 5%. This, as supported, indicates that the OP-1 model will be suitable for simulation[21] and prediction, i.e., approximating purposes in residential grid-connected PV systems.

2.2 Review Table

Table 1 portrays the objective, methodology, key findings, and contribution of the existing method. We considered eight papers that used a different methodology for the process. Each method has certain benefits and shortcomings that were explained in detail.

Table 1: *Review Based on Existing Methods*

S/N	Authors	Objective	Methodology	Key Findings	Contribution
1	Omorogiuwa and Kingsley [18]	To evaluate the cost-effectiveness of solar PV systems for the engineering faculty of the UNIPORT.	Cost analysis of solar PV system components and installation, using local and international prices.	Solar PV systems can be cost-effective for the Engineering faculty, with a payback period of less than 5 years.	Thestudy contributes to the understanding of the feasibility of solar PV systems for universities in Nigeria.
2	Ibrahim*et al*[12]	To simulate and predict the performance of residential grid-connected photovoltaic systems.	Simulating software models PV system performance with sun, temp, and setup.	Simulation predicts residential PV system performance, influenced by sunlight and temperature.	The study contributes to the development of accurate simulation models for residential grid-connected PV systems.
3	Sudharshan*et al*[30]	To review the impact of different irradiance forecasting techniques on solar energy prediction.	A systematic review of existing studies on irradiance forecasting techniques for solar energy prediction.	Irradiance forecasting techniques differ in accuracy, location, and application.	Research shows how irradiance forecasting affects solar energy prediction, prompting further investigation as the basis for further research.
4	Omorogiuwa and Roland [20]	To design and simulate a solar monitoring tracking system.	Designand simulation of a solar monitoring tracking system using a software tool.	The study found that the proposed solar monitoring tracking system can improve the efficiency of solar panels and reduce energy loss.	The study contributes to the development of cost-effective and efficient solar monitoring tracking systems for solar energy applications.
5	Xu*et al.*[31]	To develop an intelligent forecasting model for regional power grids with distributed generation.	Propose a hybrid forecasting model combining machine learning and traditional methods for regional power grid forecasting.	The advanced model enhances power grid forecasts and minimizes distributed generation uncertainty.	The study contributes to the development of accurate and reliable forecasting models for regional power grids with distributed generation.
6	Moshksarand Ghanbari [15]	To develop a model-based algorithm for maximum power point tracking of PV systems.	Revolutionize PV systems with a groundbreaking algorithm for maximum power.	The algorithm enhances PV system efficiency by accurately tracking power.	The study contributes to the development of accurate and efficient maximum power point tracking algorithms for PV systems.
7	Seyedmahmoudian*et al.*[27]	Develop an efficient metaheuristic approach for short-term forecasting of building-integrated photovoltaic system output power.	Hybridized artificial bee colony algorithm and back-propagation neural network.	Improved accuracy of power forecasting using hybridized artificial bee colony algorithm and back-propagation neural network.	A metaheuristic approach for short-term photovoltaic power forecasting.
8	Patel*et al.*[23]	Predict power output in small-scale off-grid photovoltaic systems using machine learning.	Utilizes XGBoost algorithm to predict power output from time series data.	XGBoost algorithm outperformed other machine learning models for power prediction.	A practical machine learning approach for power prediction in small-scale PV systems.

2.3 Identified Research Gap

This study addresses the lack of comprehensive models for optimizing solar PV power generation in specific facilities like MHs. Previous research has focused on general solar PV systems without considering the unique energy requirements and financial constraints of these facilities. The study develops and evaluates the OP-1 model within the context of an MH facility, providing insights into optimizing solar PV power generation while ensuring financial viability. The findings from this research can inform future developments and implementations of solar PV systems in similar institutional settings, bridging a crucial research gap in renewable energy and sustainable infrastructure development.

3. Materials and Methodology

The research study conducted a thorough evaluation of a grid-connected Solar-PV systems model over a 3-year timeframe from 2017 to 2019. A unique OP-1 model was employed, which underwent extensive development and analysis using the MATLAB® software. To determine the faculty's daily energy demand, the approach involved identifying appliances with power ratings and operation duration. This information was crucial in calculating the load and subsequently determining the sizes of the system components. The NASA data was utilized to assess the plant's output, while mathematical modeling was employed to establish the optimal parameters for the system. Climate data from the NASA repository for the specified years was incorporated to enhance the evaluation process.

Furthermore, the research included the utilization of the Hybrid renewable energy simulator HOMER® for visualization and techno-economic analysis, facilitating the selection and sizing of components for the planned plant. The primary objective of the proposed system was to generate electricity throughout daylight hours, with excess power being fed back into the grid and the ability to draw power from the grid during periods of cloud cover or at night. The grid-connected configuration consisted of various components such as solar panels, a grid-connected inverter, metering devices, and circuit breakers. To ensure improved accuracy, a novel RSOEroutine was implemented, resulting in an enhanced error response compared to the existing Poly-1 model.

3.1 Site Characteristics

A minimum of 383.90kW grid-connected PV system with at least 450 solar-PV parallel connected panels is to be installed on the rooftop of the MH twin-tower facility which is located in the Abuja campus, UNIPORT. The MH facility is located close to the Abuja campus car park with GPS coordinates at 4.8994oN-S, and 6.9233oE-W at an altitude (elevation) of 2.0m. Thestudy sitewas gathered from Google Earthwhich shows the aerial view of MH in Figure 1.

Fig. 1. *Aerial MH Facility, Abuja Campus, University of Port-Harcourt (Source: Google Earth Satellite Imagery)*

3.2 Assumptions of Research Study

The research study outlines MA to establish the framework for simulation by formulating principles/propositions within the model's boundaries as follows:

i. The system supplies solar-generated DCpower to the hostel during sunshine hours.

ii. The system-generated power at sunshine hours is greater than or equal to the total loading power of the hostel facility.
iii. No energy storage units are provided by the system.
iv. Excess power generated by the system is transmitted to the grid which provides its energy storage media.
v. Power drawn by each appliance occurs at pre-specified times of the day; no random appliance switching at random times of the day is allowed.

In accounting for MA-I following MA-II guidelines, it is assumed that the system's sole purpose is to provide solar-converted DC energy to hostel students. Therefore, students can charge their solar battery banks, solar-powered DC fans, rechargeable solar lanterns, laptops, and rechargeable ceiling bulbs using existing wall-connected converters. Additionally, it is presumed that electronic gadgets, predominantly found in the hostel common room, have the necessary conversion electronics to function. These assumptions allow the model designer or engineer to concentrate on the power system's generation aspects, which aligns with the objective of this research study.

3.3 Solar-PV Power Generator Modelling

To effectively model the power capability of anS-PV generator system, there is a need to specify certain S-PV intrinsic and system parameters in addition to specifying the required loading demanded of the S-PV generator system. For a given potential solar energy site, the solar power may be estimated as described in [36]:

$$P_{pv} = N_s \times N_p \times V_{oc} \times I_{sc} \times FF \tag{1}$$

Where,

$P_{pv(rated)}$ = Rated PV power, kW;

N_s = Number of PV modules connected in series

N_p = Number of PV modules connected in parallel

V_{oc} = Open circuit voltage of single PV module at standard test conditions

I_{sc} = Short-circuit current of single PV module at standard test condition

FF = Fill factor of PV module

The intrinsic S-PV parameters, V_{oc} and I_{sc} are typically estimated considering some additional intrinsic parameters as in Eqn 2 and Eqn 3 as:

$$V_{oc} = V_{oc(stc)} - K_v T_c \tag{2}$$

$$I_{sc} = \left(I_{sc(stc)} + K_i\left(T_c - 25\right)\right)G \tag{3}$$

Where,

K_v = PV module open-circuit voltage temperature coefficient correction factor, V/oK

K_i = PV module short-circuit current temperature coefficient correction factor, A/oK

G = global solar irradiance, kW-hr/m2/day

T_c = PV cell temperature, oK

The actual cell temperature, T_c, is affected by the environment including an ambient temperature parameter and the global solar irradiance at the location of interest. This cell temperature is estimated as:

$$T_c = T_{amb} + \left(0.0256 \times G\right) \tag{4}$$

T_{amb} = ambient temperature, oK

3.4 The Poly-1-Order Model and Solar-PV Power-Irradiance Model Fitting

Researchers have proposed numerous models to adapt to input features, addressing the age-old challenge of model adaptation. The model fitting process involves determining input coefficients that effectively represent the output state, often achieved through linear regression of the response variable (y) against the predictor variable (x) [37]:

$$y = mx + c \tag{5}$$

Where, m = Slope or gradient of the regression line

c = the intercept of the line.

The parameters, m,and c, are typically referred to as the coefficients of a Polynomial-of-Order-1 or simply Poly-1 model. The Poly-1 model is a type of linear regression model that is typically solved using the well-known method of least squares (mols). The solution of the slope, m, by mols, is represented by the generalized model in Eqn 6.

$$m = \frac{\sum_{i=1}^{|D|}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{|D|}(x_i - \bar{x})^2} \tag{6}$$

Where,

D = the number of feature data points

x_i represents the individual x-values in the dataset.

$\bar{x}$ represents the mean of the x-values.

y_i represents the individual y-values in the dataset.

$\bar{y}$ represents the mean of the y-values.

Σ represents the summation operator.

This equation calculates the slope coefficient, m, by taking the sum of the products of the differences between each x-value and the mean x-value, and the differences between each y-value and the mean y-value, divided by the sum of the squared differences between each x-value and the mean x-value.The Poly-1 model, though simple and highly efficient in solving linearly separable problems. It is widely used in scientific and engineering fields and recommended for understanding the behavior of complex processes. However, its linear nature can limit its ability to capture non-linear patterns in data, leading to compromised results and large prediction errors. This is particularly evident with outliers, which affect various models, including AI models, but have a more significant impact on the Poly-1 model. To address this, a modification to the predictor variable's input feature representation is proposed, inspired by sparse-connectivity and random shuffling principles, aiming to optimize the Poly-1 model.

3.5 OP-1Model and Solar-PV Power-Irradiance Model Fitting

The optimization of the Poly-1 model may be approached from the feature data point of view by generating a random sparse set of feature inputs of the predictor variable, x, say, xsparse, using the sparse set rather than the original predictor set in the mols solution, and then performing a sequence of iterations stopping when an acceptable error criterion is met.The sequence of steps is as described in the following algorithm:

Algorithm 1: OP-1 Model

Input: x, y

Compute x_{sparse} **as:** $x_{sparse} = x.*\, rand_k \begin{cases} 0, rand_k = rand > t_h \\ x, otherwise \end{cases}, k = 1 : length(x)$

Compute OP-1 model slope:

$$m_{sparse} = \frac{\sum_{i=1}^{|D_{sparse}|}\left(x_{sparse\,(i)} - \bar{x}_{sparse}\right)\left(y_{sparse\,(i)} - \bar{y}_{sparse}\right)}{\sum_{i=1}^{|D_{sparse}|}\left(x_{sparse\,(i)} - \bar{x}_{sparse}\right)^2}$$

Compute OP-1 model intercept: $c_{sparse} = \bar{y}_{sparse} - m_{sparse}\,\bar{x}_{sparse}$

Compute OP-1 prediction model: $y = m_{sparse}\, x_{sparse} + c_{sparse}$

In this regard and considering Algorithm-1, the OP-1 model acts as a sparse-connectivity-based model, which additionally exploits the random-shuffling technique to iterate towards an optimal solution. The flowchart depicting the OP-1 model processing is shown in Figure 2.

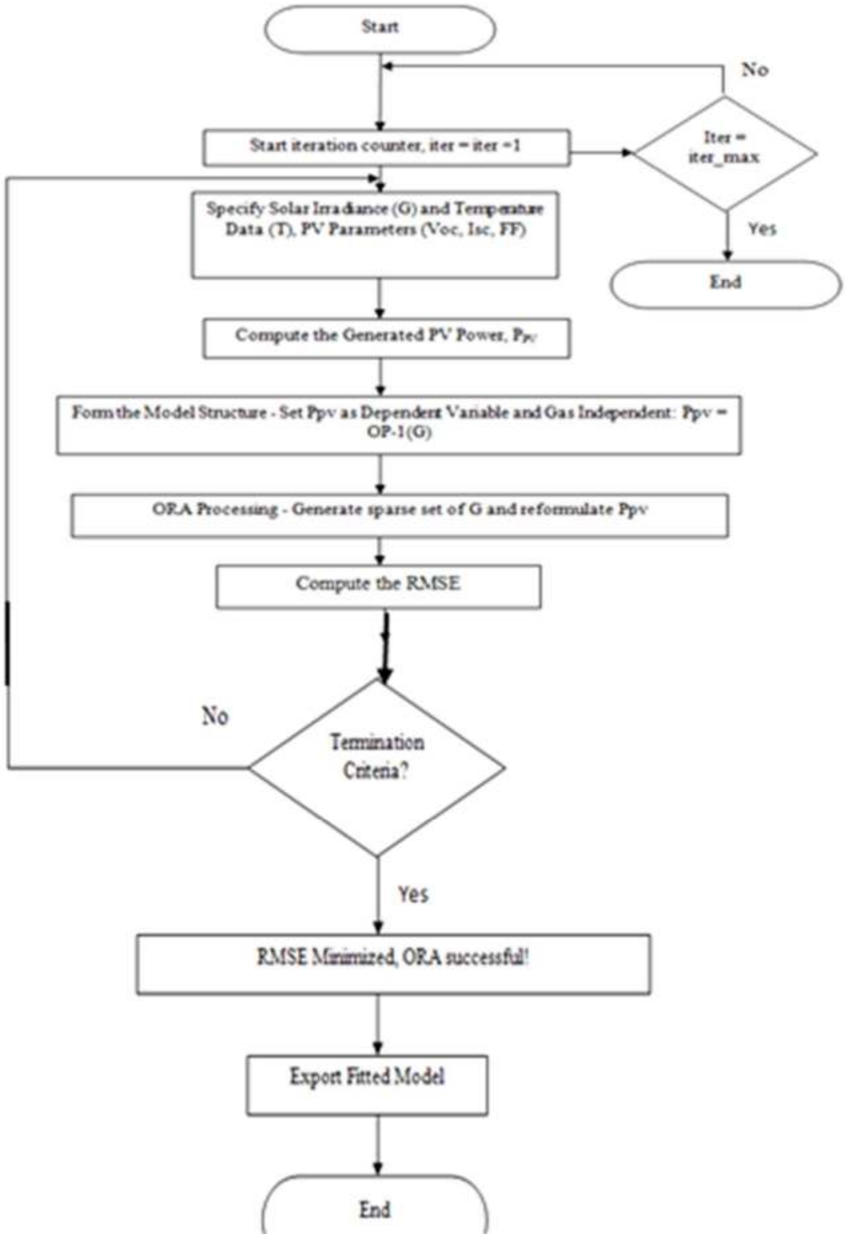

Fig. 2. *OP-1 model processing flowchart*

3.6 Termination Criteria

The ORA process starts with setting and incrementing the iteration counter, defining Solar-PV parameters, and formulating the model using outlier rejection analysis. If the outlier level metric (RMSE) is acceptable, the simulation ends; otherwise, the process is repeated until all iterations are completed.

4. Results

Answers to Research Questions

Research Question 1: What are the energy consumption patterns and load profile demands of the MH facility when utilizing the OP-1 model design solar-PV system?

Load Profile Data

To accommodate the changing electricity demand throughout the day, it's crucial to accurately depict the load pattern of the hostel. This profile helps determine the necessary solar panels and converters. Table 2displays the projected load profile for the MH facility.

Table 2: *Load Profile Data for MH facility (Source: Field Study)*

Appliances	QTY	Rated Power (W)	Working Time (h)	No. of Hours Per Day (h)	Total Power Rating (W)	Total Wart/hr (Wh/day)
Lighting	400	12	00am – 07am; 14pm – 23pm	18	4800	36,400
Fans	60	100	00am – 07am; 14pm – 23pm	18	6000	108,000
Laptops	200	110	08am – 13pm	6	22,000	132,000
Phones	232	15	05am – 16pm	12	3400	41,400
Rechargeable Lanterns	232	12	08am – 13pm	6	2784	16,704
TOTAL	1124	249	NA		55860	337,612

Data in Table 2 shows peak appliance activity between 05:00 AM and 16:00PM, mainly due to abundant energy bulb use. Laptops consume the most energy.

Analysis of Solar Radiation on Horizontal Surface

At any given moment, the solar radiation outside the Earth's atmosphere (referred to as Io) that falls onto a horizontal surface is:

$$I_o = I_{sc}\left[1.0 + 0.033\cos\left(\frac{360n}{365}\right)\right]\cos\theta_z \tag{8}$$

Where Isc is the solar constant and n is the day of the year. The recommended arranged days for each month and values of n by month are given in Table 3.

Table 3: *Months for Solar Radiations on Horizontal Plane*

Month	n for ith day of the month	For the Average Day of the Month		
		Date	**Days of the year(n)**	**Declination (δ)**
Jan.	i	17	17	-20.9
Feb.	31+i	16	47	-13.0
March	59+i	16	75	-2.4
April	90+i	15	105	9.4
May	120+i	15	135	18.8
June	151+i	11	162	23.1
July	181+i	17	198	21.2
Aug.	212+i	16	228	13.5
Sept.	243+i	15	258	2.2
Oct.	273+i	15	288	-9.6
Nov.	304+i	14	318	-18.9
Dec.	334+i	10	344	-23.0

Where i represents the number of days in a month.

Energy Data and System Specifications

The range settings for the study site (UNIPORT MH) and Solar-PV module specs are shown in Table 4.

Table 4: *Defaulted Solar PV and Battery Parameter ranges*

Parameter	*Min. Value*	*Max. Value*	*Unit*
Number of Parallel Connected PV Modules (N_p)	1	80	NA
Global solar irradiance (G)	1	*5*	*kW-hr/m²/day*
Ambient Temperature (*T*)	26	29	^oC
System Loading (T_L)	75	75	kWh

Data in Table 4provides sample data (100 out of 365) of solar irradiance and temperature values for model-fitting (2017-2019), with full data available as software files.

System Configurations

The HOMER® software architecture includes grid, load profiling, grid-tie converters, battery module, and Solar-PV components for assessing Solar-PV grid potentials based on data in Table 5. Fig 3 represents the flow of current from the grid.

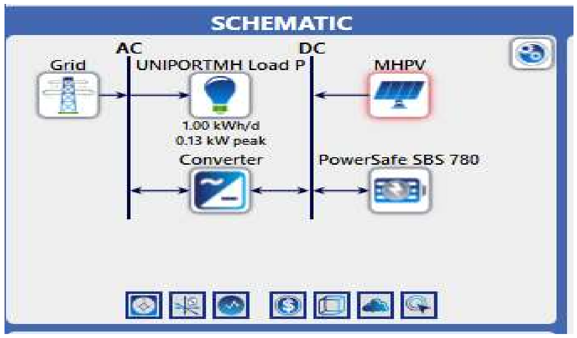

Fig. 3. *Architecture of the proposed system in HOMER® software*

Table 5: *Solar-PV System Data Configuration Options*

Component	Configuration	Value	Units
Electric Load	Load Profile Data	383.90KW	kW
Grid	Grid electricity cost	1.00	$/kWh
	Price for excess electricity fed back into the grid	0.50	
Solar-PV	Capacity	384KW	kW
	Capital Cost	1,110.00	$
	Replacement Cost	1,100.00	$
	O & M Cost	5.00	$
	Derating Factor	90	%
	Upper and Lower Limits	820 – 5	kW
	Time	25	Yrs.
Battery Module	Capacity		kW
	Initial investment cost	135	$
	Cost of replacement	135	$
	O & M Cost	10	$
	String size (No. of Batteries)	50	%
	Upper and Lower Limits	207 – 20	kW
	Time	10	Yrs.
Converters	X	X	X

The simulations' findings considered load profile demand, boundary constraints, and optimized system architecture with electrical production in mind.

Load Profile Results

The load profile simulation results using the HOMER® software tool are shown in Fig4.

Fig. 4. *Load Profile Simulation in HOMER® Software*

The energy demand in hostel buildings is highest from 9:00 am to 3:00 pm, with an average of 383.90 kWh and a peak power of 48.90 kW. Optimized states enable cost-effective generation throughout the year.

Research Question 2: How viable is the implementation of a solar-PV system with an OP-1 model design for generating electricity in the MH facility?

The results considering the viability of theOP-1 model design for generating electricity in the MH facility are presented in Figures (5 and 6) and Table 6for 2019 only.

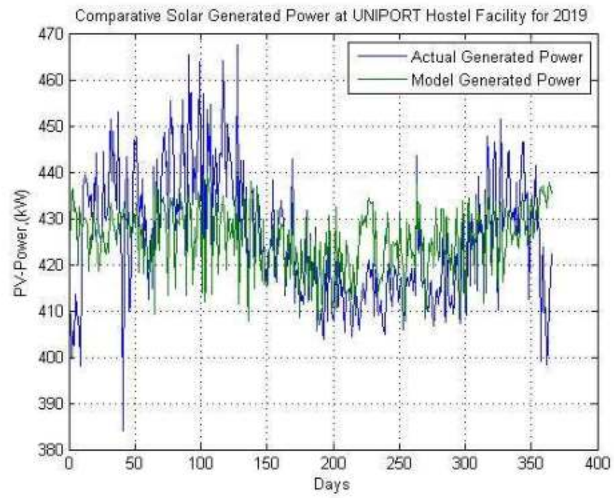

Fig. 5. *Comparative results of actual and model Solar-PV power for Poly-1 Model 2019*

Table 6: *Actual vs. Predicted values corresponding to Year 2019, optimal case*

Actual Value (kW)	OP-1 Value (kW)
409.35	433.24
399.64	445.55
405.65	446.84
402.48	439.14
413.60	440.25
410.57	438.03
407.44	421.00
406.57	440.93
397.95	437.51
419.79	432.81
436.80	436.14
439.43	437.09
438.41	436.06
437.32	434.86
432.61	419.29
434.75	430.76
435.12	427.08
425.45	436.83
437.45	439.48
433.89	431.01

Data in Table 5 outlines the actual and predicted kW values in 2019 under ideal conditions. With a range of 421.00 kW to 446.84 kW, the predicted values closely aligned with actual values ranging from 397.95 kW to 439.43 kW, with a deviation of 5 kW. The optimal outcome showed potential energy conservation by consistently performing higher than the actual figures. Some predicted values exceeded actual ones by up to 16.14 kW, excluding only a few exceptions highlighted in rows 7, 15, and 16.

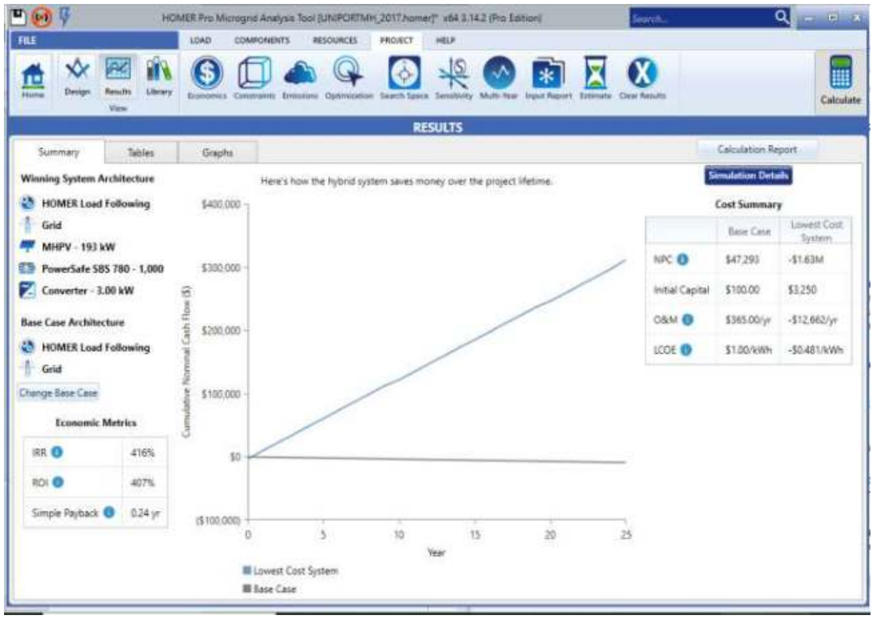

Fig. 6. showing the economic viability of the model Solar-PV power for Poly-1 Using the HOMER® Software

The result shows the winning system meeting load demand and yielding a 407% ROI, despite high capital costs. The optimized Solar-PV size is 193kW.

5. Discussion

The energy consumption patterns and load profile demand within the MH facility were analyzed using the OP-1 model design solar-PV system. The provided data in Table 2contained comprehensive information about various appliances, including their quantity, rated power, working time, and total power rating. For instance, the lighting system consisted of 400 lights with a rated power of 12W. It operated from 00:00 to 07:00 and 14:00 to 23:00, totaling 18 hours per day and resulting in a daily power consumption of 36,400 Wh. Likewise, the table revealed that 60 fans with a rated power of 100W were operational during the same hours as the lighting system, resulting in daily power usage of 108,000 Wh. Additionally, 200 laptops with a rated power of 110W were used from 08:00 to 13:00, consuming 132,000 Wh per day. Moreover, 232 phones with a rated power of 15W operated from 05:00 to 16:00, totaling 12 hours per day and consuming 41,400 Wh. More so, 232 rechargeable lanterns with a rated power of 12W ran for 6 hours per day from 08:00 to 13:00, consuming 16,704 Wh. Summing up the power consumption of all appliances, an overall power rating of 55,860W and total energy consumption of 337,612 Wh per day was calculated. To estimate solar irradiance at the designated study site, Table 3providesinformation on solar radiation and declination values for each month. This data was essential for the analysis. Additionally, Table 4offered various defaulted solar PV and battery parameters relevant to the study site, including the number of connected PV modules and the system loading. With this data in hand, a thorough evaluation of the economic viability of implementing the OP-1 model design solar-PV system for electricity generation in the MH facility was conducted. Consequently, the proposed system not only met the load demand but also provided an impressive ROI of 407%. This meant significant savings for the utility grid despite the high initial capital costs. It is worth noting that the optimized solar-PV size was determined to be 193kW, which was lower than the base peak generation value of 383.90k.

6. Advantages and Disadvantages

Advantages

- This method provided a mathematical model based on input-output data, making it a reliable and accurate model for approximating solar photovoltaic (PV) power generation.

- It provided a remarkable 407% return on investment (ROI) and substantial savings for the grid.
- The excess power is fed back into the grid and the ability to draw power from the grid during periods of cloud cover or at night.

Disadvantages

- The linear model may limit its ability to capture non-linear patterns in data and result in compromised results and large prediction errors.
- It is difficult to assess the robustness and reliability of the model.
- The paper focuses on the specific case of the medical hostel facility at the University of Port Harcourt, Rivers State, Nigeria, and may not be directly applicable to other contexts or locations.

7. Conclusion

In conclusion, the study conducted on the MH twin-tower facility in the UNIPORT Abuja campus reveals the potential for installing a grid-connected PV system. With a peak generation value of 383.90kW and a comprehensive analysis of energy consumption patterns, it is evident that the proposed PV power plant on the rooftops of the buildings can meet the facility's electricity requirements. Moreover, the economic viability of the OP-1 model design solar-PV system is remarkable, offering an ROI of 407%. This signifies significant savings for the utility grid, despite the initial capital costs. Based on the findings, the recommended solar-PV system size for optimal performance is 193kW, which is lower than the initial proposal but still sufficient to meet the facility's load demand. Implementing this optimized solar-PV system will not only ensure a reliable and sustainable source of electricity for the MH facility but also contribute to reducing the campus's carbon footprint and dependence on traditional grid power.The future scope includes the potential challenges or limitations of implementing the proposed OP-1 solar-PV system, such as the availability of resources, maintenance requirements, or potential technical issues, and a comprehensive analysis of the environmental impact or sustainability of the proposed OP-1 solar-PV system.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

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