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Design Anaylsis of a Solar Power System for the Faculty of Engineering, Rivers State University

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ABSTRACT

The aim of this project was to design a solar system for the Faculty of Engineering, Rivers State University, Port Harcourt. To achieve the aim, energy audit, battery sizing, charge controller sizing, inverter sizing, and photovoltaic system sizing were carried out. The results of the design for the system to have a single day of autonomy showed a total energy requirement of $908{,}264WHr$, which would require a 360V, 1000AH nominal battery; 988 PV panels of 360W each; $250KVA$ rated inverter; 6 charge controllers rated 180A/200A each; panel coverage area of $1{,}615.855m^2$. Also, the Installation was estimated to cost 110,802.000. It was recommended that the government should encourage the use of solar PV home systems by providing financial assistance through soft loans, as well as the research be used to aid understanding on design process.

KEYWORDS: ***Solar System, Energy audit. Sizing***

1. INTRODUCTION

According to Oji *et al.* (2012), the earth as a resource system has a limited capacity for supporting a growing human population with an intensive exchange of materials and energy with its environment, hence the need for a growing awareness to achieve a more sustainable societal use of materials. The world is now taking quantum leaps into power generation using Renewable energy sources. This transition is partly due to the alarming rise in Green House Gases which are already negatively affecting the climate in the world and recently around December 2015. (Benjamin & Dickson, 2017).

Conventional methods of providing electricity through long distance high voltage transmission and distribution network are not always economically viable. In addition to cost implications, remote distribution lines and other equipment for the extension are prone to vandalism and theft (Salawu & Adetona, 2001). Grid extension lead to poor electricity supply because of overload and high installation and maintenance costs (Adegoke & Akintunde, 2000).

Currently, the Nigeria electricity installed capacity is 12,522MW which is mostly from fossil fuels and still grossly inadequate to meet the energy needs of more than 200 million Nigerians and as such the distribution companies out of no other alternatives resolve to the use of rationing technique, the introduction of photovoltaic technologies is a relief to the situation faced by Nigeria as it would go a long way to compliment the power situation (Msughter & Celestine, 2015).

The sun provides the energy to sustain life in our solar system. In one hour, the earth receives enough energy from the sun to meet its energy needs for nearly a year. Photovoltaic is the direct conversion of sunlight to electricity. It is an attractive alternative to conventional sources of electricity for many reasons: it is safe, silent, and non-polluting, renewable, highly modular in that their capacity can be increased incrementally to match with gradual load growth, and reliable with minimal failure rates and projected service lifetimes of 20 to 30 years. It requires no special training to operate; it contains no moving parts; it is extremely reliable and virtually maintenance free; and it can be installed almost anywhere. The intensity of the sunlight that reaches the earth varies with time of the day, season, location, and the weather conditions. The total energy on a daily or annual basis is called irradiation and indicates the strength of the sunshine (Ali *et al*. 2020)

Different geographical regions experience different weather patterns, so the site of implementation is a major factor that affects the photovoltaic system design from many sides; the orientation of the panels, finding the number of days of autonomy where the sun does not shine in the skies, and choosing the best tilt angle of the solar panels. Photovoltaic panels collect more energy if they are installed on a tracker that follows the movement of the sun; however, it is an expensive process. For this reason, they usually have a fixed position with an angle called tilt angle β. This angle varies according to seasonal variations (Masters, 2013).

Daniel *et al.* (2019) carried out a solar electricity system design of 172.84kWP for administrative buildings at Federal Polytechnic, Ede, Nigeria. The proposed project' design was simulated and the results show that its real-life performance is highly promising. The solar system was estimated to require a PV Generator capacity of 161.55kWh; Battery capacity of 3600Ah with 7 connected serially and 6 connected serially (60V 150Ah each); 3 70kW single phase inverter; and a charge controller rating of 160A 500V. The least energy yield of the PV system occurs in June with 549.93kWh/day as against the maximum demand of 457.30kWh/day. The system performance is much higher in the months of September to March as solar irradiance is higher in these months. The PV plant has active service life of over 25years without significant change in its efficiency. The benefits of the proposed project are manifold. The estimated cost of the project was N45,000,000 which is much cheaper than diesel generator and interestingly, is appreciably less than the cost of unreliable power supply from the grid.

Moien and Marwan (2019) designed and simulated a PV system operating in grid-connected and stand-alone modes for areas of daily grid blackouts in Gaza. The electricity in Gaza, Palestine, is limited and scheduled for 4-10 hours per day due to political reasons. This status represents a real problem for different sectors. Hence, the research was aimed at presenting an effective solution especially for the energy supply problem in the residential sector by using an unconventional PV system which operates in stand-alone and grid-connected modes. The system includes a storage battery block with a proper capacity to secure for continuous power supply of a residential house with a daily energy load of 10 kWh. It was found that an unconventional PV system of 3.2 kWp and a storage battery block of 19.2 kWh will be able to cover the total daily energy demands of the house including the outlined electricity cutoff hours. The design of this system and specifics of its components are presented in this paper. The system was simulated by Matlab software, where the daily load curve, grid cutoff hours, and the monthly solar radiation are considered. The obtained simulation results show that the produced PV energy exceeds the load demands during nine months of the year, and thereby, a high battery state of charge (SOC) in the range of 73-84% is achieved. During the three months of the lowest solar radiation (Dec.-Feb.), the produced PV energy is equal to the load demand while the battery state of charge varies in the range of 40-49% which verifies the appropriateness of the proposed PV system. The daily energy yield of the PV system varies between 2.6 and 5.4 kWh/kWp in January and July, respectively, which corresponds to a performance ratio of 90% and 66.25%, respectively.

Ali *et al.* (2020) design & sized a stand-alone solar power system for a house in Iraq. To achieve the aim, the total average energy consumption and sizing of the solar array was carried out. The total average energy consumption was estimated as 5700 W.h, it was determined that the house would require a PV 11 PV modules to be connected 11 parallelly and 1 serially, the capacity of the battery bank was evaluated as 1900 *A h* (250 AH, 12V-DC each) which requires 8 batteries with 2 connected serially and 4 connected parallelly, the voltage regulator required was determined as 2, and a inverter capacity of 2555W.

This work seeks design a solar system to power the Faculty of Engineering, Rivers State University, such that when implemented it can help save cost of power supply and also eliminate the epileptic power situation experienced by the faculty.

2. MATERIALS AND METHODS

2.1 Materials

The following materials were used in this work

i. Photovoltaic panels
ii. Inverter
iii. Litium ion batteries
iv. Solar charge controller

The data used in this work was obtained by carrying out an energy audit of the Faculty of Engineering building which includes the classroom (EDH, EDR, MDR, and EN 1-12) and office blocks. The data includes Equipment, quantities, power ratings, and hours of operations. Also, according to Theraja and Theraja (2012), the daily energy requirement is the amount of energy required, Q, to satisfy the power demand of an installation and it is given by;

$$Q = \sum Lr \qquad (1)$$

where

L = Amount of load
r = Load rating (in watts)

The total watt hour can also be determined as the total installation

$$W_H = \sum Qt \qquad (2)$$

where

W_H = Total installation capacity in watt hour
Q = Energy required
t = Time or duration of load on power (in hours)

2.2 Energy Requirements for Classrooms

A description of Appliances as found in the classroom blocks (EDR, MDR, EDH, LT 1-4 and EN 1-12) is presented in Table 1 considering the Appliance quantity, ratings, total wattage, hours of operation and total energy required.

Table 1: Energy Required for Classrooms

S/N.	Components	Quantity	Ratings (W)	Total Wattage (W)	Hours of Operation (Hrs)	Total Energy Required (WH)
1	Fans	X_1	A	T_1	K_1	R_1
2	Air Conditioner	X_2	B	T_2	K_2	R_2
3	Bulbs	X_3	C	T_2	K_3	R_3
					Total	$\mathbf{Z_1}$

Hence, the total energy to power the Faculty of Engineering classrooms becomes

$$Z_1 = R_1 + R_2 + R_3 \qquad (3)$$

where

Z_1 = Total Energy required to power the classrooms
R_1 = Energy required to power the fans

R_2 - Energy required to power the air conditioners
R_3 = Energy required to power the bulbs

2.3 Energy Requirements for Offices

A description of Appliances as found in each office is tabulated considering the Appliance quantity, ratings, total wattage, hours of operation and total energy required is presented in Table 2.

Table 2: Energy Required for Offices

S/N	Components	Quantity	Rating (W)	Total Wattage (W)	Hours of Operation (Hrs)	Total Energy Required (WH)
1	Fans	E_1	D_1	F_1	G_1	H_1
2	Laptops	E_2	D_2	F_2	G_2	H_2
3	Printers	E_3	D_3	F_3	G_3	H_3
4	Refrigerators	E_4	D_4	F_4	G_4	H_4
5	Air Conditioner	E_5	D_5	F_5	G_5	H_5
6	Television	E_6	D_6	F_6	G_6	H_6
7	LED Light bulb	E_7	D_7	F_7	G_7	H_7
8	Desktop Computers	E_8	D_8	F_8	G_8	H_8
9	Scanner	E_9	D_9	F_9	G_9	H_9
10.	Water Dispenser	E_{10}	D_{10}	F_{10}	G_{10}	H_{10}
					Total	$\mathbf{Z_2}$

Hence, the total energy to power the Faculty offices becomes

$$Z_2 = H_1 + H_2 + H_3 + H_4 + H_5 + H_6 + H_7 + H_8 + H_9 + H_{10} \tag{4}$$

where

Z_2 = Total energy required to power the offices
H_1 = Energy required to power fans
H_2 = Energy required to power laptops
H_3 = Energy required to power printers
H_4 = Energy required to power refrigerators
H_5 = Energy required to power air conditioners
H_6 = Energy required to power televisions
H_7 = Energy required to power LED light bulbs
H_8 = Energy required to power desktop computers
H_9 = Energy required to power scanners
H_{10} = Energy required to power water dispensers

2.4 Miscellaneous Energy Requirement

A description of Miscellaneous energy that could be required is presented in Table 3.3 detailing appliances, quantity, ratings, total wattage, hours of operation and total energy required.

Table 3: Miscellaneous Energy Required

S/No	Component	Quantity	Rating (w)	Total Wattage (w)	Hours Operation	Total Energy Required (WH)

1	Toilet Bulbs	1_1	J_1	K_1	L_1	M_1
2	Bulbs on Walkway	I_2	J_2	K_2	L_2	M_2
3	Water Pump	I_3	J_3	K_3	L_3	M_3
					Total	$\mathbf{Z_3}$

Hence, the total miscellaneous energy required becomes

$$Z_3 = M_1 + M_2 + M_3 \tag{5}$$

where

Z_3 = Total Miscellaneous Energy Required
M_1 = Energy Required to Power the Toilet Bulbs
M_2 = Energy Required to Power the Bulbs on Walkway
M_3 = Energy Required to Power the Water Pump
M_4 = Energy Required to Power the Cell Phone Charger

2.5 Total Energy Required

The total energy consumption of the building is derived using Equation (3.6), by summing the total energy required by the classroom, offices and miscellaneous.

$$Z = \Sigma Z_1 + \Sigma Z_2 + \Sigma Z_3 \tag{6}$$

where

Z = Total energy required to power the Faculty
ΣZ_1 = Total energy required by classrooms
ΣZ_2 = Total energy required by offices
ΣZ_3 = Total miscellaneous energy required

2.6 Inverter Sizing

The size of the inverter required can be determined using general power equation. Theraja and Theraja (2012) asserted that the power of a generator required by any given load is given as thus;

$$S = \frac{WH_T}{P_f} + 25\%\, WH_T \tag{7}$$

where

S = Inverter power rating
w_T = Total load demand
P_f = Power factor

Where the additional 25% WH_T accounts for factor safety. It can be noted that the higher the inverter power rating, the more relative higher voltage rating, and the lesser the current rating (to minimize losses). Also, the total wattage is determined as

$$W_T = T_1 + T_2 + T_3 + F_1 + F_2 + F_3 + F_4 + F_5 + F_6 + F_7 + F_8 + F_9 + F_{10} + K_1 + K_2 + K_3 \tag{8}$$

2.7 Battery Sizing

PV battery system assesses various strategies from a financial perspective. The valuable existence of the battery is limited to 5,000 cycles or in the planned living time of 20 years. The maintenance of photovoltaic and rechargeable annual activities and expenditure systems is set at 1.5% per the speculative cost. Assume that the cost system for the battery and PV is comparable to their size. According to Dumkhana and Idoyiboyeobu (2018), the following mathematical models will determine the size of battery to be installed.

The battery Capacity can be determined as;

$$AH = \frac{WH_T}{0.85 \times 0.6 \times V_b} \times Days\ of\ autonomy \tag{9}$$

The number of batteries required, would be;

$$N_B = \frac{AH}{C_b} \tag{10}$$

where

WH_T = Total Watt hour
N_B = Number of Batteries Required
C_b= Individual Battery Capacity

AH = Battery Capacity
V_b = Battery Nominal Voltage
T_p= Total Power Required

Also, the total watt hour is determined as

$$WH_T = Z_1 + Z_2 + Z_3 \quad (3.11)$$

2.8 Panel Sizing

Once the total load to be energized using the PV system is determined, the capacity of solar panels required to generate that much amount of power would follow suit. It is an inherent property of any panel to have internal losses. According to Moien and Marwan (2019) the PV array peak power PPV is obtained using Equation (12)

$$P_{PV} = \frac{E_d}{PSH \times \eta_{CR} \times \eta_{INV}} \quad (12)$$

where

E_d = Daily energy consumption of the faculty

PSH = Peak sunshine hours (hours/day)

η_{CR} = Charge controller efficiency

η_{INV} = Inverter efficiency.

Number of panels required, would be;

$$N_P = \frac{P_p}{P_r} \quad (3.13)$$

where

N_P = Number of panels required
P_p = Actual PV power required
P_r = Panel Rating (of the solar panel selected)

The total area of coverage of the panels would be;

$$A = L \times W \times N_P \quad (14)$$

where

L = Length of a Panel
W = Width of a Panel
N_P = Number of Panels

2.9 Charge Controller

The charge controller, sometimes referred to as photovoltaic controller or charger, is very necessary for systems which involve batteries. The main functions of the charge controller is to counteract the battery spoofing and monitor charging and discharging of the battery. It prevents the battery from being completely charged or discharged. This is imperative as overcharging can lead to destruction of the battery and under charging decreases the battery life. Another important reason to use a charge controller is to prevent a reverse current flowing from battery to the system i.e conditioning unidirectional flow of current. (Kishore & Barath, 2019). For the purpose of this work, the Maximum Power Point Tracking (MPPT) was adopted as it will yield higher returns compared with a Pulse Width Modulation controller as the panel voltage increases (Osaretin & Edeko, 2015). Also, the minimum current required is determined as

$$M_n = N_S \times S_{CC} \times F_{OC} \quad (15)$$

where

M_n= Minimum current required

S_{CC}= Short circuit current

F_{OC} = Factor of safety

2.10 Design Considerations

The proposed PV system components considers the following parameters

i. Annual average solar energy intensity on horizontal surfaces in Port Harcourt is 1.585 kWh/m^2 day, which corresponds to average Solar insolation (peak sunshine hours, PSH) = 3.792 h/day (Adebowale *et al.* 2017)
ii. The efficiency of the inverter is 85%, while the efficiency of the charge controller is 120% for the charge regulator and a power factor of 0.8
iii. The system voltage is chosen to be 360V, 1000AH Life Lithium-ion battery, life PO4 batteries can only be connected in parallel and as such a single 360V, 1000AH battery bank is selected for financial flexibility. On installation all that is required is assemblage of the batteries
iv. The PV modules are selected to as 360W (24V) monocrystalline because of it's high efficiency and less degradation over the life time periods in comparison with other PV technologies.

3. RESULTS

3.1 Energy Requirements for Classrooms

The energy audit of the classrooms in Faculty of Engineering was carried out, and the power required for each of the equipment/components were determined. Also, the data obtained was analyzed accordingly considering hours of operation as presented in Table 4.

Table 4: Energy Requirement for Classroom Blocks

S/N	Components	Quantity	Rating (W)	Total Wattage (W)	Hours of Operation (Hrs)	Total Energy Required (WH)
1	Fans	84	75	6,300	15	94,500
2	Air Conditioner	21	800	16,800	15	252,000
3	Bulbs	131	6	786	15	11,790
						358,290

3.2 Energy Requirements for Offices

The energy audit of the offices in Faculty of Engineering was carried out, and the power required for each of the equipment/components were determined. Also, the data obtained was analyzed accordingly considering hours of operation as presented in Table 4

Table 5: Energy Requirement for Offices

S/N	Components	Quantity	Rating (W)	Total Wattage (W)	Hours of Operation (Hrs)	Total Energy Required hours (WH)
1	Fans	15	75	1,125	9	10,125
2	Laptop	23	65	1,495	9	13,428

3	Printer	14	75	1,050	9	9,450
4	Refrigerators	11	77	847	9	9,317
5	Air Conditioner	45	1120	50,400	9	453,600
6	Television	14	41	574	9	5,166
7	LED Light Bulb	85	10	850	9	7,650
8	Desktop Computers	6	20	120	9	1,080
9	Scanners	8	14	112	9	1,008
10	Water Dispenser	6	140	840	9	7,560
						518,384

3.3 Miscellaneous Energy Required

The Miscellaneous Energy required was analyzed accordingly as presented in Table 6 considering hours of operation.

Table 6: Miscellaneous Energy Required

S/No	Component	Quantity	Rating (w)	Total Wattage (w)	Hours Operation	Total Energy Required (WH)
1	Toilet Bulbs	26	10	260	24	6,240
2	Bulbs on Walkway	115	10	1150	24	27,600
3	Water Pump	1	250	250	3	750
						31,590

Using Equations (8) the total wattage of the Faculty of Engineering is calculated as

$$W_T = 6{,}300 + 16{,}800 + 786 + 1{,}125 + 1{,}495 + 1{,}050 + 847 + 50{,}400 + 574 + 850 + 120 + 112 + 840 + 10 + 10 + 250 = 82{,}959\text{W}$$

From Equations (3.11) obtaining the total daily watt hour of the faculty, we have

$$Z = 358{,}290 + 518{,}384 + 31{,}590$$

$$Z = 908{,}264WHr$$

Thus, 908,264WHr is the daily watt hour of the installation.

3.4 Inverter Sizing

Using Equation (7), the capacity of the inverter required is

$$S = \frac{82{,}959_T}{0.8} + 25\% \, (82{,}959)$$

$$S = 124{,}438.5\, W = 155.55KVA$$

Hence, an inverter 250KVA is selected considering surge, Air Conditioners and the inverter capacity availability in the market.

3.5 Battery Sizing

Considering a 360V, 1000AH nominal battery and 1 day of autonomy, the battery capacity was calculated using Equations (9) as

$AH = \frac{908{,}264}{0.85 \times 0.6 \times 360} \times 1$

$AH = 4{,}946.97 AH$

3.6 Panel Sizing

The PV array peak power PPV was obtained using Equations (12)

$P_{PV} = \frac{908{,}264}{3.792 \times 0.95 \times 0.85}$

$P_{PV} = 296620\text{V}$

Also, the number of panels required is determined using Equations (9) considering a 300W solar panel

$N_P = \frac{296620}{300}$

$N_P \cong 988\ Panels$

The solar panel configuration will be installed in 6 banks of PV arrays of which each contains 11 PV modules in series and 15 PV modules in parallel.

3.7 Panel Coverage Area

Considering a 360W Monocrystalline PV with a Length of 1.651m and a width of 0.9906m, the panel coverage area was determined using Equations (14).

$A = 988 \times 1.651 \times 0.9906$

$A = 1{,}615.85 m^2$

3.8 Charge Controller

From Equation (15), the minimum current required is determined as

$Minimum\ current\ required = 15 \times 8.5 \times 1.15$

$= 146.625 A$

Since there are 6 banks of PV array, 6 Charge controllers of 180A/200A was selected as it is the closest readily available in the market.

3.8 Cost Estimate

From the analysis carried out and sequel to a market survey carried out, the cost of Installation of a solar system for the Faculty of Engineering can be calculated as shown in Table 7.

Table 7: Cost of Installing a Solar System for the Faculty of Engineering

S/No	Material	Quantity	Unit Cost (#)	Total Cost (#)
1	Battery	1	28,151,000	28,151,000
2	Solar panel	988	75,000	74,100,000
3	Charge controller	6	30,000	180,000
4	Inverter	1	7,871,000	7,871,000
5	Accessories		500,000	500,000

	Total =	110,802.000

IV. CONCLUSION

The aim of this work was to design a solar power system for Faculty of Engineering, Rivers State University, Port Harcourt, to achieve this, energy audit, sizing of sizing of inverter, battery, charge controller and Photovoltaic system and cost estimate for the installation of the solar system for the Faculty of Engineering was carried out considering that the system was designed to have one day of autonomy. The Results obtained showed that

i. The daily energy requirement was determined as $908{,}264WHr$
ii. The battery capacity was determined as $4{,}946.97AH$, which would require a single piece of 360V, 1000AH Life Litium ion nominal battery
iii. The PV array peak power was determined as $296620V$, which requires 988 pieces of 360W solar panel, of which the panel configuration will be installed in 6 banks of PV arrays of which each contains 11 PV modules in series and 15 PV modules in parallel.
iv. The panel coverage area was determined as $1{,}615.85m^2$
v. An inverter capacity of 250KVA was selected
vi. The cost of installing the solar system for the Faculty of Engineering was estimated as #110,802.000.

The following recommendations were also made

i. The research should be used to aid understanding on design process
ii. As the PV system has low running cost and is environmentally friendly, there is need to integrate such renewable energy system with the national strategies.
iii. The Government should encourage the use of solar PV home systems by providing financial assistance through soft loans.

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