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Design and Analysis of Solar Power System for the Mechanical Engineering Workshop and Laboratories of Rivers State University, Nigeria

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Abstract: This study provides an effective solution to the problem of erratic power supply to the Rivers State University Mechanical Workshop and Laboratories by using solar power system designed to operate in stand-alone mode. It includes conducting an energy audit to estimate energy consumption in the workshop and Laboratories, sizing of the solar components to required capacities that will cover the energy consumption. The energy audit conducted shows that the Workshop and Laboratories consumed 200kW. The design analysis carried out on the proposed system revealed that 300kW of energy is required from the system which required a total of 350 PV modules, covering an array area of 314m^2 amounting to a peak power, output voltage and output current of 80kW, 300V and 267A, respectively. The proposed system designed would generate an average of 216kW of energy in 6.5-hours of sun shine, which would be stored in 883kW capacity battery bank, containing 21 batteries of 48V and 1000Ah each wired into 3 parallel strings of 7 Batteries per string.

Keywords: Analysis, Design, Laboratory, Solar power system, Workshop

1. INTRODUCTION

The ability to harness solar energy and use it for the society has improved in past decades. A lot of research is on how to exploit these alternative energy sources in a large scale. [1] In their book showed that Nigeria receives abundant solar energy that can be usefully harnessed with an annual average daily solar radiation of about 5.25 kWh/m^2/day and an average amount of sunshine hours of about 6.5h which gives an average annual solar energy intensity of 1,934.5 kW/m^2/year. [2] Developed solar photovoltaic power supply system to power office appliances. The system consists of photovoltaic array, mounting frame, storage device, inverter, charge controller and wiring system.

The system was tested in Akure, Nigeria (Latitude 7.15°N) and the results obtained showed a good performance of the system. An average solar power output of 334 watt was obtained during the test, while the total load of office appliances carried by the system was 290 watt. [3] Reviewed and analyzed the renewable energy potentials of Nigeria with special attention and consideration to the past, present and future of solar energy development. The analysis showed that solar energy is expected to produce 1.26%, 6.92% and 15.27% of the electricity consumed by 2015, 2020 and 2030 respectively.[4] designed and evaluated PV system for supplying lighting for renewable energy laboratory in Higher Institute for Mechanical and Electrical Engineering, Zwara, Libya. Intuitive and numerical methods and HOMER software were used to design and evaluate the PV system.

The result showed that the solar energy utilization is an attractive option with energy cost of 0.151 USD/kW which is minimal when compared with diesel generator operating cost which is 0.558 USD/kW. [3] Stated that Nigeria has renewable energy resources including biomass, wind, hydropower and solar energy. These resources can sufficiently meet the country’s energy demands, but statistics show that Nigeria still lacks adequate supplies to meet her electricity demands. His study reviews the renewable energy potential in Nigeria and also gives overview information of the past, present and future of solar energy in Nigeria. He stated the solar radiation distribution of the country is suitable for all solar technology applications and that more attention should be given to renewable energy development, especially solar energy. This will help solve electricity production issues in Nigeria and reduce energy poverty in the country. [5] Examined renewable energy sources benefits, potentials and challenges in Nigeria.

The study stated that renewable energy improves the security of a country, and reduces greenhouse gases. The study aligned in stating that renewable energy reduces greenhouse gases by at least 3.2 kg carbon dioxide equivalents per one kilogram of biodiesel. The study observed that the challenges working against the full-scale implementation of solar energy in Nigeria include available technology, the political climate, and the weather conditions of the country.

[6] Stated that costly and eco-destructive diesel based systems are usually used for electrifying rural areas in Malaysia and that the fuel transportation is another obstacle in this regard. Moreover, unpredictable fluctuation of fuel price makes the system cost unstable. And he stated that the diesel based systems can be replaced with renewable energy (RE) systems. He analyzes the potentiality of renewable energy in Sarawak, East Malaysia and said that solar system is suitable replacement of

diesel based system. [7] Developed an Off-grid (stand-alone) photovoltaic (PV) systems.

In his design, the electrical energy demand (load) of the Government Technical College (GTC), Wudil Kano was estimated based on watt-hour energy demands. The estimated load is 48.787 kW. An off grid PV system was designed based on the estimated load. Based on the equipment selected for the design, 72 PV modules, 20 batteries, a voltage regulators and an inverter will be required to supply the electrical energy demand of the college. The proposed off-grid PV system requires copper wires of cross-sectional areas 1.22 mm^2, 32 $mm^2$and 3 mm^2 for its installation. The cost estimate of the systems is relatively high when compared to that of fossil fuel generator used by the college. The payback period of the system is estimated to be 2.8 years, which is obviously much shorter than the lifespan of the selected PV modules which is 30 years**.**

The full potential of the solar system is absolutely enormous as the power generation is a function of the solar irradiant that is always high in Africa and the declining solar equipment costs are expected to significantly increase solar installations in Africa with an industry projection forecasting that the continent's annual PV market will expand to 2.2 GW in the nearest future. Consequently, other researchers have concluded that as Solar power is increasingly affordable, solar power system installation is also growing rapidly. This research focused on the design of a solar power system for Rivers State University Mechanical workshops and laboratories to curb the problem of power shortage. The aim of this study is to carry out analysis and design of a solar power system that will serve as an alternative power supply in the Mechanical Engineering workshop and laboratories of Rivers State University.

2. MATERIALS AND METHODS:

2.1 Methods

The methods that were used and implemented in the study are enumerated in the following sections.

2.2.1 Energy Audit Conduction

Energy audit is conducted to estimate the total energy consumption or energy demand in the Mechanical Engineering workshop and Laboratories. This was done by checking the list and design parameters of the electrical equipment used in the Mechanical Engineering workshop and laboratories. The electrical equipment available at the workshop and laboratories are itemized with their power ratings and times of operation during the day.

2.2.2 Design and Sizing of the Solar Power System

Sizing the proposed Solar Power System components shown in Figure 1 consider evaluating the adequate power ratings for each component of the solar system to meet the total energy requirement of the equipment in workshop and laboratories and at the same time calculate the cost of installation and leveled cost of energy (LCOE). The proposed Solar Power System operates as explained in the Schematic diagram shown in Figure 1. The diagrams illustrate the harvesting of solar energy by the PV array and converting directly into electricity.

Solar Power System is classified according to how the system components are connected to other power sources such as stand-alone and utility-interactive systems. In a stand-alone system depicted in Figure 1, the system is designed to operate independent of the electric utility grid, and is generally designed and sized to supply certain DC-AC electrical load. The system components include the PV array, battery bank, inverters, solar charge controller, accessories and back-up generator.

(i) PV Array

Solar power system uses PV array as the main source for the generation of the electrical power supply. PV array is a number of solar panels electrically connected together. A solar panel is made of a number of individual PV cells connected in series. The number of panels to be used is dependent on the load requirements and available solar irradiation in the area.

(ii) Battery Bank

Battery stores energy for supplying to the equipment when there is a demand. Battery bank which is involved in the system to make the energy available at night or at days of autonomy (sometime called no-sun-days or dark days), when the sun is not providing enough radiation. The batteries are arranged on rack.

(iii) Solar Charge Controller

The charge controller is to regulate the charge going into your battery bank from your solar panel array and prevent overcharging and reverse current flow at night. Charge controller maximize the chances of your batteries and other photovoltaic components lasting longer, thus increase the life expectancy and efficiency of your entire solar system. Charge controllers make sure the battery is charged by utilizing maximum power point tracking (MPPT). MPPT charge controller is used in the very common case where your PV arrays voltage is higher than your battery bank voltage.

(iv) Inverters

The inverter is required to convert the direct current (DC) output of the solar panels or battery into AC current. There are two types of inverters based on the form of wave they produced. They are called pure sine wave and modified sine wave. In this research, the pure sine wave inverter is preferred for its efficient performance and ability to operate any type of load. The selected inverter using Homer application software is inverter 2900T with 99% efficiency and 1% cable losses.

(v) Accessories

Accessories refer to other components of the system that are required to ensure the other items are safely and appropriately connected. These includes: Cables and connectors which are used link components of the system, Mounting Frame works which are used to fix the solar panel on rooftops, Battery rack which is used to accommodate the batteries, Power Meter which is used to Measures the electric current produced by the solar panels, Battery monitor is used to track the remaining battery capacity and the time remaining in your battery bank.

(vi) Back-up Generator

A reserve generator is a back-up electrical framework that works naturally. Close to a utility blackout a programmed exchange switch detects the power misfortune, directions the generator to begin and afterward moves the electrical burden to the generator. The backup generator starts providing capacity to the circuits. After utility power restores, the programmed exchange switch moves the electrical burden back to the utility and sign the reserve generator to stop. It at that point comes back to backup mode where it anticipates the following blackout. To guarantee a legitimate reaction to a blackout, a reserve generator runs week by week individual tests. A 25kv generator was selected as a back-up generator to charge the Battery in the absence of sunshine.

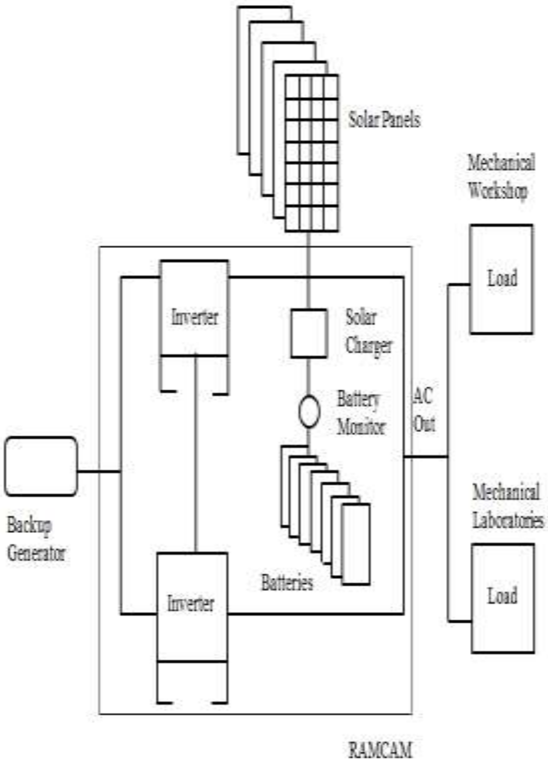

Figure 1: Schematic diagram of the proposed Solar Power System

2.3 Analytical Methods

2.3.1 Sizing of the PV Array

The PV array is usually specified in terms of current and voltage. The amount and intensity of solar insulation controls the amount of output current (I) and the operating temperature of the solar cells affects the output voltage (V) of the PV array.

(i) Energy required from the PV array

The daily energy required from the PV module is calculated by the formula

$$E_{req} = E_d \text{ x } SF \qquad (1)$$

Where:

E_{req} = Energy required from the PV module (kWh/day),
E_d = Energy consumption (kW), and
SF = Safetyfactor which has a value of 1.5 [8]

(ii) PV array area

The larger the total surface area of the PV array, the more solar power it will produce. The PV array area is calculated by the formula.

$$PV_{area} = \frac{E_{req}}{G_{av} \times n_{pv} \times TCF} \qquad (2)$$

Where:

PV_{area} = PV array area(m^2),
E_{req} = Energy required from the PV module (kWh/day),
G_{av}= Average daily solar energy input (kW/m^2/day),
η_{pv}= PV Energy conversion efficiency (%),
TCF = Temperature Correction Factor [9]

(iii) PV array peak power

PV array peak power is the power output under standard test conditions. PV array peak power is given by

$$P_{pvp} = PV_{area} \text{ x } G_{ref} \text{x} \eta_{pv} \qquad (3)$$

Where;

P_{pvp} = PV array peak power(kW),

G_{ref} = Solar radiation at standard test condition amounting to 1000 W/m^2 [9].

(iv) PV Output Power

DC power generated from the PV system is mainly dependent on different factors, including PV peak power at standard test condition, solar radiation and cell temperature. PV Output Power is given by

$$P_{pvout} = P_{pvp} f_{pv} \left(\frac{G}{Gref} \right) \left[1 + K_T \left(T_C - T_{ref} \right) \right] \qquad (4)$$

Where:

P_{pvout} = PV Output Power (kW),
G = solar radiation incident on the PV array in the current time step (W/m^2),
f_{pv} = PV derating factor (%),
K_T = Temperature power coefficient (°C^{-1}),
T_{ref} = Temperature at standard test condition amounting to 25°C,
T_c= PV cell temperature (°C) [10].

The cell temperature is obtained using the equation

$$T_c = T_a + \frac{G}{G_{NOCT}} \left(T_{NOCT} - T_{a,\,NOCT} \right) \qquad (5)$$

Where:

T_a = Ambient temperature at PV installation location (°C),
T_{NOCT} = Nominal operating cell temperature (°C),

$T_{a,NOCT}$= Ambient temperature NOCT conditions amounting to 20°C,
G_{NOCT} = Solar radiation at NOCT conditions amounting to 800W/m^2 [11].

(v) Output Voltage of the PV Array

Output Voltage of the PV Array is proportional to the daily load and is based on the battery capacity selected for the system [7].Output Voltage of the PV Array is given by

$$V_{pv} = \frac{E_{req}}{C_b} \qquad (6)$$

Where:
V_{pv} = Output Voltage of the PV Array (V),
E_l = Daily energy consumption (kW),
C_b = Unit battery capacity (Ah) [12].

(vi) Output Current of the PV Array

The output current of the PV array is given by

$$I_{pv} = \frac{P_{pvp}}{V_{pv}} \qquad (7)$$

Where:
I_{pv} = Output current of the PV array (A),
P_{pvp} = PV array peak power (kW),
V_{PV} = Output Voltage of the PV Array (V) [12].

(vii) Number of PV modules

The number of modules to be connected in parallel will be given as:

$$N_p = \frac{I_{pv}}{I_{mp}} \qquad (8)$$

Where:
N_p = Number of modules connected in parallel,
I_{mp} = Current available from a module under maximum power condition (A) [13].
The number of modules to be connected in series of the photovoltaic array will be given as:

$$N_s = \frac{V_{pv}}{V_{mp}} \qquad (9)$$

Where:
Ns = Number of modules connected in series,
Vmp = Voltage of the module at maximum power condition (V) [13].
Total number of module is given by

$$N_{mtotal} = N_p \text{ x } N_s \qquad (10)$$

Where:
N_{mtotal}=Total number of module [14].

(viii) Energy Conversation Efficiency

The conversion efficiency of a solar power system is the percentage of the solar energy shining on a PV device that is converted into usable electricity. It is given by

$$\eta = \frac{P_{pvout}}{PV_{pvp}} \qquad (11)$$

Where:
η = Energy Conversation Efficiency [15].

3.3.3 Sizing of the Battery Bank

(i) Storage Capacity

The energy harvested from the solar PV array is stored in a battery bank arranged in parallel string. The required Battery Bank storage capacity is given by:

$$c_B = \frac{E_1 \times DOA}{\eta_B \times DOD \times V_{2q}} \qquad (12)$$

Where:
C_B= Battery bank storage capacity (Wh),
DOA = Numbers of days of autonomy,
DOD = Battery Depths of Discharge,
η_B= Battery efficiency (%)
V_b =Battery bank voltage (V) [10].

(ii) Battery Strings

A battery string comprises a number of batteries connected in parallel to produce a battery capacity with the required usable voltage Total parallel battery strings is given by:

$$TPBS = \frac{C_B}{C_b} \qquad (13)$$

Where;
TPBS = Total parallel battery strings, C_B = Battery bank storage capacity (Ah), C_b= Unit battery capacity (Ah) [13].

$$B/S = \frac{V_{pv}}{V_b} \qquad (14)$$

Where:
B/S = Batteries per string,
V_{pv} = Battery bank voltage (V),
V_b = Unit battery voltage (V) [13].

$$N_{Btotal} = B/S \text{ x } TPBS \qquad (15)$$

Where:
N_{Btotal} = Total Number of Batteries [13].

2.3.4 Sizing of inverter

Inverter size depends upon total connected load and it capacity often is given as kVA.Total inverter loadis expresses as:

$$P_{T,inv} = P_{pvp} \text{x } SF \qquad (16)$$

Where:
$P_{T,inv}$= Total inverter load (kVA) [14].
Inverters are connected in parallel and total number of inverter needed for the system is given as:

$$N_{inv} = \frac{P_{T,inv}}{P_{inv}} \qquad (17)$$

Where:
N_{inv}=Total number of inverter,
P_{inv} = Capacity of a single inverter (kVA) [14].

3.3.5 Solar Charge Controller Sizing

Rating of a charge controller depends on short circuit current of the array and is given by following equation

$$I_{cc} = I_{sc} \times N_p \times SF \qquad (18)$$

$$N_{cc} = \frac{I_{cc}}{I_{cc,\sin gle}} \qquad (19)$$

Where:

Ncc = Total numbers of charge controller requires,

Icc = Rating of a charge controller (A),

I_{sc} = Short circuit of PV module (A),

$I_{cc,single}$ = Rating of a single charge controller (A) [14]

3. RESULTS AND DISCUSSION:

3.1 Load Analysis

The results of the energy audit conducted are presented in Table (1 to 12).

Table 1 Appliances in Applied Thermodynamic Laboratory

S/N	Appliances	Rated Power (W)	Quantity	Rated Power (kW)	Times of Operation(h)	Energy Consumption (kW)
1	Standing Fan	10	1	0.1	3	0.3
2	Energy saver	25	20	0.5	5	2.5
3	Refrigerator	200	1	0.2	8	1.6
4	Ceiling	100	15	1.5	4	6
5	Piping friction machine	200	1	0.2	3	0.6
6	Benollis Apparatus	300	1	0.3	4	1.2
7	Francis Turbine	2000	1	2	4	8
8	Air conditioner	1500	2	1.5	5	7.5
	Total	4335	41	6.3	36	27.7

Table 1 shows the number of appliances and equipment in the Applied Thermodynamics Laboratory and the daily total energy consumption of 27.7kW.

Table 2: Appliances in Tribology Laboratory

Appliances	Rated Power(W)	Quantity	Power(kW)	Times of Operation(h)	Energy Consumption (kW)
Wear and friction m/c	200	1	0.2	3	0.6
Four ball machine	200	1	0.2	4	0.8
Michell pad	200	1	0.2	3	0.6
Pin on disc	200	1	0.2	4	0.8
Energy Saver	25	4	0.1	8	0.8
Total	825	8	0.90	22	3.6

Table 2 shows the number of appliances and equipment in the Tribology Laboratory and the daily total energy consumption of 3.6kW.

Table 3: Office in Applied Thermodynamics Laboratory Unit

S/N	Appliances	Rated Power(W)	Number	Power(kW)	Times of Operation(h)	Energy Consumption (kW)
1	Lighting Energy saver	25	1	0.025	8	0.2
2	Standing Fan	120	1	0.12	6	0.72
3	Refrigerator	400	1	0.4	8	3.2
4	Fluorescent bulbs	40	12	0.48	8	3.84
5	Total	585	15	1.025	30	7.96

Table 3 shows the number of appliances and equipment in the Applied Thermodynamics Laboratory Unit and the daily total energy consumption of 7.96kW.

Table 4: Theory of Machines Laboratory Unit

S/N	Appliances	Rated power(W)	Number	Rated Power(kW)	Times of Operation(h)	Energy Consumption (kW)
1	Lighting Energy saver	25	9	0.225	8	1.8

2	Universal Governor	1500	1	1.5	3	4.5
3	Fluorescent	40	8	0.32	8	2.56
4	Total	1562	18	1.757	19	8.86

Table 4 shows the number of appliances and equipment in the Theory of Machines Laboratory Unit and the daily total energy consumption of 8.86kW.

Table 5: Offices in Theory of Machines Laboratory

S/N	Appliances	Rated Power(W)	Quantity	Rated Power(kW)	Times of Operation(h)	Energy Consumption(kW)
1	Lighting Energy saver	25	3	0.075	8	0.8
2	Standing Fan	120	2	0.24	6	1.44
3	Refrigerator	400	1	0.4	8	3.2
4	Fluorescent bulbs	40	10	0.4	8	3.2
5	Total	585	16	1.115	30	8.64

Table 5 shows the number of appliances and equipment in the Offices in Theory of Machines Laboratory and the daily total energy consumption of 8.64 kW.

Table 6: Appliances in Plumbing and Press Shop

S/N	Appliances	Rated power(W)	Quantity	Power(kW)	Times of Operation(h)	Energy Consumption(kW)
1	Energy saver bulbs	25	15	0.375	8	3
2	Pressing Engine	800	1	0.8	4	3.2
3	Ceiling Fan	100	15	1.5	9	9
4	Total	925	31	2.675	21	15.2

Table 6 shows the number of appliances and equipment in the Plumbing and Press Shop and the daily total energy consumption of 15.2kW.

Table 7: Appliances in Welding Shop

S/N	Appliances	Rated Power(W)	Quantity	Rated Power(kW)	Times of Operation(h)	Energy Consumption(kW)
1	Dc Arc	500	1	0.5	4	2
2	Grinding Machine	800	1	0.8	3	2.4
3	Rotary function machine	600	1	0.6	3	1.8
4	Energy saver bulbs	40	6	0.24	8	1.92
5	Total	1940	9	2.14	18	8.12

Table 7: shows the number of appliances and equipment in the Welding Shop and the daily total energy consumption of 8.12kW.

Table 8: Appliances in Plant Maintenance Shop

S/N	Appliances	Rated Power(W)	Quantity	Rated Power(kW)	Times of Operation(h)	Energy Consumption(kW)
1	Compressor	1000	1	1	4	4
2	Car lift	2500	1	2.5	2	5
3	Energy	25	8	0.2	8	1.6
4	Fluorescent	40	4	0.16	8	1.28
5	Total	3565	14	3.86	22	11.88

Table 8: shows the number of appliances and equipment in the Plant Maintenance Shop and the daily total energy consumption of 11.88kW

Table 9: Appliances in Machine Shop

S/N	Appliances	Rated power (W)	Quantity	Power (kW)	Times of Operation(h)	Energy Consumption(kW)
1	Shopping small size Machines	1000	1	1	4	4
2	Shopping big size machine	1500	1	1.5	4	6
3	Horizontal milling machine	2500	1	2.5	3	7.5
4	Energy machine	3500	1	3.5	2	7
5	Cylindrical Grinding machine	1800	1	1.8	4	7.2
6	Tool cutting machine	3000	1	3	3	9
7	Vertical milling machine	3500	1	3.5	3	10.5
8	Energy saver	25	16	0.4	8	3.2
9	Ceiling fan	100	6	0.6	8	4.8
10	Total	16925	29	17.8	39	59.2

Table 9 shows the number of appliances and equipment in the Machine Shop and the daily total energy consumption of 59.2 kW.

Table 10: Appliances in the Offices and Stores in the Workshop

S/N	Appliances	Rated power(W)	Quantity	Power(kW)	Times of Operation(h)	Energy Consumption(kW)
1	Energy saver	25	3	0.075	8	0.6
2	Plasma Television	300	1	0.3	8	2.4
3	Ceiling Fan	100	2	0.2	8	1.6
4	Fluorescent	40	1	0.04	8	0.32
5	Total	465	7	0.615	32	4.92

Table 10: shows the number of appliances and equipment in the Offices and Stores in the Workshop and the daily total energy consumption of 4.92 kW.

Table 11: Appliances in Carpentry Workshop

S/N	Appliances	Rated Power(W)	Quantity	Power(kW)	Times of Operation(h)	Energy Consumption(kW)
1	Rebating machine	1500	1	1.5	2	3
2	Bench saw machine	1500	1	1.5	2	3
3	Thickness Machine	1500	1	1.5	2	3
4	Surface planer	1500	1	1.5	2	3
5	Radial arm Machine	2500	1	2.5	2	5
6	Mortising Machine	2000	1	2.0	3	6
7	Total	10500	6	10.5	13	23

Table 11: Shows the number of appliances and equipment in the Carpentry Workshop and the daily total energy consumption of 23kW.

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Table 12: Appliances in Turning Section

S/N	Appliances	Rated power(w)	Quantity	Rated Power(Kw)	Times of Operation(h)	Energy Consumption (kWh)
1	Harrison 155 machine	1000	1	1	2	2
2	Harrison 300 machine	1500	1	1.5	2	3
3	Colchester lathe 1000	3000	1	3.0	2	6
4	Onak 180 machine	3000	1	3.0	2	6
5	Colchester 800	1000	1	1.0	3	3
6	Grinding machine	500	1	0.5	2	1
7	Total	10000	6	10	13	21

Table 12: shows the number of appliances and equipment in the Turning Section and the daily total energy consumption of 21kW

Table 13 will show the total rated power (W), number of Appliances, Power (kW) Hours used /day and Kw.

Table 13: Rated Power (KW) and Energy Consumption (kWh) Analysis from the different Workshops and Laboratory in the Department of Mechanical Engineering

Workshops/ laboratories	Rated Power(kW)	Energy Consumption (kWh)
Thermodynamic laboratory	6.3	27.7
Tribology laboratory	0.9	3.6
Office in Applied in Applied Thermodynamics laboratory	1.025	7.96
Theory of machines laboratory	1.757	8.86
Plumbing and pressing shop	2.675	15.2
Welding shop	2.14	8.12
Plant and maintenance shop	3.86	11.88
Machine shop	17.8	59.2
Common room	0.615	4.92
Carpentry shop	10.5	23
Turning section	10	21
Offices in theory of machine unit	1.115	8.64
Total	58.237	200.08

From Table 13 the daily Energy Consumption in the Mechanical Engineering Workshop and Laboratories is 200kW.

3.1.2 Design Analysis

(i) Energy required from the PV module

Recall (1); Ed = 200kW

E_{req} = 200kWh x 1.5=300kW

(ii) Analysis of PV array area

Recall (2);

The average peak sunlight hour in Port Harcourt is 3.75 hrs and the peak solar radiation is 1kW/m^2 [13]. Therefore G_{av}=3.75kWh/m^2, E_{load} = 700kWh, η_{pv}= 0.255, TCF = 1.00 (Appendix C)

$$PV_{area} = \frac{300}{3.75 \text{ x } 0.255 \text{ x } 1} \approx 314\text{m}^2$$

(iii) Analysis of the PV array peak power

Recall (3.3); PV_{area} = 314m^2, η_{pv}= 0.255

P_{pvp} = 314x 1000 x 0.255 = 80070W≈ 80kW

(iv) Analysis of the Output Voltage and Current of the PV Array

Rechargeable Lithium Battery 48V and 1000Ah for Solar Energy System is selected for the design [16] is safe when installing the battery bank in a commercial building.

Recall (6); E_{req} =300kW, C_b= 1000Ah (Appendix D)

$$V_{pv} = \frac{300000}{1000}$$

$$V_{pv}= \frac{300000}{1000} = 300\text{V}$$

Recall (7); P_{pvp} =80kW, V_{pv} = 300V

$$I_{pv} = \frac{80000}{300} = \approx 267A$$

The output voltage and output current of the entire solar power system design are 300V and 267A, respectively.

(v) Number of PV modules

Recall (8); I_{pv}= 267A, I_{mp}= 7.69A (Appendix A)

$$N_p = \frac{267}{7.69} \approx 35$$

Recall (3.9); V_{pv} = 300, V_{mp} = 31.2V (Appendix A)

$$N_S = \frac{300}{312} = \approx 10$$

Recall (3.10); N_s = 10, N_p = 35

N_{mtotal} = 35 x 10 = 350

Thus, a total of 350 PV modules are required for the design.

(iv) Analysis of the Battery Bank Storage Capacity

Recall (12); E_{req} = 300kWh, DOD = 0.8, DOA = 2, V_{pv} = 300V, η_B= 0.85

$$C_B = \frac{300000}{0.85 \text{ x } 0.8 \text{ x } 3000} \approx 2941Ah$$

Energy storage capacity of the battery bank = 2941 x 300 ≈883kWh

(vii) Analysis of the Number of Batteries Required

Recall (13); C_B = 2941Ah, Cb = 1000Ah

$$TPBS = \frac{2941}{1000} \approx 3 \text{ Strings}$$

Recall (14); V_{pv} = 300V, V_b = 48V

$$B/S = \frac{300}{48} \approx 7$$

Recall (15); TPBS = 3, B/S = 7

$N_{battery}$ =7 x 3 = 21

Therefore, a total of 21 Batteries of 48V, 1000Ahcapacity each, arranged in 3 parallel strings of 7 Batteries per string is required for the design.

(viii) Analysis of the Inverter Power Rating

Recall Equation 16; P_{pvp} = 80kW, SF = 1.5,

$P_{T,inv}$= 120kVA

Recall (17); P_{Tinv} = 120kVA, P_{inv}= 60kVA (Appendix D)

$$N_{inv} = \frac{120}{60} = 2$$

Thus, a total of two 60kVA Inverter is required for the design.

(ix) Analysis of the solar charge controller rating

Recall (3.18); I_{sc} = 9.29A (Appendix A), N_P = 35, SF = 1.5

I_{cc} = 9.29x 35 x 1.5≈ 488A

Recall (3.19); Icc = 488A, $I_{cc,single}$= 220A

$$I_{CC} \frac{448}{220} \approx 2$$

Thus, a total of two 220A charge controller is required for the design.

From NIMET data, it shows that the average solar radiation potential of Port Harcourt is about 155.9W/m^2, the average output power, energy generated in 6.5 hours of sun shine are and the energy conversion efficiency are approximately 12kW, 180kWh and 15%, respectively.

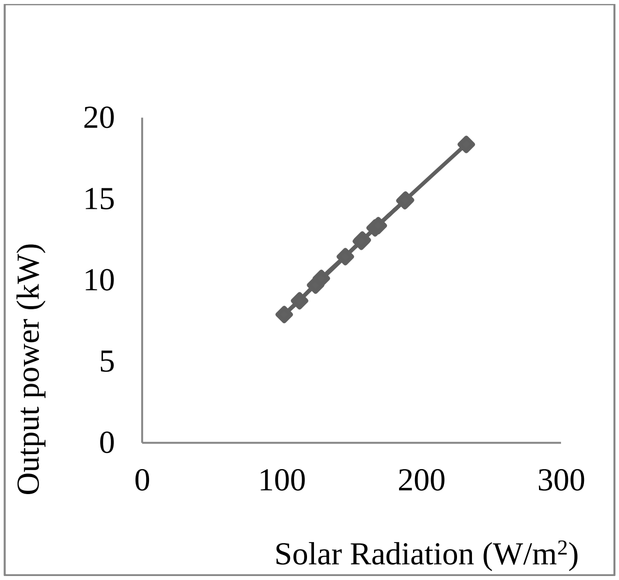

Figure 1: Output power against Solar Radiation

Figure 1 shows that the PV output power is directly proportional to solar radiation since the graph is a straight line. This implied that when solar radiation increases PV output power also increases. An output power of 7.8889kW was recorded when the solar radiation was 101.6585W/m^2 in July, output power of 18.3681kW was recorded when the solar radiation was 231.9561W/m^2 in December, which show an increased output power of 10.4792kW.

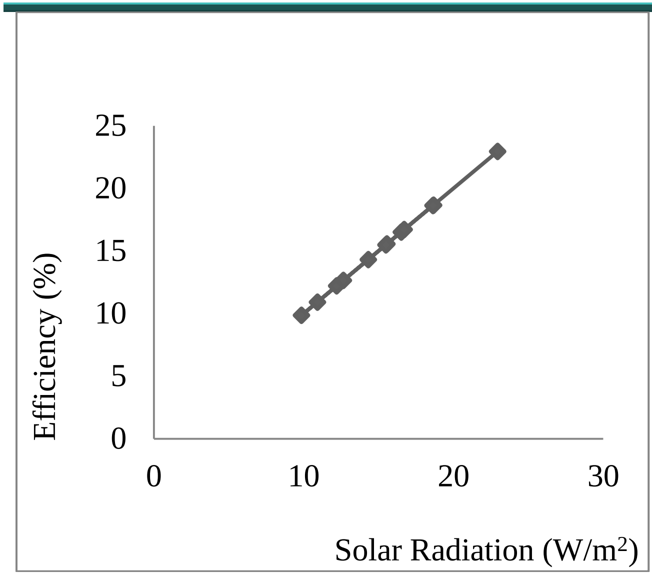

Figure 4.2: Efficiency against Solar Radiation

Figure 2 shows that solar radiation is also directly proportional to the energy conversion efficiency. Thus output power and solar radiation directly determines the efficiency of a solar power system.

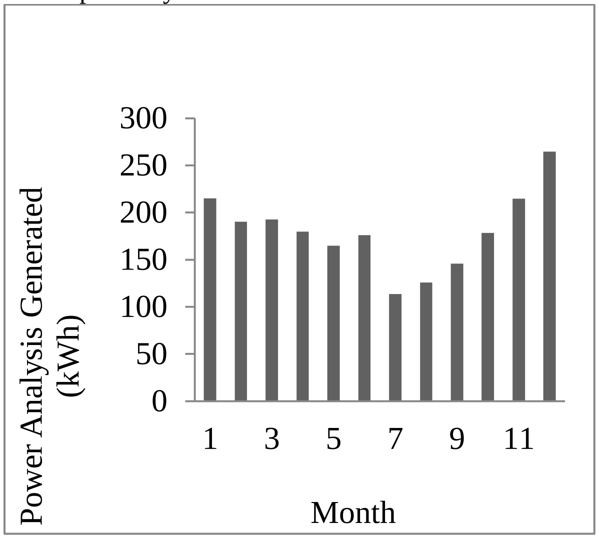

Figure 3: Monthly Power Generated by PV System

Figure 3 shows the monthly energy generated by the proposed solar power system considering 6.5 hours of sunshine per day. It is clear that the energy generated by the system exceeds the energy demand of 200kW in January, November and December, while it is almost equal to the energy demand during the remaining nine months. The excess generated energy would be used to charge the battery bank according to its State of charge (SOC) or supplied to the departmental office. During the nine months, February – October, which are the lowest solar radiation in the year, the energy generated is barely sufficient to cover the load demand the backup generator is used to charge the battery bank and to cover the energy demand at the same time.

CONCLUSION

The energy audit conducted in the workshop and Laboratories showed that the total energy demand amounts to 200kWh in 6 working hours per day. The components of the system designed were properly sized to secured capacities that will be able to cover the total daily energy demands of the Workshop and Laboratories using appropriate mathematical formulations. The 300kWh/day of energy required from the system requires a total of 350 PV modules, covering an array area of 314m^2. The peak power of the array, output voltage and output current amount to 80kW, 300V and 267A, respectively. The analysis carried out on the proposed system designed shows that the system will generate an average of 216kWh of energy in 6.5-hours of sun shine per day. The energy generated will be stored in 883kW Battery bank, containing 21 batteries of 48V and 1000Ah capacity each wired into 3 parallel strings of 7 Batteries per string.

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