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Design And Sizing Of Grid-Connected Mobile Solar Kit

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Abstract: ***Photovoltaic systems use photoelectric effect for the direct conversion of solar irradiance into electricity. This can be used as electrical power source for homes and businesses to meet their daily energy requirement. It is a neat, silent and elegant process of generating electric power in environmentally friendly manner. This paper presents an approach for the optimum design and implementation of a 108 Wh mobile grid-connected PV system installation in the city of Uyo, Nigeria. The process of acquiring PV power involves designing, selecting and determining specifications of different components that are used in the system and conforming them to the load estimation. The approach proposed in this paper is based on the optimal configuration of the components according to not only Maximum Power Point MPP voltage range but also maximum DC input current of the inverter. The highest production of 28.78 kWh occurs in January while the least energy production is 16.18 kWh in July. Energy production capability and the estimation of the component for other output sizes have been carried out. An estimated inverter value of 694.4 Wh will work together with batteries of 170.20 Ah, a charge controller of 24.11 A and a solar panel of 231.47 W to power a load of 500 W. The system can serve as a good source of clean energy and hence reduce the rate of emission of greenhouse gases into the atmosphere.***

I. INTRODUCTION

There is a rapid increase in the demand for electricity in the developing countries of the world. It is a challenge to meet this demand without affecting the climate and the environment. Fossil fuels are the major source of power production in the world today. This poses a threat to the climate as power production is globally the largest source of Greenhouse Gases [5]. A good alternative to the use of fossil fuel is renewable energy. Renewable energy resources include wind, solar, geothermal, biomass etc.

Solar power is considered as the most promising renewable energy resource. A prominent way of harnessing solar power is the use of photovoltaic (PV) cells to generate electricity. The advantage of solar cells is that they do not have mechanical parts. They depend on photoelectric effect of materials to emit electrons when light strikes the surface. PV cells have no greenhouse gas emission, are safe and environmentally friendly. The worldwide cumulative installed capacity of solar PV at the end of 2016 was 303 GW. That equates to producing 375 billion KW of solar power each year, which represents 1.8% of the electricity demand of the planet [22]. Nigeria has 485.1G Wh.day^{-1} of solar energy in natural units and we enjoy an average of 6.2 hours of daily sunshine. Despite this, Nigeria recorded 1.2 GW utility scale solar project in 2016 [8]. Nigeria's utilization of solar power is seen in the deployment of direct use system for water pumping, stand-alone systems with batteries for rural electrification and grid-tied systems.

Several researches have been done on solar PV utilisation and potential in Nigeria. Akinyele and Rayudu [1] focused on PV distributed generation for energy-poor household in Nigeria. The authors maintained that the optimal performance of PV system for poor communities require proper design and engineering using suitable simulation tool. Johnson and Ogunseye [12] used PVSOL 2016 simulation software to simulate the design of grid-connected PV system for local government offices in Nigeria. They concluded that the least daily energy production of 445.23 kWh exceeds the maximum energy demand of 131.51 kWh in Ife Central Local Government Secretariat. Many other researches have been done for stand-alone and grid-tied systems installed on buildings. There is however a need for a portable stand-alone or grid-tied system that can be carried about for outdoor purposes. This is because many small business operators resort to the use of generating sets during power outages and outdoor businesses. If this solar kit is used, it will be supplying energy all the time using the sun, battery or grid and hence lead to the reduction in the emission of greenhouse gases.

The grid-tied or on-grid solar kit designed in this paper is constructed based on the size of the appliances that will be used on it. It is portable and can be used for both indoor and outdoor purposes in the city of Uyo which has an average solar radiation of 11.38 $MJ.m^{-2}$ (3.16 $kWh.m^{-2}$) [2]. Since the average solar radiation in Uyo is less than that of the country of 5.5 $kWh.m^{-2}.day^{-1}$ [15], the kit can also be useful in other parts of the country. Equipment specifications are provided based on the availability of the best components in the market and also based on the financial capability of the researcher.

There are two major approaches employed in the designing of photovoltaic systems. One is the use of manual sizing method; the other is the use of software for the simulation of the components. The optimum approach is one that gives accurate result of the simulation.

The manual method of sizing involves getting the radiation data of the site, determining the expected energy yield on a photovoltaic module based on the tilt angle of the site, determination of the total load and the operational time of the appliances, determination of the sizes of the inverter and battery, determination of the size of the charge controller and the sizes as well as quantity of the photovoltaic module, space requirement and number of strings of the photovoltaic. Other factors considered are shading analysis and economic considerations.

On the other hand, simulation tools might contain the solar radiation information of certain geographical regions. Simulation tools can be used for optimizing, sizing, prefeasibility calculations, shading analysis, circuit designing etc. Some software use the in-built climatic data of a location to give results of hourly, monthly and daily and annual irradiation on horizontal and tiled surfaces. Nowadays, PV simulation software also give the energy data of some PV components like PV module, inverter, battery, charge controller already available in the market from some manufacturers. Some examples of simulation software are HOMER, PV-chart, PB planner, PVSyst, PVSOL, Hybrid II etc.

Both methods of designing are very useful. The use of software simulation package renders easy, faster and accurate result while the manual sizing methods are cumbersome and different for different researchers and designers.

The grid-connected or grid-tied system is mainly composed of a matrix of photovoltaic arrays which convert the sunlight to direct current, a power conditioning unit which converts the direct current to alternating current. The generated alternating power is injected into the grid and/or utilised by local loads. In some cases, storage devices are used to improve the availability of the power generated by the photovoltaic system [18].

Simonsen [20] opines that the power conditioning unit (PCU) is used to control the direct current produced from the photovoltaic arrays and to convert this power to high quality alternating current before injecting it into the electric grid. Photovoltaic systems can be divided according to the number of power processing stages into single-stage and two-stage systems. In single-stage system, an inverter is used to perform all the required control tasks. But in the two-stage system, a DC-DC converter or optimiser precedes the inverter and the control tasks are divided among the two converters. Two stage systems provide higher flexibility in control as compared to single-stage system, but at the expense of additional cost [14].

Johnson and Ogunseye [12] in their design of a grid-connected photovoltaic system for local government offices in Nigeria included MPPT charge controller to monitor the charging of the battery so as to avoid the battery from being over-charged. They also included an over current and over voltage protection to protect the modules and conductors from excess current fault. Surge and lightning protection, isolating devices at the DC side to allow solar energy source to be disconnected if a fault occurs were also among the devices incorporated in their design. In some cases, transformers are added to step-up the voltage from the inverter to the grid voltage or step down the utility voltage to individual loads [17]. Other devices of the photovoltaic system could include mounting structures, cables, controls, lightning conductor etc.

II. METHODOLOGY

A. THE SYSTEM DESIGN

Grid-connected system designing involves the determination of the capacity (in terms of power, voltage and current) of each component with the view of meeting the load requirement of the electrical appliances for which the design is made. The designing of the grid tied solar kit will be done manually since most simulation software are not developed for small output power. The designing involves the following.

- ✓ Determination of the size of the total output power of the system
- ✓ Sizing of the photovoltaic system components

B. DETERMINATION OF THE TOTAL OUTPUT POWER OF THE SOLAR KIT

The total output power of the kit depends on the power rating of the appliances that are going to be used on the system. The system is designed for low power rating devices like energy saving lamps, mobile phones and rechargeable lamps. Cell phones use approximately 2 to 6 watts when charging, energy serving lamps power rating range from 15 watts to 30 watts while the power rating of rechargeable lamps range from 3 to 10 watts. This implies that if a cell phone of 5 watts, energy lamp of 15 watt and rechargeable lamp of 7 watts are connected to the kit the total power will be given as

$$TP = 5\,W + 15\,W + 10\,W = 27\,W$$

If these three appliances should run for four hours, the total power used will be

$$27 \; x \; 4 \; = 108 \; Wh$$

On this note, the total power of the kit is estimated at 108 W. Other appliances of lower power rating can be used provided the duration of usage does not exhaust the battery energy. The total power is to be multiplied by 1.25 to get the requirement for an option of 25% extra kept for a reasonable future load expansion

$T_L = TP \; x \; 1.25$

This gives the total load deliverable to the inverter as

$T_L = 108 \; x \; 1.25$

$T_L = 135 \; Wh$

C. SIZING OF THE PHOTOVOLTAIC SYSTEM COMPONENTS

Photovoltaic system components include photovoltaic module, inverter, charge controller, and solar battery. Sizing involves the process of determining the size or capacity of the photovoltaic system components that will be able to deliver the determined total power at the stipulated duration of time. Sizing of the components involves the following steps

- ✓ Site description and radiation analysis
- ✓ Determination of the size of the inverter
- ✓ Determination of the size of the solar battery
- ✓ Charge controller specification
- ✓ Photovoltaic module specification

a. SITE DESCRIPTION AND RADIATION ANALYSIS

The proposed photovoltaic solar kit is going to be used in the city of Uyo. Uyo is a town located in the Southern part of Nigeria with latitude 5.02° N and longitude 7.55° E with an altitude of 38.1 m above sea level. This geographical location implies that the solar module in Uyo should be facing the North. The average solar radiation in the location is 11.38 MJ.m^{-2}. Uyo has a tropical climate, rainfall is significant in most months of the year. The average annual temperature in Uyo is 26.4 °C. The maximum and minimum temperatures are 30.5 and 22.5 °C respectively [7].

The values of the monthly day number, n, declination angle, δ, tilt angle β, elevation angle, α, solar radiation on horizontal surface, H, (obtained from Umoh and Akpan [2]) and the estimated radiation on tilted surface H_t are shown on Table 1. From the table, the average tilt angle for the year is 5.08° while the average radiation on tilted surface is 12.09 MJ.m^{-2} (3.36 kWh.m^{-2})

Months	N	δ^0	β^0	α^0	H (MJ.m^{-2})	H_t (MJ.m^{-2})
Jan	15	-21.26	26.31	63.69	12.79	14.27
Feb	46	-13.28	18.33	71.67	12.64	13.35
Mach	74	-2.82	7.87	82.13	12.91	13.03
April	105	9.41	-4.36	94.36	13.45	13.49
May	135	18.79	-13.74	103.74	12.08	12.44
June	166	23.31	-18.26	108.26	10.75	11.33
July	196	21.52	-16.47	106.47	9.31	9.71
Aug	227	13.78	-8.73	98.73	9.75	9.87
Sep	258	2.22	2.83	87.17	10.62	10.63
Oct	288	-9.59	14.64	75.36	11.10	11.47
Nov	319	-19.15	24.20	65.80	12.43	13.63
Dec	349	-23.34	28.39	61.61	10.42	11.85

Table 1: Values of Day Number, N, Declination Angle $\boldsymbol{\delta}$, Tilt Angle $\boldsymbol{\beta}$, Elevation Angle $\boldsymbol{\alpha}$, and Solar Radiation on Tilted H and Horizontal H_t Surfaces for Uyo (after Umoh and Akpan 2011)

b. DETERMINATION OF THE SIZE OF INVERTER

The inverter should be specified according to the load requirements of the appliances to be used. Since the kit is going to be used on a range of appliances, the inverter size should be able to accommodate at most a load of 135 Wh. The continuous power load to the inverter (TPI) is given by [10] as

$$TPI = \frac{TP}{\eta_{inv}} \quad (1)$$

Where η_{inv} is the efficiency of the inverter

Now continuous (DC) input current (I_{dc}) to an inverter from PV modules can be determined, if the system DC voltage (V_{dc}) is specified, according to equation 2

$$I_{dc} = \frac{TPI}{V_{dc}} \quad (2)$$

This parameter is needed for battery selection and design.

c. DETERMINATION OF BATTERY SIZE

Batteries are a major component in the stand-alone PV systems. Battery storage is conventionally measured in Ah (ampere hour) unit. For a safe operation of the PV system, one has to anticipate periods with cloudy weather and plan a reserve energy capacity stored in the batteries. This reserve capacity is referred to as PV system Autonomy, which means a period of time that the system is not dependent on the energy generated by PV modules, and is rated in days. The capacity [Ah] of the batteries is calculated by Leonics [16] as

$$B_{AH} = \frac{TP1 \; x \; N_{backup}}{\eta_{bat} \; x \; DOD \; x \; V_{dc}} \quad (3)$$

Where N_{backup} is the number of days of backup power, η_{bat} is the efficiency of the battery, DOD is the depth of discharge of the battery.

The charging current of the battery is given as

$$I_{bat} = \frac{1}{10} \; x \; B_{AH} \quad (4)$$

Depth of Discharge (DoD) of the battery is the percentage of total charge, that is, energy of battery that can be allowed to power the load. The energy required to charge the battery is given in equation 5 by Pal, Das and Raju [19]

$$E_{bat} = \frac{V_{dc} \; x \; B_{AH}}{\eta_{Bat}} \quad (5)$$

Where η_{Bat} is the efficiency of the battery

To obtain the charging time of the battery, Khan [13] considers 40% losses due to battery thus the new battery capacity will be

$$NB_{AH} = 40\% \; of \; B_{AH} + B_{AH} \quad (6)$$

Where NB_{AH} is the new battery capacity with 40% losses

d. CHARGE CONTROLLER SPECIFICATION

A good charge controller must be able to withstand the array current as well as the total load current and must be designed to match the voltage of the PV module as well as that of the battery bank. Elbasset and Hassan [13] determined the charge controller size using the module power output and the battery voltage in equation 7 as

$$CC_{amps} = \frac{PV_{power}}{V_{dc}} \; x \; 1.25 \quad (7)$$

Where 1.25 is a safety factor to account for variable power output, CC_{amps} is the charge controller current capacity, PV_{power} is the power rating of the PV module, V_{dc} is the battery voltage.

e. MODULE SPECIFICATION

A grid-connected photovoltaic system may consist of a number of panels (array), which are normally mounted on tilted horizontal surfaces. Guda and Aliyu [11] used equation 8 to determine the photovoltaic array voltage (V_{pv}) as

$$V_{pv} = \frac{CC_{volt}}{\eta_{cable}} \quad (8)$$

Where CC_{volt} is the charge controller voltage capacity, η_{cable} is the efficiency of the cable

Similarly, the current needed by the array (I_{pv}) is

$$I_{pv} = \frac{TPI}{V_{dc}\ x\ E_{sh}} \quad (9)$$

E_{sh} is the equivalent sun hours of the location

The required power of the photovoltaic array (PV_{power}) is given as

$$PV_{power} = I_{pv}\ x\ V_{dc} \quad (10)$$

Comparing equations 8 and 9, it therefore follows that the photovoltaic array power is given as

$$PV_{power} = \frac{TPI}{E_{sh}} \quad (11)$$

The energy generated by the solar module is given by Alenezi, Sykulski and Rotaru [3] as

$$E = A\ x\ r\ x\ H\ x\ PR \quad (12)$$

Where E = Energy (kWh), A = total solar panel area (m^2), r = solar panel yield or efficiency, H = annual average solar radiation on tilted panels, PR = performance ratio (coefficient for losses, default value is 0.75).

D. SIMULATION RESULT

a. INVERTER SPECIFICATION

Since the kit is going to be used on a range of appliances, the inverter size should be able to accommodate at most a load of 135 Wh. Using equation 1 the inverter specification can be given as

$$TP1 = \frac{135}{0.9} = 150\ \text{Wh}$$

This means that the total power load into the inverter should be 150 Wh.

0.9 is the efficiency of the inverter. The continuous input DC current into the inverter is I_{dc} is given from equation 1 as

$$I_{dc} = \frac{150}{12} = 12.5\ A$$

The inverter parameter is summarized in Table 2

For this kit, Suoer grid tie 300W MPPT solar inverter with 12VDC – 230VAC was used. This means that the size of the inverter used is bigger than the size calculated. This makes it possible for the system to accommodate more load in case of future increase in the size of the battery

Parameters	Parameter Value	
Total Continuous output Power TP	108 W	
Efficiency η_{inv}	90%	
Input power to the inverter TP1	150 W	
Input DC voltage	10.0 – 15.0 VDC	
Continuous input current to inverter I_{dc}	12.5	A

Table 2: Inverter Summary

b. BATTERY SPECIFICATION

System Voltage is rated at 12VDC; this means that the battery voltage should also be 12 VDC. The days of autonomy is taken to be two days, this is enough to back up the battery bank. The summary of the battery sizing obtained from equations 3, 4 and 6 is given in Table 3. Top-light Gel 12VDC 40AH solar battery was used in this work. The battery size is a little bigger than the estimated battery size.

Parameter	Parameter Value
Autonomy (N_{backup})	2
Battery type	Lead Acid Type
Depth of Discharge DoD	80%
Required capacity of Battery Bank (B_{Ah})	36.76 Ah
Battery Operating Voltage (V_{dc})	12 VDC
Charging current of Battery	3.67 Ah
Battery Capacity	40 Ah
Battery Efficiency	0.85
Energy Required to charge Battery	518.96 Wh
Charging time of battery from solar	11.2 hrs

Table 3: Battery Summary

c. CHARGE CONTROLLER SPECIFICATION

The charge controller is sized to perform the function of limiting the rate at which electric current is added or drawn from the batteries. The current required by the charge controller to charge the battery can be determined according to equation 7. Other specifications of the charge controller are summarized in Table 4

Parameter	Parameter Value
Type	MPPT
Required Charging Current	5.21 A
Rated Input Current	20 A
Nominal Charging Voltage	12/24 V

Table 4: Charge Controller Summary

d. PV MODULE SPECIFICATION

In this designing we have chosen the SunPower 80 Wp module. PV module layout will be designed according to maximum voltage (V_m) and the maximum current (I_m). The maximum current to be generated by the solar module for the load is given according to equation 9 as

$$I_{pv} = \frac{12.5}{3} = 4.17\ A$$

The required power of the PV module obtained from equation 10 is given as

$$PV_{power} = 4.17\ x\ 12 = 50.04\ W$$

Table 3.5 gives a specification of the solar panel used for the construction

Module Type	Polycrystalline
Maximum Power ($\pm 5\%$)	80 Wp
Current Maximum Power (I_{mp})	4.44 A
Voltage Maximum Power (V_{mp})	18.0 v
Short Circuit Current I_{sc}	4.7 A

Open Circuit Voltage V_{oc}	21.6 v
Maximum System Voltage	1000 Vdc
Module Dimension	119 x 54 cm
Weight	8.5 kg

Table 5: Solar Module Specification

E. LIST OF MATERIALS

The materials used in the construction of the solar kit are classified into two groups namely

- ✓ The PV System components and
- ✓ The balance of system components

Having completed the sizing of the photovoltaic components, the following are the sizes of the components acquired for this kit

- ✓ Polycrystalline module of 80 W
- ✓ Solar battery - 40 Ah, 12 V
- ✓ Charge controller - 20 A
- ✓ Inverter - 300 W, 12 VDC – 230 VAC

The balance of system components include

- ✓ Heat exhaust fan - 24W, 220V AC: This will help to cool the system
- ✓ Battery charger: helps in converting the 220/230 VAC from the grid to 12 VDC needed by the battery
- ✓ Casing: This is used to enclose the component. All the components except the PV are connected in the module
- ✓ Cables: The cable used for the PV output/system input is a copper wire of 6 mm. This was used in order to draw more current because the thicker the wire, the more the current it can conduct without generating a lot of friction and heat. For the system and inter-connections of other devices, a cable of 1.5 mm was used to minimize losses.
- ✓ The grid input section was connected with a cable of 4 mm.
- ✓ Change over switch: This helps to change over power to grid if the kit was used before the power from the mains is supplied. This happens if the system was already connected to the mains during the power outage
- ✓ Solar module mount: The mount is a foldable rack constructed to tilt the module to any latitude and to face any direction depending on where it is used.

CIRCUIT DIAGRAM: The circuit is shown in figure 1. It comprises of the solar photovoltaic modules, charge controller, inverter, battery bank, battery charger, automatic change over, indicator and fan to cool the system

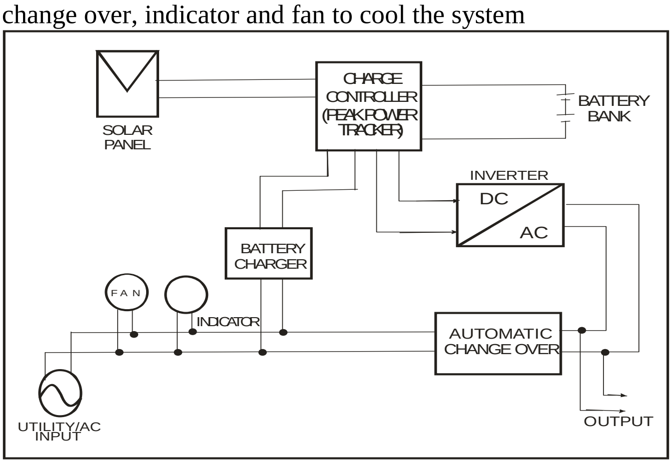

Figure 1: Block Diagram of the Circuit

III. RESULT

Using the values of the solar radiation obtained, the energy generated by the module in different months of the year has been evaluated on Table 6 using equation 12. From the table, high values of energy are obtained between January and April while the lowest energy is obtained in July. The energy generated by the tilted module is higher than that generated by a horizontally placed module. The tilt angle is determined by the monthly declination of the site.

The tilt angle is adjusted based on the season of the year. Optimally, the dry season tilt of 25° and a rainy season tilt of 0° will produce maximum result.

MONTH	H (MJ.M^{-2})	H (kWh.m^{-2})	E_H (kWh)	H_t (MJ.m^{-2})	H_t (kWh.m^{-2})	E_t (kWh.m^{-2})
January	12.79	3.563	21.317	14.27	3.964	23.783
February	12.64	3.511	21.067	13.35	3.708	22.250
March	12.91	3.586	21.517	13.03	3.619	21.717
April	13.45	3.736	22.417	13.49	3.747	22.483
May	12.08	3.356	20.133	12.44	3.456	20.733
June	10.75	2.986	17.917	11.33	3.147	18.883
July	9.31	2.586	15.517	09.71	2.697	16.183
August	9.75	2.708	16.250	09.87	2.742	16.450
September	10.62	2.950	17.700	10.63	2.953	17.717
October	11.10	3.083	18.500	11.47	3.186	19.117
November	12.43	3.453	20.717	13.63	3.786	22.717
December	10.42	2.894	17.367	11.85	3.292	19.750

Table 6: Values of Solar Radiation (in MJ.M^{-2} and kWh.m^{-2}) on Horizontal Module H, and Tilted Module H_t, Energy on Horizontal E_H and Tilted Module E_t

A grid-tied solar kit has been developed based on the design methodology. The total rated output energy is 108 Wh. The amount of energy generated by the solar module depends on the irradiance received by the module and the temperature of the module.

The values of the solar power generated by the module were measured for three days. The values were taken on the sixth and twenty third of September, and also on the sixth of October. The values of the solar irradiance were measured using a solar power meter while the values of voltage and current were measured using voltmeter and ammeter respectively. In each of the days, the system started to generate energy as early as 7 am even up to 6 pm. The power production reached maximum values between 10 am and 1pm in the first and second days but on the third day, the maximum values were attained from 11 am (Table 9). It was cloudy in early hours of the third day. The sharp reduction in the irradiation of the first day (Figure 3) was caused by partial cloud cover and few drops of rain between 11am and 12 noon. The highest solar irradiance received by the module is obtained by 1 pm of the first day (Table 7). This also generated the highest power from the module. Fig 8 shows that the module power generated on the first day was generally higher than those generated on other days. It was observed that the current generated by the module is not proportional to voltage generated. This is because the solar module current is determined by size of the solar cells and on the efficiency while the voltage depends on the number of solar cells. The average module power of the three days in Table 10 shows that the module is able to generate considerable energy that can charge the battery.

Time	Solar Irradiance ($W.m^{-2}$)	I (A)	V (v)	Module Power (W)
7 am	15.20	0.01	13.0	0.13
8 am	45.90	0.11	13.6	1.49
9 am	316.00	2.52	15.5	39.06
10 am	674.50	3.98	15.8	62.88
11 am	591.80	3.78	15.5	58.59
12 noon	323.60	2.72	15.0	40.80
1 pm	915.20	4.33	15.2	65.82
2 pm	211.60	1.62	14.5	23.20
3 pm	215.90	1.53	15.0	22.80
4 pm	173.90	0.73	14.5	10.59
5 pm	79.70	0.35	14.0	4.90
6 pm	22.80	0.03	12.0	0.36

Table 7: Generated Solar Power on 6th September, 2017

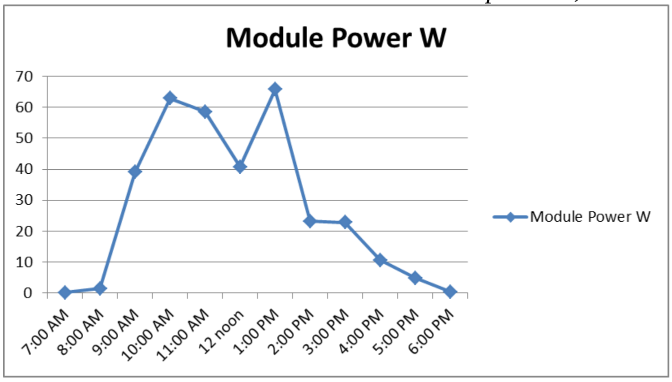

Figure.2: Graph of Module Power Against Time of the Day (6th September, 2017)

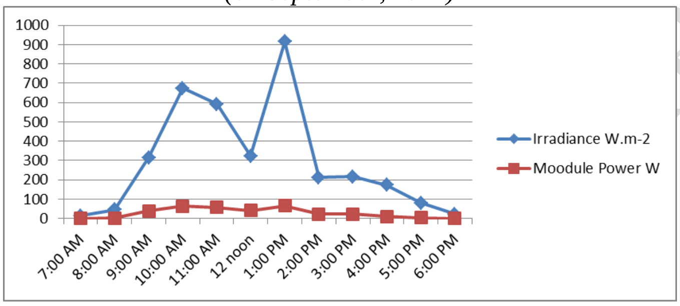

Figure 3: Comparison of Available Solar Irradiance and Module Power (6th September, 2017)

Time	Solar Irradiance ($W.m^{-2}$)	I (A)	V (v)	Module Power (W)
7 am	32.00	0.20	14.50	2.90
8 am	106.60	0.45	15.00	6.75
9 am	223.50	0.62	15.50	9.61
10 am	395.20	1.82	16.00	29.12
11 am	134.00	1.50	15.20	22.80
12 noon	270.00	1.20	15.30	18.36
1 pm	313.30	2.52	15.00	37.80
2 pm	386.70	3.40	14.50	49.30
3 pm	332.00	1.10	15.00	16.50
4 pm	50.60	0.20	13.50	2.70
5 pm	45.10	0.10	12.30	1.23
6 pm	21.80	0.03	8.00	0.24

Table 8: Generated Solar Power on 23rd September, 2017

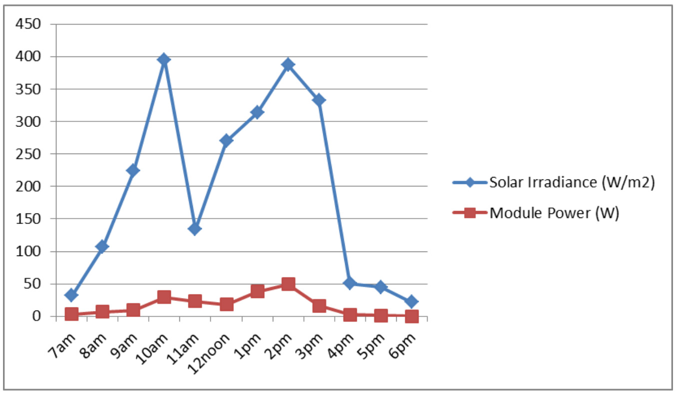

Figure 4: Comparison of Available Solar Irradiance and Module Power (23rd September, 2017)

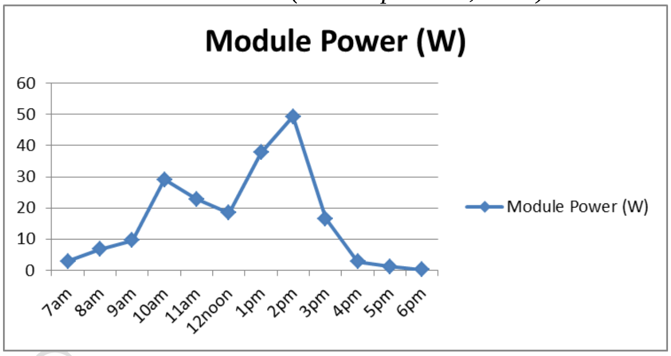

Figure 5: Graph of Module Power Against Time of the Day (23rd September, 2017)

Time	Solar Irradiance ($W.m^{-2}$)	I (A)	V (v)	Module Power (W)
7 am	18.60	0.10	13.20	1.32
8 am	121.30	0.51	15.10	7.70
9 am	263.80	0.70	15.60	10.92
10 am	286.40	1.30	15.80	20.54
11 am	384.20	3.33	15.20	50.62
12 noon	397.00	3.50	15.10	52.85
1 pm	399.60	3.81	15.40	58.67
2 pm	382.00	3.26	14.70	47.92
3 pm	325.10	2.96	14.50	42.92
4 pm	261.40	1.23	14.80	18.20
5 pm	86.10	0.42	14.00	5.88
6 pm	20.70	0.02	8.20	0.16

Table 9: Generated Solar Power on 6th October, 2017

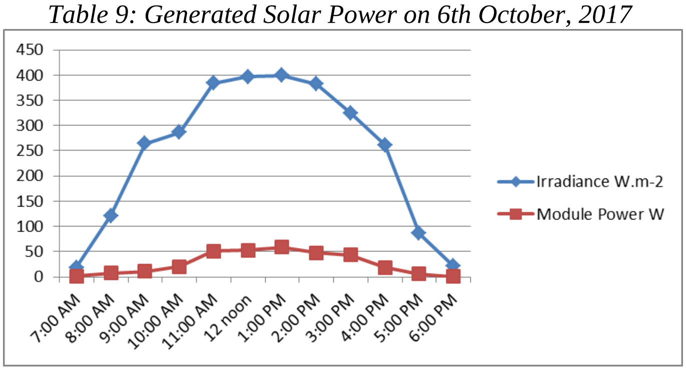

Figure 6: Comparison of Available Solar Irradiance and Module Power (6th October, 2017)

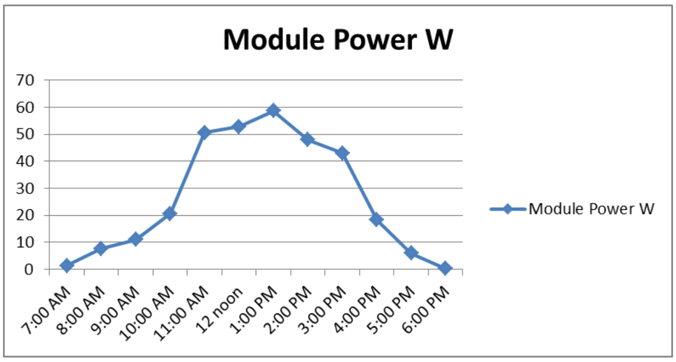

Figure 7: Graph of Module Power Against Time of the Day (6th October, 2017)

Time	Day 1 (6th Sept, 2017) Solar Irradiance ($W.m^{-2}$)	Module Power (W) Day 1	Day 2 (23rd Sept, 2017) Solar Irradiance ($W.m^{-2}$)	Module Power (W)	Day 3 (6th Oct, 2017) Solar Irradiance ($W.m^{-2}$)	Module Power (W)
7 am	15.20	0.13	32.00	2.90	18.60	1.32
8 am	45.90	1.49	106.60	6.75	121.30	7.70
9 am	316.00	39.06	223.50	9.61	263.80	10.92
10 am	674.50	62.88	395.20	29.12	286.40	20.54
11 am	591.80	58.59	134.00	22.80	384.20	50.62
12 noon	323.60	40.80	270.00	18.36	397.00	52.85
1 pm	915.20	65.82	313.30	37.80	399.60	58.67
2 pm	211.60	23.20	386.70	49.30	382.00	47.92
3 pm	215.90	22.80	332.00	16.50	325.10	42.92
4 pm	173.90	10.59	50.60	2.70	261.40	18.20
5 pm	79.70	4.90	45.10	1.23	86.10	5.88
6 pm	22.80	0.36	21.80	0.24	20.70	0.16
Mean		27.55		16.44		26.48

Table 10: Comparison of the Solar Irradiance and the Module Power for the Three days

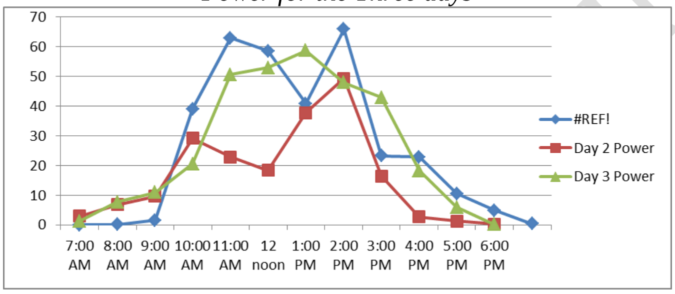

Figure 8: Comparison of Module Power for the Three days

The highest value of measured power generated by the module on the second day (23rd September 2017) was 49.30 W. This was obtained at 2 pm. This value is a little more than half of rated maximum power specified by the solar module manufacturer. This is because of partial cloud cover in the rainy season.

The little showers experienced on the first and second days did not stop the module from generating power. In fact some values were obtained in the rain. Figures 2, 5 and 7 show that maximum power can be obtained from the module from as early as 9.00 am till 3.00 pm depending on the weather of the day.

IV. ESTIMATED SIZES FOR OTHER OUTPUT VALUES

Using the simulation method used in this report, the sizes of the solar kit appliances can be estimated to take care of other load values. For the estimation, the following conditions hold

DOD = 80%
η_{bat} = 0.85
V_{dc} = 12 v
Autonomy = 2 days
ESH (Estimated Sunshine Hours) = 3 hours

Output Load (W)	T_L (Wh)	Inverter Capacity (Wh)	Battery (Ah)	Charge Controller (A)	Module Power (W)
100	125.0	138.8	34.02	4.82	46.27
108	135.0	150.0	36.76	5.21	50.04
150	187.5	208.3	51.05	7.23	69.43
200	250.0	277.7	68.06	9.64	92.57
250	312.5	347.2	85.10	12.06	115.24
300	375.0	416.7	102.13	14.47	138.90
350	437.5	486.1	119.14	16.88	162.04
400	500.0	555.6	136.16	19.29	185.18
450	562.5	625.0	153.19	21.70	208.33
500	625.0	694.4	170.20	24.11	231.47

Table 11: Estimated Values for Other Sizes

V. DISCUSSION

A close examination of table 6 shows that the months of October to May receive more solar radiation than other months. The highest value of solar radiation and energy occurred in January which is a month in the harmattan season (November-February). This occurrence is not expected because the solar radiation intensity is greatly reduced by aerosol mass in the atmosphere (Augustine and Nnabuchi, [4]). It should be noted that insolation instruments record hours of bright sunshine when solar radiation flux is above the threshold value of 210 $W.m^{-2}$. Hence, a high mean daily sunshine hour is obtained in January because it has a high clearness index. It is also observed from the table that the energy generated by the tilted panel is higher than the one generated by the horizontal panel in all the months except in September. In this month the panel can be kept horizontally. This supports the report of Akpan Umoren and Markson [2] in which September has the highest transposition factor in the rainy season.

From Tables 7, 8, and 9 it is visible that the system begins generating energy at 7 am though on a minute scale. The voltage generated at this period is higher than the nominal voltage of the battery. The highest recorded voltage of the measurements did not come with the highest recorded current. The highest current comes with a high irradiance and a high irradiance cannot produce the highest voltage. The difference comes from the fact that voltage is affected by temperature. As the irradiance increases, the surface temperature of the module increases. This supports the result of Chikate and Sadawate [6] that increase in the cell temperature of the module results in a decrease in the open circuit voltage of the module while the short circuit current increases with increase in temperature. Also, voltage is determined by the number of solar cells while the current depends on the size of the solar cells and their efficiency.

As the voltage fluctuates with temperature, the MPPT charge controller ensures that the charging voltage is maintained at 12 v. The highest recorded power for the three days is 65.8 W obtained at 1 pm of the first day. The weather of these days was characterised by frequent cloud cover in some hours of the morning and late afternoon. This weather did not stop the system from generating useful energy for the battery. The mean generated current of 1.1 A (for the second day indicates that it will take 51 hours (about four and a half days) to fully charge the battery. In this period the battery will be mostly charged by the grid.

Dry season power will not be like this because solar power in the dry season can rise up to 1300 $W.m^{-2}$. The second graph shows that the power generated by the module is proportional to the solar power.

It can be seen from Table 11 that the size of the system depends primarily on the size of the battery and the inverter. Also, the inverter used for this research can also be used to run a 150 W and 200 W solar kit. The charge controller of 20 A used in this research can equally be useful for output of 400 W. Finally, the solar module of 80 W used here can be used for an output of 150 W. These appliances were oversized to allow for future expansion and durability.

The days of autonomy could change based on the rate of usage of the battery, that is, the wattage of the appliances used and the duration of usage. The estimated sunshine hours of three hours would allow for situation in the rainy days. This makes this kit to be useful even in other parts of the country which have longer hours of sunshine.

VI. CONCLUSION

An approach for the optimum design of a mobile grid-tied PV system based on the optimal configuration of the PV module, inverter and battery has been presented in this paper. The PV module is oriented based on the latitude and cardinal point of the city of Uyo on Akwa Ibom State.

The optimal configuration consists of an 80 W panel mounted on a foldable rack and tilted according to the season of the year; 40 Ah 12 v battery, 300 W inverter, 20 A charge controller and other components. The total rated output of the system is 108 Wh. The least energy yield is 16.18 kWh which occurs in July and the highest is 23.78 kWh occurring in January. The design implementation is worthwhile for individuals and businesses. Since this system is able to generate power in Uyo which is in the tropical rainforest, it can equally be used in other locations which have higher values of average solar radiation.

This study has contributed to knowledge in the sense that it has utilized the simulation method used here to estimate the size of PV system appliances for other rated output. The same design procedure and estimated values can be applied to other locations.

The study presents an energy solution that offers clean and reliable energy at all times. It also presents a simple approach to the construction of a grid-tied solar system without sizing the components. The kit constructed in this study is recommended for use at any location as an alternative source of energy.

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