

Design of an Industrial Off-Grid Photovoltaic System for the Intensive Care Unit at the University of Benin Teaching Hospital

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Abstract

The world is progressively shifting away from conventional power sources based on fossil fuels and toward renewable energy sources due to the aggravation of noise, harmful fume pollution and the dreaded climate change. The primary goal of this effort was to develop an industrial standalone photovoltaic system for essential loads to increase the efficiency and dependability of the power supply in the UBTH distribution network. UBTH's electrical distribution network underwent an energy audit, and the important loads were those that had a direct influence on patients' health and were operated continuously for 24 hours. A load/energy audit was conducted on a catalog of electrical appliances to determine the energy demand in the intensive care unit, which amounted to a total of 36.02 kW and thus, was used in the design of the photovoltaic system based on known theories. Calculations were made to determine the output power required from the photovoltaic system design and thus gave rise to the calculated number of photovoltaic panels. The choice of batteries, charge controllers, multi-cluster boxes, inverters, circuit breakers and cables was made in line with the design specifications. According to the results, the intensive care unit required an average of 864.48 kWh of energy per day to run for twenty-four (24) hours a day, and 1061.06 m² of PV space. Thus, a total of 495 photovoltaic panels were required to cater for the required energy, including a calculated amount of 240 batteries to power the ICU at nightfall. In developing nations, we advocate solar technology for organizations like hospitals in rendering essential services seamlessly, since the sun has a proud position among the renewable energy sources being used due to its ubiquity.

Keywords: Photovoltaic system; Load audit; Intensive care unit; Energy demand; Climate change

Introduction

According to the IEA report, the electricity markets faced an exceptionally high demand across the world in 2021, with power demand increasing by more than 6% as a result of strong economic expansion [1]. Wholesale power prices increased as a result of the accelerated recovery in global energy demand, which put pressure on coal and natural gas supply networks. Electricity production from coal and gas reached historic highs despite the phenomenal expansion of renewable energy. Thus, the annual carbon dioxide emissions from the electricity sector soared globally to a new record high after declining in previous years. China, the United States, and India top the 2021 global list of highest CO₂ emissions due to their dense population and industrialization [2]. In 2021, Nigeria was ranked among the top five polluting countries of production-based CO₂ emissions with 136,986,780 metric tons, which is the highest in comparison with that of previous years. This evidentially shows a distinctive mismatch between the demand and supply of energy for economic growth. The greenhouse gas emissions in Nigeria emanate from various sources which have energy generation as a major share of 32.6% among other sources [3].

Energy generation precedes thermal power generation for large-scale power grids up to the use of fuel and diesel generators for small-scale businesses and residents. The Energy Commission of Nigeria reported that about \$22 billion was spent on fueling generators each year. The punch newspaper reported that 40% of Nigerian households make use of this generator due to the epileptic nature of electric power availability across the nation. In recent times, Nigeria has the largest economy in sub-Saharan Africa is faced with the limitation of insufficiently wheeling around 4000 MW of electric power to its populace of over 195 million people, despite the country's capability of generating 12,566 MW for existing power plants. This setback has continually arisen from the general difficulties encountered by the Nigerian power industry regarding the implementation of electricity policies, regulatory uncertainties, gas supply, transmission system limitations, and significant planning flaws that have prevented the sector from being commercially viable [4].

It is quite unfortunate that the nation is persistently investing billions of naira in the production of hydroelectric and thermal power while having a huge potential to develop its solar energy that would offer a reliable power supply. The spike in diesel prices in Nigeria has relatively constituted a surge in the demand for solar power for mainly residential use due to the abundance of sunlight across the country. However, the adoption of solar power systems in Nigeria is estimated to be below 2%, as some businesses believe they are unsuited for usage on a wide scale. A great majority of Nigerians generally believe that solar energy system is fairly expensive to install and reliable. In reality, solar energy systems are upgradeable to suit their demand and they have inconsequential running costs over time after their initial high cost of installation. Furthermore, the energy added up from other renewable sources like water and wind will give less than 1% of solar energy [9]. Thus, the sun produces significantly more energy than mankind will ever use from a general perspective [5].

The adverse effect of the Nigerian epileptic power availability has paralyzed various essential services, especially in the health sector, where patients are left to bear the brunt of hospitals running skeletal services with costly healthcare charges due to the rising cost of diesel and petrol needed for their backup generator. Following a case study, the management of the university of Benin Teaching Hospital (UBTH) operates on over 30 diesel-generating units alongside public power supply, to maintain a constant electric power supply for essential services. This is due to the current state of UBTH's power supply and consumption which is hampered by an increase in downtime brought on by the high maintenance costs of the backup power supply and related technological know-how and power demand needed by new structures and equipment. Furthermore, a field study revealed various critical areas of UBTH like the Intensive Care Unit (ICU), where any power downtime cannot be tolerated as its equipment must continually operate to serve patients with a razor's edge between life and death. The key electrical equipment needed for saving lives in the ICU at UBTH includes mechanical ventilators, patient monitors, suction machines, mobile X-ray machines, defibrillators, infusion pumps, lighting fixtures, and air conditioners [6].

Conclusively, the necessity for a safe, affordable, and reliable renewable power to supply critical loads for essential services forms the basis of this research study. Therefore, solar power is considered and proposed for the critical loads of the Intensive Care Unit in UBTH (Figure 1).

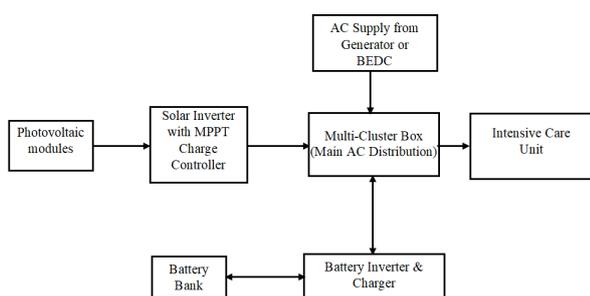


Figure 1: Block diagram of the industrial off-grid photovoltaic system design.

Figure 1 depicts the direction of DC power flow from the photovoltaic panels to a solar inverter with an integrated MPPT charge

controller for optimal efficiency of the system. The solar inverter converts the input DC electric power to AC electrical energy and then fed into a multi-cluster box for smart AC distribution of off-grid system interconnections. The DC battery bank either feeds the system through its inverter or recharges from the supply in the multi-cluster box, depending on the load demand that is a function of the power flow [7].

Materials and Methods

Materials

The equipment required for the installation of the PV system includes:

- Photovoltaic panels
- Solar Inverter with an inbuilt charge controller
- Multi-cluster Box
- Battery bank
- Battery inverter and charger

The above materials will form the PV system that will be integrated into the existing public utility supply and backup diesel generators that gives electricity to the ICU.

Methods

A load assessment was conducted in the intensive care unit of UBTH and power ratings (watts) of all the electrical appliances were listed accordingly. Thereafter, the itemized result from the loaded audit was used in the calculation of the energy demand per day (watt-hour) as shown in Table 1. The resultant computation is then used to estimate the capacity of the PV panels, inverters, battery banks and power cables with the aid of existing theories. The battery is expected to cater to the ICU loads during off-peak periods of the PV system. The existing power utility supply and the backup diesel generator were considered as redundancy to charge the battery bank for periods of inadequate solar radiation that may occur at some point in the year. The design layout of the PV array with its land requirement was also established [8].

Electrical appliances	Quantity	Power rating (kW)	Total load (kW)
Mechanical ventilators	6	1.185	7.11
Patient monitors (Type1)	6	0.06	0.36
Suction machine	7	0.18	1.26
HP air conditioning unit	2	1.13	2.26
Refrigerator	4	0.08	0.32
13 amps sockets (SPARE)	4	0.3	1.2
Lighting points	13	0.1	1.3
Mobile X-ray machine	1	2.4	2.4
Patient monitors (TYPE2)	9	0.06	0.54
Defibrillators	2	0.08	0.16

Suction machine	7	0.18	1.26
Water heater	1	3.5	3.5
Hand dryer	2	1.5	3
Lighting points	10	0.1	1
1.5 HP air conditioning unit	6	1.13	6.78
2 HP air conditioning unit	2	1.5	3
Suction pump	5	0.02	0.1
Infusion pump	1	0.01	0.01
Washing machine	1	0.46	0.46
Total			36.02

Table 1: The load readings in the Intensive Care Unit of UBTH.

Pv system design

Energy demand calculation: Based on the high degree of necessity, a diversity factor of 1 was adopted for all electrical appliances in the intensive care unit. Therefore, loads are expected to operate for 24 hours of which 12 hours each will be supplied by the solar panel and battery bank. Thus, the daily energy demand of the ICU is:

$$E_{ICU} = P \times t = 36.02 \text{ kW} \times 24 \text{ hours} = 864.48 \text{ kWh}$$

Where P is the total power ratings of loads in the ICU

T is the required time of operation

Sizing of photo-voltaic panels

Number of PV panels:

The number of PV panels required is given by:

$$N_{panels} = \frac{E}{PGF \times W_p}$$

Where N_{panels} = Number of PV panels required

E = Energy demand from the PV panels per day in Wh

PGF = Panel Generating Factor

W_p = Peak rated power output of a unit PV panel in W

Considering 30% of total energy losses from 20% of battery and 10% of wiring connection losses, an allowance of 130% of the daily energy demand is required to size the PV panels. Thus,

$$E = 130\% \times 864.48 \text{ kWh} = 1,123.824 \text{ kWh}$$

The average insolation in Benin city throughout the year is 4.47 kWh/m² per day. This is equivalent to 4.47 hours of 1000 W/m² sunlight daily. Considering 15% loss for temperatures above 25°C, 5% loss for dirt and 5% loss for the aging of the module. The correction factor (CF) for PV panel efficiency is:

$$= 0.85 \times 0.95 \times 0.95 = 0.77 \text{ W/W}_p$$

Where W_p is the PV panel peak-rated output.

The Panel Generating Factor (PGF) is given as:

$$= \text{Daily hours of sunlight} \times CF = 4.47 \text{ hrs} \times 0.77 \text{ W/W}_p = 3.44 \text{ Wh/W}_p$$

This means that an average of 3.44 Wh/day is produced during the lowest solar month. Considering the existing industrial loads in the ICU, a 660 W monocrystalline solar panel is adopted for this design (Table 2).

Electrical data/STC*	
CS7N	660 MS
Nominal max. power (P_{max})	660 W
Opt. operating voltage (V_{mp})	38.3 V
Opt. operating current (I_{mp})	17.24 A
Open circuit voltage (V_{oc})	45.4 V
Short circuit current (I_{sc})	18.47 A
Module efficiency	21.2%
Operating temperature	40-85°C

Max. system voltage	1500 V (IEC) or 1000 V (IEC)
Module fire performance	Class C (IEC 61730)
Max. series fuse rating	30 A
Application classification	Class A
Power tolerance	0-10 W
Dimensions	2384 × 1303 × 35 mm (93.9 × 51.3 × 1.38 in)
Weight	34.4 kg (75.8 lbs)
Note: *Under standard test conditions of irradiance of 1000 W/m ² and temperature of 25°C	

Table 2: Design specification of a Canadian solar 660 W solar panel.

Therefore, the minimum number of PV panels required is given by the:

$$N_{panels} = \frac{1123.824 \times 10^3 Wh}{3.44 Wh/W_p \times 660 W_p} \approx 495 \text{ panels}$$

To attain an even match of the number of series and parallel configuration, 500 panels is selected for this PV design.

These panels will be shared at 100 panels per solar inverter, and each of the 5 solar inverter sets will have a 25 series × 4 parallel solar array configuration. Thus, a solar inverter will have 2 strings of individual 25 series × 2 parallel configurations.

Area of PV array space

In sizing the PV array area, the array peak watt is calculated as:

$$W_{p(array)} = \frac{E}{PGF} = \frac{1123.824 kWh}{3.44 Wh/W_p/day} = 176.3 kW_p/day$$

Selecting 21.6% efficiency (η) of a 660 W monocrystalline PV panel the minimum PV array area required is:

$$A_{min} = \frac{W_{p(array)}}{\eta \times 1 kW/m^2} = \frac{176.3 kWh}{0.216 \times 1000} = 816.2 m^2$$

Considering a factor of 130% for working space, the total PV array area for this design is:

$$A = 1.3 \times 816.2 m^2 = 1061.06 m^2$$

Inter-row spacing of PV array

The PV inter-row spacing is calculated from the diagram depicted in Figure 2. The shaded diagonal lines represent two adjacent solar

panels with L-module length and W-module width. Variable X, Y and Z are distances in meters [9].

Considering the dimension of a typical 660 w solar panel of 2.4 m length and 1.3 m width [20], the land requirement needed for the PV array space can be calculated below:

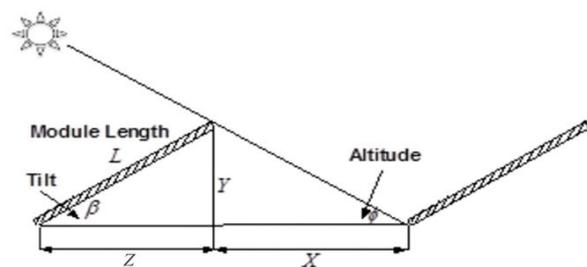


Figure 2: The geometrical relationship between the angles and modules.

The distance of X is calculated as:

$$X = \frac{Y}{\tan \phi}; \text{ But } Y = L \sin \beta; \text{ Thus, } X = \frac{L \sin \beta}{\tan \phi}$$

Where β is the tilt angle and ϕ is the altitude angle.

For optimal efficiency of the solar panel, β should vary between 30° to 45°. Therefore, an average tilt angle of 38° is adopted for this design. ϕ varies from 10° to 80° with a corresponding horizontal spacing of X.

Since $Y = L \sin \beta = 1.48 m$

Thus, the average value of the corresponding X is computed as illustrated in Table 3.

Altitude angle	X(m)
10	8.37
20	4.06

30	2.56
40	1.76
50	1.23
60	0.85
70	0.54
80	0.26
Average X value	2.45

Table 3: The altitude angle and the horizontal spacing of the modules.

This implies that the corresponding average value of X is 2.45 m.

But $Z=L\cos\beta=1.89$ m

Therefore, the spacing of adjacent modules R is $X+Z=4.34$ m.

Sizing of the battery capacity

Considering a 2 V/3000 Ah battery cell for this design with a 50% Depth of Discharge (DOD), 15% battery loss allowance and 12 hours day of autonomy, the battery bank capacity is:

$$Ah = \frac{E}{V_{dc} \times DOD \times L_{bat}} \times d_{aut}$$

Where Ah is the battery capacity

DOD is the Depth of Discharge

V_{dc} is the system's DC voltage

L_{bat} is the battery loss

d_{aut} is the days of autonomy

$$Ah = \frac{1123.82kWh}{48 \times 0.5 \times 0.85} \times 0.5 = 27.54kAh$$

Therefore, the number of batteries in series B_{series} is:

$$B_{series} = \frac{V_{dc}}{V_{bat}} = \frac{48}{2} = 24$$

Where V_{bat} is the unit battery voltage

The number of batteries in parallel $B_{parallel}$ is:

$$B_{parallel} = \frac{Ah}{Ah_{bat}} = \frac{27.54kAh}{3kAh} = 9.18 \approx 10$$

Where Ah_{bat} is the battery cell capacity

Hence the battery configuration will be 24 series \times 10 parallel=240 batteries

Sizing of the inverters

Battery inverter size: The inverter size should be 130% of the total wattage of the industrial loads. This 30% allowance is called the safety factor. Therefore,

The inverter size= $1.3 \times P$

Battery inverter size= $1.3 \times 36.02=46.826$ kW

This calculated battery inverter size will be shared amongst 2 sets of five 6 kW Sunny Island battery inverters with inbuilt DC chargers. Each set of five 6 kW Sunny Island battery inverters will accommodate an arrangement of a 24 series \times 5 parallel battery bank from section [10].

Solar inverter size

For the Solar inverter, the total load demand E_{sinv} will be the sum of the loads in the ICU (P) and the battery load after discharge. But the battery load is equivalent to P and thus,

$E_{sinv}=2P=2 \times 36.02$ kW=72.04 kW

Solar inverter size= $1.3 \times 72.04=93.652$ kW

This calculated solar inverter size will be divided among five 20 kW Sunny Tri power solar inverters with each having 25 \times 4 solar array configurations.

A 20 kW solar inverter will make use of 2 inbuilt MPPT charge controllers of 2 strings each.

Sizing of the charge controller

A safety factor of 1.25 is necessary for calculating the capacity of the charge controller.

$$Charge\ controller\ rating = \frac{W_p \times N_{panels}}{V_{sdc}} \times SF$$

Where SF is the Safety factor and V_{sdc} is the solar array voltage.

The solar array voltage is calculated as;

$V_{sdc}=N_{series} \times V_{mpp}=25 \times 38.3=957.5$ V

Where N_{series} is the number of solar panels connected in series, and

V_{mpp} is the maximum power point voltage of a unit solar panel.

Therefore, the charge controller rating is:

$$= \frac{660W \times 500}{957.5V} \times 1.25 = 430.8 A$$

This implies that the inbuilt MPPT charge controllers of the Solar inverters should cumulatively withstand the rated current of 431 A.

Thus, since 5 sets of solar inverters with each having 2 in-built MPPT charge controllers, each solar inverter can handle 86.2 A. Thus, each MPPT charge controller with 2 strings can handle 43.1 A (22 A per string) [11].

Results and Discussion

Multi-cluster box for sunny island

The multi-cluster box increases the power of the AC main distribution unit for Sunny Island systems by 20%. This allows off-grid and hybrid systems in the power ranges of 20 to 300 kW to be implemented even more cost-effectively. To simplify installation as shown in Figure 3 all multi-cluster Boxes are completely wired and fitted at the factory and have a main connector for generators, load distribution, and PV or wind turbine systems. All data cables required for the installation are included in the delivery. With the Multi-cluster solution for Sunny Island, complex energy supply solutions are easy to implement [12].

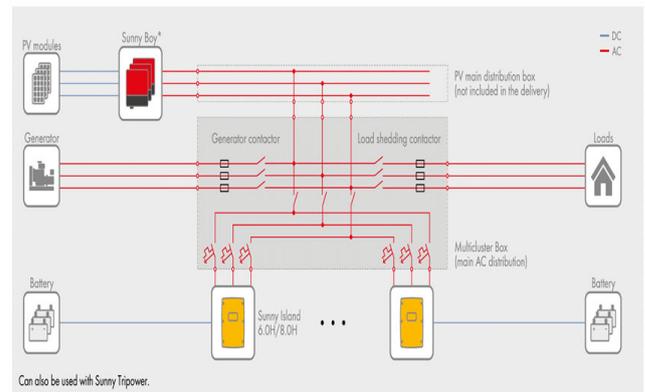


Figure 3: SMA Multi-cluster box arrangement in a distribution network.

Cable sizing

The choice of the power cable is a function of its current carrying capacity for equipment in need of electric power. It is also worth of note that the permissible voltage drop of the cable should be less than 2.5% of the equipment connected to it. This voltage drop is dependent on the short-circuit current and length of the cable for both AC and DC loads as shown in Table 4. These same principles apply to both single and three-phase systems. Copper cables are most preferable for PV installations due to their high current carrying capacity with lesser density [13].

Conductor	Reference conduit method A of in thermally Table 4D2A insulating wall (enclosed in etc.)			
	1 two-core cable, with or without protective conductor single phase Ac or DC		1 three-core or 1 four-core with or without protective conductor three phase AC	
C.S.A. (mm ²)	Current carrying capacity (A)	Voltage drop (mV/A/m)	Current carrying capacity (A)	Voltage drop (mV/A/m)
1.0	11	44	10	38
1.5	14	29	13	25
2.5	18.5	18	17.5	15
4	25	11	23	9.5
6	32	7.3	29	6.4
10	43	4.4	39	3.8
16	57	2.8	52	2.4
25	75	1.75a, 1.75d	68	1.50
35	92	1.25a, 1.25d	83	1.10
50	110	0.94a, 0.93d	99	0.81
70	139	0.65a, 0.63d	125	0.57
95	167	0.50a, 0.46d	150	0.43
120	192	0.41a, 0.36d	172	0.35
150	219	0.34a, 0.29d	196	0.29

185	248	0.29a, 0.23d	223	0.25
240	291	0.24a, 0.18d	261	0.21
300	334	0.21a, 0.145d	298	0.185
400	-	0.185a, 0.105d	-	0.160

Table 4: Cable gauge chart.

The fundamental principles for the cable type calculations required for this design are as follows:

Solar panel cable sizing:

The DC passing through each terminal of the solar panel I_{dc} gives:

$$I_{dc} = N_{parallel} \times I_{sc}$$

Where $N_{parallel}$ is the number of parallel connections of the solar panel

I_{sc} is the short circuit current of a unit solar panel

$$I_{dc} = 2 \times 18.47 \text{ A} = 36.94 \text{ A}$$

The voltage drop per ampere-meter of the DC cable is selected from its corresponding current value of $I \geq I_{dc}$ in the cable gauge chart of Figure 3 Thus, the voltage drop of cable over a measured distance gives:

$$V_{drop} = I_{dc} \times l \times V_{dam}$$

Where l is the length of the cable, and

V_{dam} is the voltage drop per ampere-meter in milli-volt (mV)

Considering a 25 m cable length, $V_{drop} = 36.94 \times 25 \times 4.4 \times 10^{-3} = 4.0634 \text{ V}$

The voltage of the solar array is:

$$V_{sdc} = 957.5 \text{ V}$$

$$2.5\% \text{ of } 957.5 \text{ V} = 23.93 \text{ V}$$

Since $V_{drop} < 2.5\%$ of V_{sdc} , 10 mm² cable is selected.

Battery cable sizing

The DC passing through the battery terminals gives:

$$I_{dc} = \frac{Ah_{bat} \times DOD}{H_{aut}}$$

Where Ah_{bat} is the Ampere-hour rating of the battery cell

DOD is the depth of discharge of the battery

H_{aut} is the hours of autonomy of the battery bank

$$I_{dc} = \frac{27.54 \text{ kAh} \times 0.5}{24 \text{ h}} = 573.75 \text{ A}$$

There are 2 sets of five 6kW Sunny Island battery inverters and thus, each set will accommodate a DC of 286.875 A. This means that the DC passing through each of the 5 battery inverters is 57.37 A.

The voltage drop of cable over 10 m gives:

$$V_{drop} = 57.37 \text{ A} \times 10 \times 1.75 \times 10^{-3} = 1 \text{ V}$$

The voltage of the battery bank is also calculated as follows:

$$V_{bank} = B_{series} \times V_{bat}$$

Where B_{series} is the number of battery cells connected in series, and

V_{bat} is the rated battery cell voltage

$$V_{bank} = 24 \times 2 = 48 \text{ V}$$

$$2.5\% \text{ of } 48 \text{ V} = 1.2 \text{ V}$$

Therefore, if $V_{drop} < 2.5\%$ of V_{bank} , a 25 mm² cable is chosen.

Inverter to ac load cable sizing:

The AC passing through the inverter terminals gives:

$$I_{ac} = \frac{P}{3 \times V_{ph}}$$

Where P is the total wattage of AC loads and

V_{ph} is the nominal phase voltage, and V_{ph} is taken as 240 V.

$$I_{ac} = \frac{36.02 \text{ kW}}{3 \times 240 \text{ V}} = 50 \text{ A}$$

The voltage drop per ampere meter of the DC cable is selected from its corresponding current value of $I \geq I_{ac}$ in the cable gauge chart. Thus, the voltage drop of a 35 m cable length gives:

$$V_{drop} = I_{ac} \times l \times V_{dam} = 50 \times 35 \times 2.8 \times 10^{-3} = 4.9 \text{ V}$$

$$2.5\% \text{ of } 240 \text{ V} \text{ is } 6 \text{ V}$$

Since $V_{drop} < 2.5\%$ of V_{ph} , 16 mm² is selected.

Circuit breaker/fuse sizing

The rating of the circuit breaker or fuse is calculated as 125% of the cable's ampacity. The provision is made for the protection of the device against overload and short-circuit.

Thus, the size of the circuit breaker required for each string of the PV array is:

PV Circuit Breaker rating=125% × ISC=1.25 × 18.47 A=23.09 A.

Therefore, a circuit breaker rating of 24 A.

Since there are 2 parallel connections in a string of PV array, then the circuit breaker ratings for the parallel combination will be 2 × 24 A=48 A

The main parameters accompanied by their related formulae and values used in the off-grid PV design are summarized in Table 5.

Parameter	Formula	Values
Daily energy demand	$P \times t$	864.48 kWh
Number of PV panels required	$\frac{E}{PGF \times W_p}$	495 panels
Total PV array area	$1.3 \times \frac{W_{p(array)}}{\eta \times 1kW/m^2}$	1061.06 m ²
Battery bank capacity	$\frac{E}{V_{dc} \times DOD \times L_{bat}} \times d_{aut}$	27.54 kWh
Number of batteries required	$B_{series} \times B_{parallel}$	240 batteries
Battery inverter size	$1.3 \times P$	46.826 kW
Solar inverter size	$1.3 \times 2P$	93.652 kW
Charge controllers' capacity rating	$\frac{W_p \times N_{panels}}{V_{dc}} \times SF$	430.8 A
PV circuit breaker rating	$125\% \times I_{sc}$	24 A

Table 5: Result parameters used in the off-grid design for the ICU at UBTH.

The design of an off-grid PV system to power critical loads in the intensive care unit at UBTH started with conducting a load audit of electrical appliances used daily. A total load of 36.02 kW was added up after the audit was carried out. This load summation was then used to compute the daily energy demand of 864.48 kWh required to put the ICU into full operation continuously. The calculated total energy demand served as an important parameter to evaluate the size of major components for the PV design. Thus, the resultant values of these PV design requirements were 500 solar panels, 1061.06 m² of PV array area with 4.34 m spacing between adjacent modules, 240 2 V/3000 Ah batteries, 2 sets of five 6 kW Sunny Island battery inverters with inbuilt DC chargers, five 20 kW Sunny Tripower solar inverter with inbuilt MPPT charge controllers, a multi-cluster box, 10 mm² solar cables, 25 mm² battery cables, 16 mm² inverter cables and 48 A solar circuit breakers rating. Finally, it is worth noting that this design will

be able to stand the test of time based on the quality of the components used.

Conclusion

In conclusion, Nigerian hospitals offer essential services that are key to saving lives and thus they must evolve to fit the societal needs in Nigeria. These medical needs cannot rely on the present deplorable state of electricity and the rising cost of diesel for generators in Nigeria. Thus, it has become obvious for the hospital to source the best available and clean electric power alternative for effective and reliable continuous operation. The paper has proposed an industrial self-sustained design of a PV system that is capable of satisfying medical needs for over a period of 25 years with minimal maintenance culture. This PV design will drastically reduce the use of public power

utilities and diesel generators, which gives a significant increase in savings for the organization. The PV design can be adapted for any industrial load with the same theories that govern its calculations. Conclusively, the PV system created exceeds the requirements of its design and achieves the main fundamental desired goal of this work.

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