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Design of Solar Electricity (PV) System to Power UBTH, Accident & Emergency Operating Theatre

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Abstract

There is a global shift from the conventional power sources based on fossil fuel to renewable energy resources as a result of the nuisance of noise, toxic fumes pollution and the global warming of the earth's atmosphere resulting in the dreaded climate change. This work presents the design of solar electricity (photovoltaic) system to power University of Benin Teaching Hospital (UBTH), Accident and Emergency operating theatre (A&E). All the electrical appliances were itemized, their power rating, usage hours and average energy/load demand for 2 suits of the operating theatre was determined. The required photovoltaic output power generated from the photovoltaic active area was calculated. The number of photovoltaic panels that would provide the PV panel output power to cater for the load was also calculated. Selection of inverter, battery banks and cables sizes were carried out. Result shows that average energy demand for the operating theatre (2 suits) in operation for twelve (12) hours a day was 147.84 kWh, PV area required was 282.569 m^2. The number of PV panels required was 140. The Total number of batteries to meet the 12 hours autonomy was ten (10). Since solar photovoltaic technology has assumed a pride of place among the renewable energy source being exploited for use and the ubiquitous nature of sunshine, we recommend solar technology for residential, commercial, hospitals and isolated communities in the developing world.

1. Introduction

Electric power sector in Nigeria witnessed a huge setback during the military government for decades. This however translated to the wide gap between demand and supply of electricity. [1]. During the period, federal Government of Nigeria was responsible for policy formulation, regulation, funding, planning and operation of the power industry through Federal Ministry of Power [2]. The competing demands of the Government treasury coupled with the lack of prioritization of infrastructure, especially in the electric sector, led to significant under investment in the industry [2]. To mitigate the electricity crisis and ensure rapid transformation of the sector, a change in government's role in the utility space was needed [3]. The alternative was to deregulate the power sector and leave everything to market forces. On 31st May, 2005 National Electric Power Authority (NEPA) was transformed by Federal Government to Power Holding Company of Nigeria (PHCN). The assets and liabilities of NEPA was transformed to PHCN and in November, 2013 PHCN was unbundled. The power sector reform objectives are; the transfer of PHCN successor companies in generation and distribution to the private sector, the creation of an independent regulator, the Nigeria Electricity Regulatory Commission (NERC) to supervise and monitor the industry. The Nigeria Bulk Electricity Trading (NBET) Plc for bulk purchase and sale of electric power, Transmission Company of Nigeria (TCN) and Rural Electrification Agency (REA) etc were incorporated [2]. Policy formulation and long term development was left to the Federal Government of Nigeria. This step was perceived by Nigerians would lead to improved efficiency, reliability and quality electric power services for some reasons. First, the private sector was perceived as having adequate resources to boost investment in the sector. Second, the investors were also expected to possess the discipline and management skills, capable of driving operations in the sector [4]. However, nothing much has been achieved in this sector. All parts of the country still experience frequent power outages, thus private generators, ranging from private home generators to large industrial standby generators abound. As a result of this, cost of services and manufacturing has increased and private home and industrial standby generators are now sources of environmental pollution [3]. Moreover, air and thermal pollution associated with the burning of fossils fuel, the toxic fumes, the global warming of the earth's atmosphere resulting in the dreaded climate change, all these combine to make fossil fuel – based power generator less and less attractive, and the renewable energy resources more and more attractive [5]. Renewable energy sources are, as the name connotes, sources that are constantly available in nature, with little or no prospect of their being extinct. Solar energy is obviously one of those sources. Others are energy derivable from the wind, geothermal, hydrological and biomass [5]. Since electrical energy is the preferred form in which energy is mostly utilized worldwide, solar photovoltaic technology has assumed a pride of place among the renewable energy sources being exploited for use, particularly in rural or isolated communities in the developing world. Apart from the ubiquitous nature of sunshine, other attributes that make solar technology attractive are those exactly opposite to the attribute of fossil fuel devices namely, freedom from pollution or toxic fumes, no waste products, renewable, small scale, modular and scalable, noise-free, maintenance free, easy to install and generally environmentally friendly [5]. This work presents design of solar electricity (PV) system to power UBTH accident and Emergency (A&E) operating theatre. Figure 1 shows, block diagram of the solar electricity (PV) systems and with little or no daily supply of public power, UBTH continue to invest heavily in power generating plants to provide self-sufficient power backup system. In the year 2015, UBTH spent ₦205,503,583.58 on electric energy consumption. 29.66% of this amount was spent on utility power supply, while 70.34% was spent running and maintaining the local generators [3]. These generators are provided in almost all the major load centres and sensitive loads as shown in Table 1. Sensitive loads such as X-ray unit, Oxygen plant, CT scan, Incubators etc are permanently on generators because frequent power outage and poor quality of power supply affect the performance of these equipment. In the operating theatres, generators are usually switched on at the beginning of surgical operation and switched off at the end of the operation due to unreliable power supply [3].

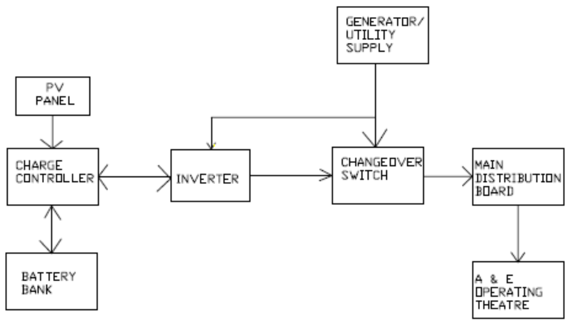

Figure 1: Block diagram of Solar Electricity (PV) system.

The PV panels absorbs solar energy from the sun and converts the energy into direct current (dc). The dc is routed through the charge controller to both the batteries and inverter. The charge controller regulators electrical power going to batteries in order to prevent batteries from over charging that may lead to potential damage. While, the inverter converts the dc to alternating current (ac) to power the load.

Table 2: The capacity, location and place of utilization of generator in UBTH

S/N	CAPACITY	LOCATION	PLACE OF UTILIZATION (ELECTRICAL LOAD)
1	Three (3) 500 kVA	Generator substation at the main hospital	Main hospital complex, Linen, Laundry, CSD, Main Theatre, Renal, Main revenue, X-ray, Engineering, Pathology laboratories and oncology ward, other wards, nursing school and SCBU
2	250 kVA	Generator substation at the Main hospital	Vamed CSSD, Unisterile centre and laundry
3	500 kVA	Generator substation at the Main hospital	General Administration Building
4	318 kVA, 288 kVA	Oba Akenzuwa	Oba Akenzuwa complex, Radiotherapy, IHT, School of Biomedical Engineering, Physiotherapy, Printing press, occupational therapy, DOT centre and COPD
5	Two (2) 500 kVA	Accident and Emergency building	A&E (accident and emergency) complex, CT scan, digital X-ray, A&E operation theatre, systemic ward, orthopedic ward
6	625kVA, 500 kVA	Pumping Station	Pumping station, CHER building, Mental health, Nursing house and mortuary
7	250 kVA	GPC building	GPC, Abuja hostel, Children play centre
8	250 kVA	Account building	Accounts & IPPIS building, main store

2.0 Materials and Method

2.1 Materials

The main components used in PV system design are as follows; see Figure 1

i. Photovoltaic panels
ii. Charged controller
iii. Inverter
iv. Battery bank

Existing components are: changeover switch, main distribution board generator/utility supply and load.

2.2 Methods

Load audit of A&E operating theatre made up of two (2) operating suit was carried out by itemizing all the electrical appliances and their power rating, see Table 3. Then the average daily energy demand in watt-hour was calculated. The average daily demand was used for sizing the PV panels and battery [6]. The number of hours the battery caters for the load is twelve (12) hours. This can be during the day or at night. Provision is also made for the existing standby generator or utility supply to charge the batteries with the aid of inverter and charge controller when the sun is not available or insufficient solar radiation.

Table 3: A&E operating theatre (2 suits) load

S/N	LOAD	QUANTITY	RATING (kW)	TOTAL (kW)
1	OPERATING LIGHTS	4	0.03	0.12
2	GENERAL LIGHTING POINTS	16	0.18	2.88
3	13Amps SOCKET (SPARE)	8	0.30	2.40
4	15Amps SOCKETS (SPARE)	4	0.50	2.00

5	ANEASTESIA MACHINE	4	0.07	0.28
6	X-RAY FILM	4	0.30	1.20
7	PRESSURE REGULATOR	4	0.13	0.52
8	2 HP AIR CONDITIONING SPLIT UNIT AIR	4	4.80	6.0
	Total for (2 suits)			15.40

Table 3, presents the load audit of the two suits, the total in the A&E is about 15.40kW.

2.3 Load demand and energy demand calculation

In load utilization, all loads may not be in operation at the same time, hence diversity factor is applied. Applying diversity factor of 0.8, the total load demand gives:
0.8 x 15.4 kW = 12.32 kW
Energy demand for two suits in operation for twelve (12) hours gives
12.32 kW x 12 hours = 147.84kWh
The symbol and abbreviations used in the PV system design is shown in Table 4.

2.4 Design of Photovoltaic panel

The area of the PV panel that can extract the required power to meet the load demand for any location with a given global horizontal irradiance was calculated from Equation 1 [7].

$$\text{PV area required} = \frac{E_{lday}}{H_{in} \times \gamma_{pv} \times \gamma_{loss} \times K_{derating}} \quad (1)$$

$$\gamma_{loss} = \gamma_{bat} \times \gamma_{inv} \quad (2)$$

$$K_{derating} = K_{temp} \times K_{prod} \times K_{shade} \times K_{dirt} \times \gamma_{wire} \quad (3)$$

$$K_{temp} = 1 + (\gamma \times (T_{cell.eff} - T_{ste})) \quad (4)$$

The required PV output power generated from the PV area, Equation (1), was calculated from Equation (5) [7].

$$PV_{output} = \text{Pv area required} \times PSI \times \gamma_{pv} \quad (5)$$

The number of modules that would provide this PV panel output can be calculated from Equation (6)

$$N_{module} = \frac{PV_{output}}{P_{mpeak}} \quad (6)$$

Using the following data [8].
$\gamma_{bat} = 0.8$, γ_{inv}, = 0.9
γ = - 0.45%/^{oc} =- 0.0045/^{oc}
$T_{cel.eff}$ = 46 ^{oc}, T_{stc} = 25 ^{oc}
$K_{prod} = 1$, $K_{shade} = 0.98$, $K_{dirt} = 0.95$
γ_{wire} =0.95, H_{in} = 5.96 kWh/m^2/day
γ_{pv} = 14.63% = 0.1463
Maximum radiation intensity (PSI) = 1000 W/m^2
Equation (2) gives $\gamma_{loss} = 0.75$
Equation (4) gives
$K_{temp} = 0.9055$
Equation (3) gives
$K_{derating} = 0.80087$
Average energy demand for A & E operation theatre (2 suits) in operation for twelve (12) hours a day = 147.84 kWh
From Equation (1) PV area required is 282.569 m^2
from Equation (5) PV_{output} = 41,339.845, approximately 41,340
Using P_{mpeak} = 300 W

The Equation (6) gives N modules = 137.7966, approximately 140
The number of PV panel require is 140.

2.5 Battery Size selection [8].

Depth of discharge: This is used to measure how much of the total capacity of the battery is being consumed. If a battery delivered 80% of its energy, the D.O.D is 80%.
Battery autonomy (H_{aut}): This is the duration where the battery is able to cater for the load demand without recharging,

E_{lday} = 14784 Wh

$E_{lday} = \frac{14784Wh}{24hr}$ = 616 W

$$B_{size} = \frac{E_{lhr} \times H_{out}}{D.O.D \times \gamma_{out}} \quad (7)$$

Using
H_{aut} = 12 hrs, γ_{out} = 0.4
D.O.D = 0.8, E_{lday} = 6.6 W
∴B_{size} = 23,100 Wh

$$\text{Total number of batteries} = \frac{B_{size}}{B_{out}} = \frac{23{,}100\ Wh}{2{,}400\ Wh} = 9.625 = 10 \quad (8)$$

The ten (10) batteries will give a total capacity of 2,400 x 10 = 24, 000 Wh
Thus, the total number of batteries required to meet the 23,100 Wh for 12 hours autonomy is 9.625 (approximately 10 batteries).

$$\text{Number of batteries in series} = \frac{System\ nominal\ voltage}{battery\ voltage} = \frac{24}{12} = 2 \quad (9)$$

$$\text{Number of batteries in parallel} = \frac{Total\ number\ of\ batteries}{number\ of\ batteries\ in\ series} = \frac{10}{2} = 5 \quad (10)$$

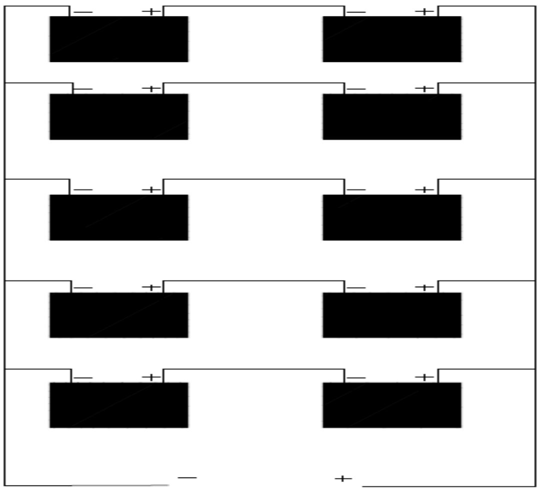

Figure 2: battery bank arrangement

2.6 Inverter selection

The inverter should met all continuous lad and surge demand at any instant. Therefore, an inverter with higher dc voltage is preferred which also reduces the size of wires to be used. The selected inverter for tjis work has 24 V dc input and 80% efficiency [9].

$$\text{Maximum ac load} = = \frac{AC\ load\ (Wh)}{DC\ inpt\ x\ Efficiency} = \frac{23100\ Wh}{24\ x\ 0.8} = 1{,}203\ W \quad (11)$$

An inverter of size 1,500 W was selected

2.7. Cable Design

To ensure a good performance and reliable system, the cables have to be properly sized. The current passing through the cable has to be determined, then the cable area that cable area that would result in minimal voltage drop [8].
In both A.C and dc wiring for standalone PV system the maximum voltage drop should not exceed 3 %. The length of cable should be enough to allow for ease of installation. There should also be some added length to allow for maintenance. For PV installations, the copper cable is used instead of aluminum type because it is more efficient, thinner, flexible and easily joined.
There are three main cable in the PV system: the cable connecting the PV array to the battery bank, the cable connecting the battery bank to the inverter, and the one connecting the inverter to the load.

2.8. Cable between PV array and battery bank

First, the current produced from the module entering the battery bank is calculated from:

$$I_{rated} = N_{mp} \text{ x } I_{sc} \text{ x } F_{safety} \tag{12}$$

Where I_{rated} is the current from the PV module, N_{mp} is the number of modules in parallel, I_{sc} is the short circuit current of the PV module, F_{safety} is Safety Factor (usually taken as 1.25) to give the cable area can be calculated from:

$$A = \frac{\rho l I}{Vd} \text{ x } 2 \tag{13}$$

Where ρ is the resistivity of copper cable (1.724 x 10-8 Ωm), l is length of copper cable, I is the current passing through the cable, V_d is the maximum allowable voltage drop.

Cable between Battery bank and inverter

The current from the battery bank can be calculated from:

$$I_{max} = \frac{P_{inverter}}{\eta_{inv} \text{ x } V_{system}} \tag{14}$$

Where I_{max} is the maximum current drawn from battery bank; $P_{inverter}$ is the inverter power rating and V_{system} is the Voltage of the battery bank.

Cable between Inverter and Load

The current from the inverter drawn from the load can be calculated from:

$$I_{phase} = \frac{P_{inverter}}{V_{output} \text{ x } \sqrt{3}} \tag{15}$$

Where I_{phase} is the phase current flowing to the load, $P_{inverter}$ is the Inverter power rating V_{output} is the output phase voltage.

4.0 Conclusion

There is a wide gap between demand and supply of electricity in Nigeria. To mitigate the electricity crisis and ensure rapid transformation of the sector, Federal Government of Nigeria deregulated the power sector. Generation and Distribution of electricity was substantially transferred to private sector while policy formulation and long term development was left to the Federal Government of Nigeria.
However, this measure did not provide the desired result and with little or no daily supply of public power, UBTH continue to invest heavily on power generating plants to provide self-sufficient power back-up system. In order to reduce the nuisance of noise, thermal and toxic fumes pollution in the hospital, there is need to explore the use of renewable energy sources especially solar technology.

Table 4: Symbol and abbreviations

Symbol	Abbreviations	Symbol	Abbreviations
E_{lday}	Average daily load demand	γ_{pv}	Efficiency of PV module
E_{lhr}	average hourly load demand	γ_{out}	battery output efficiency
H_{aut}	battery hour of Autonomy	B_{size}	battery bank size
B_{single}	capacity of single battery	N_{ms}	Number of modules in series
H_{in}	Global Horizontal Irradiance (kWh/m^2/day)	γ_{pv}	Efficiency of PV module
$K_{derating}$	Factor that accounts for losses due to temperature effect, dirt, PV output, tolerance, shading and wire.	γ_{wire}	Efficiency that accounts for wire loss
K_{dirt}	PV module dirt derating factor	P_{module}	Single module output
K_{prod}	PV module output power tolerance	P_{mpeak}	Peak power of the chosen module
K_{shade}	PV array shading factor	P_{pv}	Total PV array output
K_{temp}	Temperature loss factor	PSI	Maximum radiation intensity at standard test condition
K_{temp}	PV module temperature loss factor	PV_{output}	Power output of the PV array from the PV area.
γ_{bat}	Battery Efficiency	$T_{cell.eff}$	Nominal operating cell Temperature (NOCT) in ^oC
γ_{inv}	Inverter Efficiency	T_{stc}	Cell temperature at standard test condition in ^oC
Symbol	Abbreviations	Symbol	Abbreviations
γ_{loss}	Product of battery and inverter efficiency	V_{module}	Nominal voltage of the module at standard test condition
$N_{modules}$	Number of PV modules or PV panels	V_{system}	Voltage of the system
N_{mp}	Number of modules or PV panels in parallel	γ	Power temperature coefficient per ^oC
H_{aut}	Battery hours of autonomy	D.O.D	Battery depth of discharge

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