

Design of Stand Alone Floating PV System for Ibeno Health Centre

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Abstract: In this paper, electrical energy demand (load) of health centre at Ibeno beach in Akwa Ibom, was estimated based on watt-hour energy demand of the electrical appliances in the health centre. The estimated daily load demand is 35 kWh/day with peak load of 7.735 kW. The sea ambient temperature is about 8% lower than that obtainable on land while the wind speed on sea is about 67% higher than the wind speed on land. The cumulative effect of the lower offshore temperature and higher offshore wind speed is offshore PV cell temperature that is about 18% lower than the PV cell temperature on land. The system is designed with 3 days of autonomy and the resultant load demand will be satisfied by 11.41 kW PV modules and 4765.8Ah battery capacity which amounts to 64 units of the selected PV panels and 24 units of the selected battery.

Keywords: Floating PV, Onshore PV, Offshore PV, Cell Temperature, Renewable Energy

1. Introduction

The sun provides the energy to sustain life in our solar system. In one hour, the earth receives enough energy from the sun to meet its energy need for nearly a year [1, 2, 3, 4]. Harnessing solar energy to power electrical appliances starts by converting the energy from the sun to electricity. Photovoltaic (PV) is the direct conversion of solar energy into electricity. PV systems can be used to exploit the solar energy in almost all applications. With fossil fuel resources expected to be depleted in the years ahead, PV Power systems provide a means of providing electricity and addressing concern for fuel supply security [5, 6, 7, 8].

In recent years, the effort to improve on the energy yield of PV systems has led to the concept of floating PV. Floating PV system is just like any other PV systems, but the PV panel is mounted on top of water with the use of floaters, instead of using the land surface [9, 10, 11]. By doing this, the land is preserved for other important projects. Also, the major advantage of floating PV compare to land PV, is that, when a PV module is mounted on the water surface, it helps in reducing the cell temperature of the PV, hence, improving its efficiency.

In the developing countries, to improve access to electricity in the remote areas, decentralized off-grid extension is

considered especially, the PV power system [12, 13, 14, 15]. Such off-grid PV system uses photovoltaic technology only and are not connected to a utility grid. The system uses the DC output of the PV modules to power AC loads, while a bank of battery is used to store energy for use when there is demand. The DC output of the PV and batteries is usually converted to AC output by an inverter, and the output from the inverter is then used to run AC appliances. Off-grid PV system provides affordable electricity in area where conventional electricity grids are unreliable or non-existing. In this paper, the focus is on the determination of the offshore temperature, wind speed and PV cell temperature, as well as, sizing of off-grid offshore PV system that will be used to power a health facility located at Ibeno beach in Akwa Ibom state of Nigeria.

2. Methodology

First the daily load demand of the health facility to be supplied by the offshore PV power plant is determined. Next, the onshore meteorological data of the Ibeno Beach (site) for the PV system is obtained from NASA website. The offshore meteorological data is determined from the onshore data. The onshore PV cell temperature is determined. Finally, the sizing of the various components of the offshore PV power plant is carried out.

2.1. Load Estimation

The daily load profiles are determined by calculating the

power demand (kWh/day) for all load types in the health centre. The estimated daily energy demand is given in Table 1.

Table 1. Summarized Daily Load Demand Profile Of Health Center At Ibeno Beach.

S/n	Power Consumption	Power (Watts)	Qty	Load (watt x qty)	Hours/day	Load kWh
1	Vaccine Refrigerator/Freezer	100	2	200	24	4800
2	Small Refrigerator (non-medical use)	500	2	1000	5	5000
3	Centrifuge	575	2	1150	2	2300
4	Haematology Mixer	30	1	30	2	60
5	Microscope	15	2	30	5	150
6	Security light	40	9	360	12	4320
7	Other Lighting	20	11	220	7	1540
8	Sterilizer Oven (Laboratory Autoclave)	1564	1	1564	1	1564
9	Incubator	400	1	400	24	9600
10	Water Bath	1000	2	2000	1	2000
11	Communication Equipment Stand-by	2	1	2	18	36
12	Communication Equipment Transmitting	30	1	30	6	180
13	Desktop Computer	200	3	600	5	3000
14	Printer	75	2	150	3	450
Total Per Day				7736		35000

2.2. Meteorological Data

Table 2. Monthly Averaged Daily Insolation Incident On Horizontal Surface (kWh/m²/day).

Lat 4.53°N Lon 7.97°E	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	5.20	5.24	4.80	4.59	4.23	3.54	3.24	3.42	3.43	3.68	4.21	4.95	4.20

Table 3. Minimum, Maximum and Average Daily Temperature (°C).

Lat. 4.53 and Lon. 7.9	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Minimum	24.3	25	25.5	25.7	25.7	24.9	23.8	23.4	23.7	24.3	24.6	24.5	24.58
Maximum	30.2	30.6	30	29.9	29.6	28.2	27.1	27	27.1	27.5	28.4	29.2	28.73

Table 4. Monthly Averaged Wind Speed (m/s)/s.

Lat. 4.53E and Lon. 7.9N	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	3.14	3.35	3.01	2.52	2.46	3.32	4.3	4.54	4	3.05	2.52	2.74	3.24

2.3. Offshore Meteorological Parameters and Floating PV Cell Temperature

For offshore floating PV, the sea temperature and sea wind speed are used to determine the cell temperature of the floating PV modules. The sea temperature (T_w) is given in relation to the air (land) temperature, T_a as [16, 17];

$$T_w = 5.0 + 0.75T_a \quad (1)$$

Where T_w =sea temperature (°C) and T_a =air temperature (°C). In Table 3, the maximum annual temperature is $T_a = 28.73$ °C. Therefore,

$$T_w = 5.0 + .75T_a = 5.0 + .75 \times 28.73 = 26.5^\circ\text{C}, \quad (2)$$

The velocity of wind in the sea is always higher than that on land. The sea wind speed (V_{wSea}) is given with respect to the land wind speed (V_{wLand}) as [18, 19, 20];

$$V_{wSea} = 1.62 + 1.17 * (V_{wLand}) \quad (3)$$

From Table 4, the average land wind speed is 3.24m/s. Then

$$V_{wSea} = 1.62 + 1.17 * 3.24 = 5.4108\text{m/s}$$

PV cell temperature on land is given as [21];

$$T_c = 0.943 * T_a + 0.0195 * G - 1.528 * V_{wLand} + 0.3529 \quad (4)$$

$$T_c = 0.943 * 28.73 + 0.0195 * 1000 - 1.528 * 3.24 + 0.3529 = 43.63218^\circ\text{C}$$

PV cell temperature in the sea is given as;

$$T_{cW} = 0.943 * T_w + 0.0195 * G - 1.528 * V_{wSea} + 0.3529 \quad (5)$$

Where,

T_c = PV cell temperature and $T_w = 26.5^\circ\text{C}$

G = daily averaged irradiance in $\frac{\text{kW}}{\text{m}^2}$ or W/m^2 . From

Table 2, the monthly averaged daily irradiation = 4.2 kWh/m² per day. The irradiance, G is the power per unit area per unit time, where the unit time is one hour. For the case study, STC irradiance of 1000 W/m² will be used. So, the 4.2 kWh/m² gives 4.2 Peak Sun Hours (PSH) per day. Hence.

$$T_{cW} = 0.943 \times 26.5 + 0.0195 \times 1000 - 1.528 \times 5.4108 + 0.3529 = 35.86^\circ\text{C}$$

2.4. Derated Daily Output Energy of Offshore Floating PV Array

Photovoltaic array produces DC electricity in direct proportion to the global solar radiation. Also, performance of PV array depends on derating factors like temperature, dirt and mismatched. Therefore, the daily energy output from the PV array can be calculated as follows [22, 23, 24, 25]:

$$E_{PV} = W_p(f_{dc/ac}) \left(\frac{G}{G_{STC}} \right) [1 + \beta(T_c - T_{STC})] \quad (6)$$

Where;

W_p = Rated capacity of PV array in [kW or watts], meaning power output under (STC);

$f_{dc/ac}$ = DC to AC de-rating factor [%]. In this paper $f_{dc/ac}=0.778$;

G = Solar radiation incident on PV array in [kW/m²];

G_{STC} = Incident radiation under STC of [1 kW/m²=1000W/m²];

β = temperature coefficient of power (%/°C);

T_c = PV cell temperature in current time step (°C);

T_{STC} = PV cell temperature under STC [$T_{STC}=25^\circ\text{C}$].

Given that $f_{temp}=1 + \beta(T_c - T_{STC})$, then;

$$E_{PV} = W_p(f_{dc/ac}) \left(\frac{G}{G_{STC}} \right) (f_{dc/ac})(f_{temp}) \quad (7)$$

For the PV installed offshore (on sea),

$$f_{temp} = 1 - (\beta(T_{cW} - T_{STC})) \quad (8)$$

β = power temperature coefficient. For the module chosen $\beta = 0.48\%/^\circ\text{C}$. Then;

$$f_{temp} = 1 - (0.48\%(35.86 - 25)) = 0.947872$$

2.5. Sizing of the Offshore Floating PV Array

2.5.1. Sizing of PV Array

Let the daily energy demand from the load be denoted as E_L , then, the peak power rating (W_p) of the PV array that will supply the energy E_L is given as;

$$E_{PV} = E_L = W_p \left(\frac{G}{G_{STC}} \right) (f_{dc/ac})(f_{temp}) \quad (9)$$

Hence,

$$W_p = \frac{E_L}{\left(\frac{G}{G_{STC}} \right) (f_{dc/ac})(f_{temp})} \quad (10)$$

$$G = 4.2 \text{ kWh/m}^2, G=1 \text{ kWh/m}^2, E_L = 35 \text{ kWh per day}, \\ f_{dc/ac}=0.778 \text{ and } f_{temp}=0.947872$$

$$W_p = \frac{35}{\left(\frac{4.2}{1} \right) \times 0.778 \times 0.947872} = 11.41 \text{ kW} = 11410 \text{ Watts}$$

The system voltage selected is 48 V dc based on recommendation by Sandia [8]. The ENP Sonne High Quality 180 Watt, 24V monocrystalline module is selected in this design. It has short circuit current I_{sc} (A) of 5.38 A, panel efficiency of 14.1% and power temperature coefficient of -0.480 %/°C.

Number of modules in parallel: Total number of module in parallel (N_m) is given as;

$$N_m = \frac{W_p}{\text{Peak power of each module}} = \frac{11410 \text{ Watts}}{180 \text{ Watts}} = 63.4 \approx 64 \text{ modules} \quad (11)$$

Number of modules in series: Total number of module series (N_{ms}) is given as;

$$N_{ms} = \frac{\text{system dc voltage}}{\text{module voltage}} = \frac{48}{24} = 2 \text{ modules} \quad (12)$$

Number of modules in parallel: Total number of module parallel (N_{mp}) is given as;

$$N_{mp} = \frac{N_m}{N_{ms}} = \frac{64}{2} = 32$$

2.5.2. Sizing of the Battery Bank Capacity

The storage battery capacity can be calculated using equation [26, 27, 28]:

$$C_X = \frac{N_c \times E_L}{DOD_{max} \times V_b \times \eta_{out}} \quad (13)$$

C_X = Required battery capacity in Ah

N_c = Number of days of autonomy = 3

E_L = Estimated load energy in Wh = 35kWh = 35000 Wh

DOD_{max} = Maximum depth of discharge = 0.60;

$\eta_{Bat}=0.85$; $\eta_{inv}=0.9$

η_{out} = battery efficiency (η_{bat}) x inverter efficiency (η_{inv}) = 0.765

V_b = battery nominal voltage = 48 V.

$$C_X = \frac{N_c \times E_L}{DOD_{max} \times V_b \times \eta_{out}} = 4765.8 \text{ Ah} \quad (14)$$

The battery selected is Rolls Series 4000 Deep Cycle batteries, T12 250, having the following characteristics, a capacity of 200Ah, and a voltage of 12Vdc.

$$\text{number of batteries required } (N_{BR}) = \frac{\text{battery storage capacity}}{\text{Rated capacity}} = \frac{4765.8 \text{ Ah}}{200 \text{ Ah}} = 23.829 \text{ units}$$

$$\text{number of battery in series } (N_{BS}) = \frac{\text{system voltage}}{\text{battery voltage}} = \frac{48}{12} = 4 \text{ units}$$

$$\text{number of battery in parallel } (N_{BP}) = \left\lceil \frac{\text{bnumber of batteries required}}{\text{number of battery in series}} \right\rceil = \left\lceil \frac{23.829}{4} \right\rceil = 6$$

Hence,

$$N_{BR} = N_{BS} \times N_{BP} = 6 \times 4 = 24 \text{ batteries}$$

2.5.3. Sizing of Inverter

In sizing the inverter, the actual power drawn from the appliances that will run at the same time must be determined as first step which in this case is 18KW. Secondly, we must consider the starting current of large motors by multiplying their power by a factor of 3. Also to allow the system to expand, we multiply the sum of the two previous values by 1.25 as a safety factor [26, 27]:

$$P_{inv} = (P_{RS}) \times 1.25, \quad (15)$$

P_{inv} =Inverter power rating

P_{RS} =Power of appliances running simultaneously

$P_{LSC} = 7.736 \text{ kw}$ daily peak load

$$P_{inv} = (P_{RS}) \times 1.25 = 7.736 \times 1.25 = 9.67 \text{ kW}$$

The inverter to be used for this system should have capacity not less than 9.67kW and a nominal voltage of 48V

2.5.4. Sizing of the Regulator

The voltage regulator is typically rated against amperage and voltage capacities. The voltage regulator is selected to match the voltage of PV array and batteries. A good voltage regulator must have enough capacity to handle the current from PV array. The rated current of the regulator is given by [8, 26, 27, 28];

$$I_{rated} = N_{mp} \times I_{sc} \times f_{safety} \quad (16)$$

$$N_{mp} = \text{number of PV modules in parallel} = 32$$

$$I_{sc} = \text{short circuit current of PV modules} = 5.38 \text{ A}$$

In paper, the safety factor, $f_{safety} = 1.25$ [26, 27, 28];

$$I_{rated} = 32 \times 5.38 \times 1.25 = 215.2 \text{ A}$$

The charge controller selected in the design is Xantrex C-60, 24 V, 60 A [28]. Let I_{reg} be the ampere rating of each regulator (For Xantrex C-60, $I_{reg}=60$). Then the number of regulators required is N_{reg} where;

$$N_{reg} = \frac{I_{rated}}{I_{reg}} = \frac{215.2}{60} = 3.587 \approx 4$$

3. Results and Discussion

The results of the numerical computations of the Offshore PV system are presented in the tables 5 and 6. From the results in Table 5, the maximum onshore water temperature is 26.50°C which is about 92% of the onshore ambient temperature. So, the water temperature provides ambient temperature that is about 8% lower than that obtainable on land. Also, the wind speed on sea is about 167% of the wind speed on land. The lower offshore water temperature and higher offshore wind speed ensured that the PV cell temperature is about 18% lower than the PV cell temperature on land.

The sizing calculation result (Table 6) for the offshore PV system shows that the daily load demand of 35 kWh per day with peak load of 7.735 kW will be satisfied by using 11.41 kW PV modules. For the selected ENP Sonne High Quality 180 Watt, 24V monocrystalline PV module, a total of 64 units of the PV panels is required; 2 in series and 32 in parallel. The system is designed to supply power for at least three days in such cases when there is no solar radiation. With three days of autonomy, the required battery capacity is 4765.8Ah. For the selected battery, 200Ah, 12VDC Rolls Series 4000 Deep Cycle batteries, T12 250, a total of 24 units of the battery is required; 4 in series and 6 in parallel. 9.67 kW capacity inverter is required along with 215.2 A capacity charger controllers/ regulators. For the selected regulator, Xantrex C-60, 24 V, 60 A, four units are required.

Table 5. Design parameter and component sizing.

Description of Parameter	Onshore (on Land)	Offshore (on Sea)	Normalised With Respect to Onshore Data	
			Onshore (on Land) (%)	Offshore (on Sea) (%)
Maximum Average Daily Temperature (°C)	28.73	26.50	100	92
Monthly Averaged Wind Speed (m/s)	3.24	5.41	100	167
PV cell temperature (°C)	43.63	35.86	100	82

Table 6. Design parameter and component sizing.

S/N	Component	Description of Parameter	Result
1	Load Estimation	Total Estimated Load	35 kW/day
		Peak Load	7.736 kW
2	System DC Voltage		48 V
		Capacity Of PV	11.41 kW
3	PVArray (ENP Sonne High Quality 180 Watt, 24V monocrystalline PV module)	Modules In Series	2
		Modules In Parallel	32
		Total Number Of Modules	64
4	Days of autonomy		3
5	Battery Bank (200Ah, 12VDC Rolls Series 4000	Battery Bank Capacity	4765.8Ah

S/N	Component	Description of Parameter	Result
	Deep Cycle batteries, T12 250)	Number Of Battery In Series	4
		Number Of Battery In Parallel	6
		Total Number Of Battery Required	24
6	Inverter	Capacity Of Inverter	9.67 kW
7	Regulator (Xantrex C-60, 24 V, 60 A)	Capacity Of Regulator	215.2A
8	Number Of Regulators	Capacity Of Each Of The Selected Regulator 60A	4

4. Conclusions

In this paper, the sizing of offshore PV power system for a health facility is presented. The electrical energy (load) demand of the Health Centre at Ibeno Beach in Akwa Ibom is estimated at 35kWh/ day. The onshore air temperature and wind speed are used to determine offshore ambient temperature and wind speed for the offshore PV system sizing. In all, the offshore ambient temperature is lower than the onshore and the offshore wind speed is much higher than the onshore wind speed. The cumulative effect of the lower offshore temperature and higher offshore wind speed is lower PV cell temperature and the resultant higher energy yield. The detailed used to determine the offshore PV system component sizes are presented and discussed.

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