



Sizing Computations for Stand Alone Solar Power System for the Office Complex in the Department of Electrical / Electronic Engineering IMSU Owerri

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Abstract: In this paper, the sizing of a standalone solar power system for an office complex was presented. The focus of the paper was the presentation of analytical models and procedure that will facilitate automation of the sizing parameters computations with the use of computer program. Accordingly, the logically ordered analytical expressions for the sizing of sample standalone solar power system for the office complex in the department of Electrical / Electronic Engineering (IMSU) Owerri was presented based on the daily load demand of the electrical appliances in the department. The sample sizing computation results showed that the case study office complex located at the latitude and longitude of 5.508056 and 7.042076 respectively had a daily energy demand of 55.97 kWh/day and daily peak sun hours of 4.72 hours per day. In all, a total of 110 Despasol, DEP 150 M silicon monocrystalline 150 watts solar panels were used along with 16 Viforce 12 Volt 200 AH deep cycle batteries. The solar panel and batteries were selected to satisfy the needed 16.5 kW solar power and battery bank capacity of **3110.86 Ah**. The mathematical expressions and procedure presented in this paper will make it easier for individuals to clearly understand and automate the sizing of a standalone solar power systems.

Keywords: Solar, photovoltaic, load demand, peak sun hour, solar radiation, peak power, derating factor

I. Introduction

As the need for renewable and environmentally friendly power generation system increases, there is also the need to develop a clearer understanding of the system operation and component selection to meet any given situation and load demand [1,2,3,4,5,6,7,8]. Most often, designers that are using off-the-shelf simulation software for sizing renewable energy system such as solar photovoltaic power systems are confused about certain parameters used in the simulation and how the parameter values were obtained [9,10,11, 12]. In this case, it makes it difficult for the designer to take well-informed decisions as regards the selection of the system component sizes.

Consequently, it is recommended that simple and easy to use procedures and computation approaches should be provided for designers to help them in understanding the system sizing. Also, such software can be used in the validation of the system sizing parameter values obtained from the off-the-shelf simulation software. Accordingly, in this paper, logically arranged analytical expressions are presented for sizing a standalone solar PV system for an office complex. The case study site selected is the office complex of the Department of Electrical / Electronic Engineering in Imo State University (IMSU) Owerri. The daily load demand data, as well as meteorological data of the complex site, are provided along with the detailed mathematical expressions that are used to determine the system components parameter values. Based on the calculated components parameters values, sample actual system components were selected and the summary of the computation results and selected system components were listed for the office complex.

II. The Daily Load Demand Profile

The daily load demand profile of the offices and classrooms of the case study site is determined by computing the daily energy demand of the electrical appliances in the department. The daily energy demand profile is given in Table 1 from where it is observed that the daily load demand $E_l = 55.97$ kWh/day.

Table 1 The daily load profile of the appliances in the Department of Electrical / Electronic Engineering offices and classrooms

S/N	Appliance	Rated Power (W)	Quantity	Total Power (kW)	Number of hours of use per day (h)	Daily load demand, E_l (kWh/day)
1	Fan : Ceiling Fan	55	30	1.65	8	13.2
2	Lighting Bulbs	15	40	0.6	8	4.8
3	Lighting Bulbs	20	20	0.4	8	3.2
4	Electric Kettle	2500	1	2.5	0.5	1.25
5	Desktop Computer	125	3	0.375	8	3
6	Laptop Computer	65	36	2.34	8	18.72
7	Refrigerator	200	2	0.4	8	3.2
8	Photocopy Machine	1200	1	1.2	2	2.4
9	Water Dispenser	500	1	0.5	8	4
10	Satellite Receiver	25	2	0.05	8	0.4
11	Printer	165	2	0.33	4	1.32
12	Scanners	60	2	0.12	4	0.48

			Total	10.465		55.97
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III. The Solar Radiation Data For The Case Study Site

The site has latitude, longitude and altitude of 5.508056, 7.042076 and 89.1 m respectively. The monthly average solar radiation in Peak Sun Hours (PSH) incident on the horizontal plane for the case study site is shown in Figure 1. The values are obtained from the NASA portal [13].

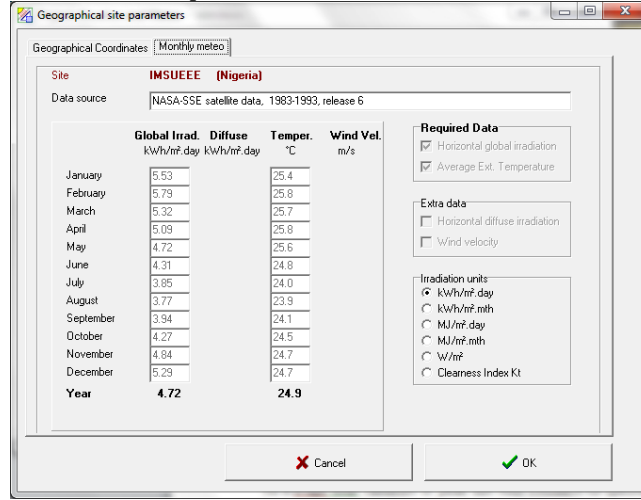


Figure 1 The daily Peak Sunshine Hours (PSH) of the case study site based on global solar radiation incident on the horizontal plane

For optimal power production from the solar power, the solar radiation incident at optimal tilt angle of the yearly fixed solar panel is preferred where the optimal tilt angle, β_{opt} is given in respect of the latitude of the site as [14, 15, 16];

$$\beta_{opt} = 3.7 + 0.69 |\phi| \quad (1)$$

where ϕ is the latitude of the site. For the latitude of 5.508056, the optimal tilt angle is

$$\beta_{opt} = 3.7 + 0.69 |5.508056| = 7.5005 \approx 8^\circ$$

Now, if global irradiation on horizontal plane is denoted as $G(\beta)$ with angle denoted as β and the global irradiation on the optimally tilted plane is $G(\beta_{opt})$, then $G(\beta_{opt})$ can be computed thus (Anyanime, Mbetobong, Emmanuel, 2016; Aggarwal 2013; Ahmad, Tiwari, 2009);

$$\frac{G(\beta)}{G(\beta_{opt})} = 1/T_f = 1 + [4.46(10^{-4})(\beta - \beta_{opt})] - [1.19(10^{-4})(\beta - \beta_{opt})^2] \quad (2)$$

Where $\beta = 0^\circ$ since it is the angle for the horizontal plane. Meanwhile, $\frac{G(\beta)}{G(\beta_{opt})}$ is called the transposition factor ($1/T_f$) and with an optimal tilt angle of 8° and $\beta = 0^\circ$, then T_f gives;

$$1/T_f = 1 - 0.003568 - 0.07616 = 0.988816 = 1.011310496593906$$

Then, from Figure 1 $G(\beta) = 4.72$ hours per day, so, from equation 2,

$$G(\beta_{opt}) = T_f(G(\beta)) = 1.011310496593906(4.72) = 4.77 \text{ hours per day}$$

IV. Sizing of the Solar Power system

A. Sizing of the PV Array

The output power, P_{pva} of the PV array is determined as

$$P_{pva} = \frac{E_l}{(\eta_i)(\eta_c)(f_{dl})(PSH)} \quad (3)$$

Where η_i is the inverter efficiency ($\eta_i = 0.90$), η_c is the charge controller efficiency ($\eta_c = 0.90$), f_{dl} are cumulative dirating factors ($f_{dl} = 0.88$), PSH is the peak sunshine hours in hours/day and E_l is the estimated daily load demand which for the case study, in Table 1, $E_l = 55.97$ Kwh/day. Annual average value of PSH is used and it is 4.72 hours per day for horizontal incident radiation and 4.76 hours per day for the optimally tilted plane. Hence, for the optimally tilted plane the output power, P_{pva} becomes;

$$P_{pva} = \frac{55.97}{(0.9)(0.9)(0.88) 4.76} = 16.5 \text{ kW} \quad (4)$$

B. Determine the number of solar panel in series

The number of solar panel in series, denoted as N_{pvs} is given as

$$N_{pvs} = \frac{V_{sys}}{V_{pv}} \quad (5)$$

Where V_{sys} is the system line voltage and V_{pv} is the nominal voltage of each solar panel. Hence, for the case study, using $V_{sys} = 24 \text{ V}$ and $V_{pv} = 14 \text{ V}$, gives;

$$N_{pvs} = \frac{V_{sys}}{V_{pv}} = \frac{24}{14} = 1.714285714285714 \approx 2$$

C. Determine the number of solar panel in parallel

The selected solar panel is the Depasol, DEP 150 M silicon monocrystalline solar panel with the following key features: Manufacturer: Depasol; Model: DEP 150 M; Rated power: 150 watts; Rated voltage: 14V; V_{mpp} : 17 V and Module area 1.246 m^2 . The number of solar panel in parallel, denoted as N_{pvp} is given as

$$N_{pvp} = \frac{P_{pva}}{N_{pvs}(P_{pv})} \quad (6)$$

Where P_{pva} is the output power of the PV array and V_{pv} is the output power of each solar panel. Hence, for the case study, using $P_{pva} = 16.5 \text{ kW} = 16600 \text{ W}$ and $P_{pv} = 150 \text{ W}$, gives;

$$N_{pvp} = \frac{16600}{2(150)} = \frac{16600}{(300)} = 55$$

D. Determine the battery bank capacity

The battery bank capacity, C_{ba} is given as

$$C_{ba} = \frac{(E_l) n_a}{(\eta_{ba})(DOD_{max})(V_{sys})} \quad (7)$$

η_{ba} is the battery efficiency = 0.85; n_a is the number of days of autonomy = 5 days; E_l is the estimated load energy in Wh = 16500 Wh; DOD_{max} is the maximum depth of discharge = 50% and V_{sys} is the system line voltage = 24 V

$$C_{ba} = \frac{(16500)5}{(0.85)(0.65)(48)} = 3110.86 \text{ Ah}$$

The Mercury 12V - 200Ah SMF deep cycle battery is selected.

F. Determine the number of batteries in the battery bank

The number of batteries in the battery bank, denoted as N_b is given as;

$$N_b = \frac{C_{ba}}{C_b} \quad (8)$$

Where C_{ba} is the battery bank capacity and C_b is the capacity of each battery. Hence, for the case study, using

$C_{ba} = 3110.86 \text{ Ah}$ and $C_b = 200 \text{ Ah}$, gives;

$$N_b = \frac{C_{ba}}{C_b} = \frac{3110.86}{200} = 15.55 \approx 16$$

G. Determine the number of batteries in series

The number of batteries in series, denoted as N_{bs} is given as;

$$N_{bs} = \frac{V_{sys}}{V_b} \quad (9)$$

Where V_{sys} is the system line voltage and V_b is the nominal voltage of each battery. Hence, for the case study,

using $V_{sys} = 48 \text{ V}$ and $V_b = 12 \text{ V}$ gives;

$$N_{bs} = \frac{V_{sys}}{V_b} = \frac{48}{12} = 4$$

H. Determine the number of batteries in parallel

The number of batteries in parallel, denoted as N_{bp} is given as;

$$N_{bp} = \frac{N_b}{N_{bs}} \quad (10)$$

Where N_b is the number of batteries in the battery bank and N_{bs} is the number of batteries in series. Hence, for the case study, using $N_b = 116$ and $N_{bs} = 4$, gives;

$$N_{bp} = \frac{N_b}{N_{bs}} = \frac{16}{4} = 4$$

The selected battery is the Viforce 12 Volt 200 AH deep cycle battery with the following features: voltage: 12 Volt; amperage: 200 AH; battery chemistry: SLA, AGM; battery dimensions of 20.75 in x 8.11 in x 8.43 in and weight: 52kg

V. The Summary of the system components and their parameters

The summary of the solar power system components and the relevant parameter values are given as follows:

- 1) The daily load demand 55.97 kWh/day
- 2) The site latitude, longitude and altitude 5.508056, 7.042076 and 89.1 m respectively
- 3) The optimal tilt angle = 8°
- 4) The transposition factor on the optimal tilt plane = 1.011310496593906
- 5) The early average PSH for solar radiation of the horizontal plane = 4.72 h/day
- 6) The early average PSH for solar radiation of the optimally tilted plane = 4.77 h/day
- 7) The PV array peak output power = 16.5 kW
- 8) The system line voltage = 24 V

- 9) The selected solar panel is the Depasol , DEP 150 M silicon monocrystalline solar panel with the following key features
 - a) Manufacturer: Depasol
 - b) Model : DEP 150 M
 - c) Rated power: 150 watts
 - d) Rated voltage: 14V
 - e) Vmpp : 17 V
 - f) Module area $1.246 m^2$
- 10) The nominal voltage of each solar panel =12 V
- 11) The number of solar panel in series = 2
- 12) The number of solar panel in parallel = 55
- 13) The output power of each solar panel = 150 watts
- 14) The selected battery is the Viforce 12 Volt 200 AH deep cycle battery with the following features;
 - a) Voltage: 12 Volt
 - b) Amperage: 200 AH
 - c) Chemistry: SLA, AGM
 - d) Battery Dimensions:
 - e) 20.75 in x 8.11 in x 8.43 in
 - f) Weight: 52kg
- 15) The battery bank capacity = 3110.86 Ah
- 16) The number of batteries in the battery bank = 16
- 17) The number of batteries in series = 4
- 18) The number of batteries in parallel = 4

VI. Conclusion

The sizing of a standalone solar power system for an office complex is presented. The presentation is targeted at automation of the sizing parameters computations with the use of computer program. As such, the logically ordered analytical expressions for the sizing of the standalone solar power system for the office complex in the department of Electrical / Electronic Engineering (IMSU) Owerri was presented based on the daily load demand of the electrical appliances in the department. The case study site provided requisite data for sample numerical computation of the sizing parameters. Moreover, the computation results provided values that served as a guide in the selection of actual system components. However, the presentation so far has not considered the detailed loss factors and system performance analysis. These are recommended as issues for further studies.

VII. References

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