Sizing Of PV Array And Battery Bank Of An Off-Grid Solar Power System For A Health Facility With 3-Priority Load Categories

Hope Linus Edet[1]
Department of Electrical/Electronic Engineering,
University of Uyo, Akwa Ibom, Nigeria

Akaninyene Bernard Obot[2]
Department of Electrical/Electronic Engineering,
University of Uyo, Akwa Ibom, Nigeria
akaninyeneobot@uniuyo.edu.ng

Nseobong Okpura[3]
Department of Electrical/Electronic Engineering,
University of Uyo, Akwa Ibom, Nigeria

***Abstract*— Sizing of PV array and battery bank of an off-grid solar power system for a health facility with 3-priority load categories is presented. The health facility is located in Eket, Akwa Ibom State, and it is located at latitude of 4.6370226 and longitude of 7.919093 with total load is 333.8 kWh per day. The study considered the effect of varying the days of power autonomy on the PV system while keeping the peak sun hour (PSH) constant. The results showed that the battery units increased from 260 at 1 day of power autonomy to 1810 at 7 days of power autonomy while the PV array is not affected. Again, the normalized missing energy dropped from 4.7 % at 1 day power autonomy to 4 % at 7 days power autonomy whereas the normalized unused energy increased from 25.6 5 at 1 day power autonomy to 35.8 % at 7 days power autonomy. On the other hand, the PV modules decreased from 728 at PSH of 4.901 to 562 at PSH of 6.82 while the days of power autonomy is 3. The variation in PSH does not affect the battery bank. In all, the results showed that increasing the days of power autonomy increases the battery bank capacity and number of battery units required while the PV array is not affected. On the other hand, increasing the solar radiation decreases the PV array power and number of PV modules required while the battery bank is not affected.**

Keywords*— *PV array Sizing, loss of load, battery bank sizing, off-grid solar power system, prioritized load

1. Introduction

In recent time years, solar power system has gained much attention as the dominant alternative energy in the Nigeria and beyond [1,2,3]. This has been occasioned by the solar radiation and sunshine hours in Nigeria that are suitable for large scale solar energy harvesting [4,5]. In addition the rising cost of energy from the national grid coupled with poor access to the national grid in remote locations across Nigeria has prompted the adoption of alternative energy to the grid source [6,7].

In practice, solar power system designers normally adopt strategies to minimize cost or required area of installation while satisfying the load demand [8,9]. For off-grid solar power systems, the key components are the battery bank and the PV array [10,11]. The bigger the PV array, the larger the area required whereas more days of power autonomy may require more storage capacity [12,13]. Hence, PV system designers always use analytical models or simulation software to determine the PV array and battery bank capacity required for any given load demand [14,15]. In this study, the focus is to evaluate the impact of varying the solar radiation data and the days of power autonomy on the PV array and the battery bank. The outcome of the study will assist PV designers in making informed decision on the choice of days of power autonomy and solar data for sizing their PV power systems.

2. Methodology

2.1 The case study facility site and the load demand profile

The research considered a solar power for a health facility, in Eket, Akwa Ibom State, and it is located at latitude of 4.6370226 and longitude of 7.919093 shown in Figure 1. The hospital's electrical load is categorized into three different priority levels. The first level or priority 1 is for those loads that must be powered following their load demand specifications and without any power outage. The lowest level or priority 3 loads are those loads that will be powered when there is sufficient energy supply such that powering those priority 3 loads will in no way affect the power supply to the other two higher priority levels 1 and 2. In operation, the priority 2 loads are needed to be powered but if there is shortfall in energy supply even after the priority level 2 loads are powered down, then the priority 2 load can be powered down to ensure that the priority level 1 loads are not affected.

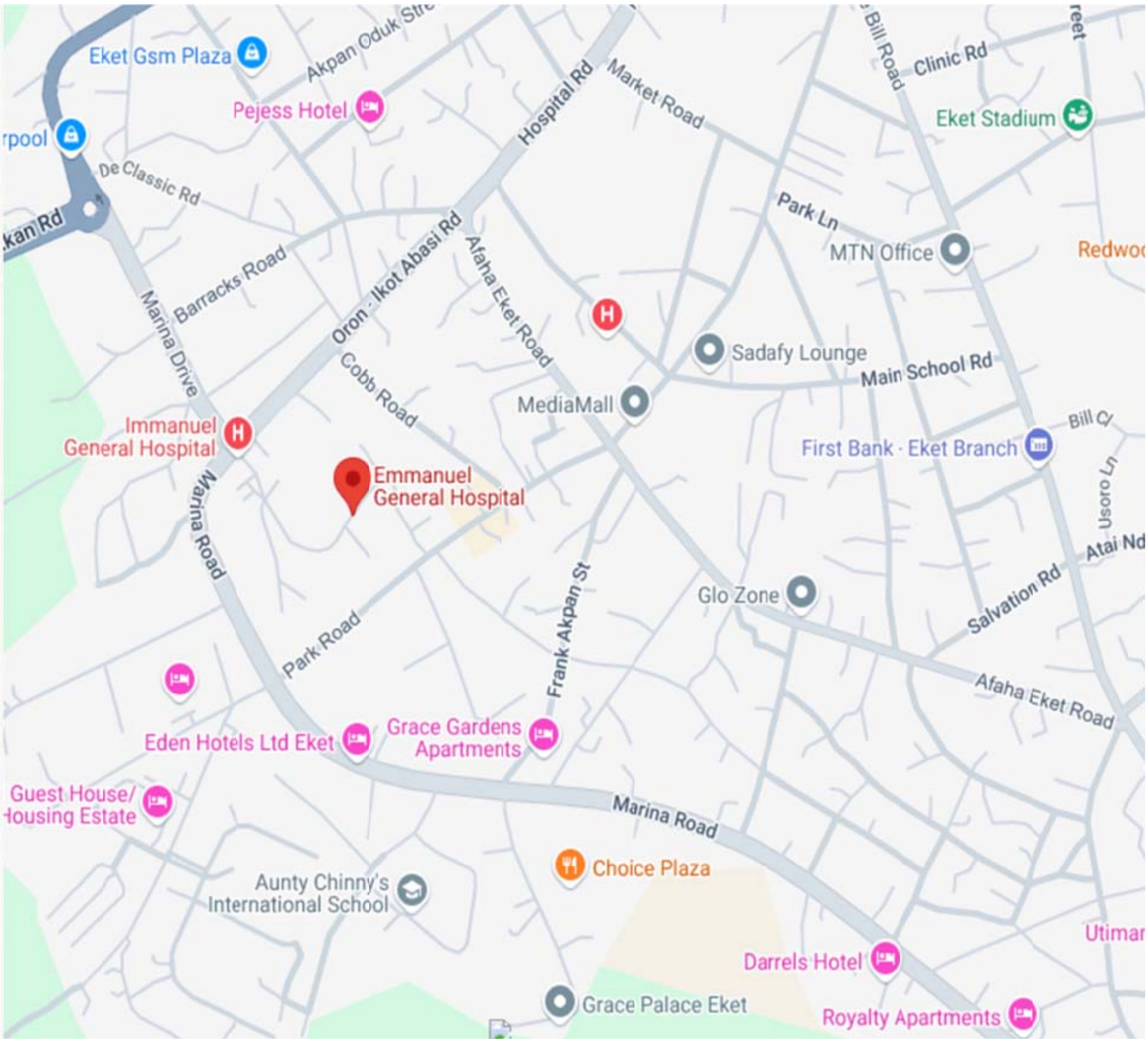

Figure 1 The map location of the case study health facility, Immanuel General Hospital (Eket) in Akwa ibom State

The case study health facility has three priority levels for the various electrical load in its load demand profile. The three load priorities are presented separately and then the summary of the total load is presented in another table. Specifically, the desired load demand and load priority level assignments to the various load categories are presented as shown in Table 1, Table 2, Table 3 and Table 4.

Table 1 Priority 1 Load Profile

S/N	Appliance Description	Load Priority	Qty.	Rated Power (Watts)	Number of Hours Operated	Total Power (Watts)	Total Energy in Wh per day	Total Energy in kWh per day
1	Blood bank Fridge	1	3	50	24	150	3600	3.6
2	Vaccine Fridge	1	3	80	24	240	5760	5.76
3	Microscope	1	2	15	10	30	300	0.3
4	Operating Lamp	1	3	125	10	375	3750	3.75
5	Hematology Mixer	1	3	28	10	84	840	0.84
6	Incubators	1	4	400	24	1600	38400	38.4
7	Curing light	1	2	90	10	180	1800	1.8
8	Microwave	1	2	700	10	1400	14000	14
9	Medical Centrifuge	1	2	578	10	1156	11560	11.56
10	Washing Machine	1	2	450	24	900	21600	21.6
11	Syringe Pumps	1	2	600	2	1200	2400	2.4
12	Lighting	1	15	100	24	1500	36000	36
13	Air conditioners	1	3	746	24	2238	53712	53.712
14	Drier	1	1	500	24	500	12000	12
15	PC and Printer	1	2	120	24	240	5760	5.76
16	Ceiling Fan	1	4	100	12	400	4800	4.8
				Priority 1	Sub Total	12,193.0	216282	216.282

Table 2 Priority 2 Load Profile

S/N	Appliance Description	Load Priority	Qty.	Rated Power (Watts)	Number of Hours Operated	Total Power (Watts)	Total Energy in Wh per day	Total Energy in kWh per day
17	TV	2	2	50	24	100	2400	2.4
18	Ceiling Fan	2	6	100	12	600	7200	7.2
19	Blood bank Fridge	2	1	50	24	50	1200	1.2
20	Vaccine Fridge	2	1	80	12	80	960	0.96
21	Microscope	2	1	15	8	15	120	0.12
22	Operating Lamp	2	2	125	8	250	2000	2
23	Hematology Mixer	2	1	28	8	28	224	0.224
24	Incubators	2	1	400	8	400	3200	3.2
25	Curing light	2	1	90	8	90	720	0.72
26	Microwave	2	1	700	8	700	5600	5.6
27	Medical Centrifuge	2	1	578	8	578	4624	4.624
28	Washing Machine	2	1	450	8	450	3600	3.6
29	Syringe Pumps	2	1	600	4	600	2400	2.4
30	Lighting	2	22	100	12	2200	26400	26.4
31	Air conditioners	2	2	746	6	1492	8952	8.952
32	Drier	2	1	500	3	500	1500	1.5
33	PC and Printer	2	1	120	6	120	720	0.72
				Priority 2	Sub Total	8,253.0	69420	69.42

Table 3 Priority 1 Load Profile

S/N	Appliance Description	Load Priority	Qty.	Rated Power (Watts)	Number of Hours Operated	Total Power (Watts)	Total Energy in Wh per day	Total Energy in kWh per day
34	TV	3	2	50	24	100	2400	2.4
35	Ceiling Fan	3	4	100	12	400	4800	4.8
36	Blood bank Fridge	3	1	50	24	50	1200	1.2
37	Vaccine Fridge	3	1	80	12	80	960	0.96
38	Microscope	3	1	15	8	15	120	0.12
39	Operating Lamp	3	2	125	8	250	2000	2
40	Hematology Mixer	3	1	28	8	28	224	0.224
41	Incubators	3	1	400	8	400	3200	3.2
42	Curing light	3	1	90	8	90	720	0.72
43	Microwave	3	1	700	8	700	5600	5.6
44	Medical Centrifuge	3	1	578	8	578	4624	4.624
45	Washing Machine	3	1	450	8	450	3600	3.6
46	Syringe Pumps	3	1	600	4	600	2400	2.4
47	Lighting	3	10	100	12	1000	12000	12
48	Air conditioners	3	1	746	6	746	4476	4.476
49	Drier	3	1	500	3	500	1500	1.5
50	PC and Printer	3	1	120	6	120	720	0.72
				Priority 3	Sub Total	6,107.0	48144	48.144

Table 4 Summary of the Load Profile of the Three Priority load Categories

S/N	Total Power (Watts)	Total Wh per day	Percentage of the Grand Total Energy (%)
Priority 1	12,193.0	216,282.0	64.8
Priority 2	8,253.0	69,420.0	20.8
Priority 3	6,107.0	48,144.0	14.4
All the loads	**26,553.0**	**333,846.0**	**100.0**

According to the load demand profile in Table 4, the total load is 333.8 kWh per day which is consumed by 26.553 kW power demand. The priority 1 load has power demand of 12.193 kW which is about 45.9 % of the total power demand. However, in terms of daily energy demand, the priority 1 has total of 216.282 kWh demand per day which is about 64.8 % of the daily energy demand.

Similarly, the priority 2 load has power demand of 8.253 kW which is about 31.1 % of the total power demand. However, in terms of daily energy demand, the priority 2 has total of 69.4 kWh demand per day which is about 20.8 % of the daily energy demand. Equally, the priority 3 load has power demand of 6.107 kW which is about 23.0 % of the total power demand. However, in terms of daily energy demand, the priority 3 has total of 48.144 kWh demand per day which is about 14.4 % of the daily energy demand.

2.2 THE SIZING OF THE STANDALONE SOLAR POWER SYSTEM

2.2.1 MODEL THE ENERGY YIELD OF THE SOLAR PANEL IN EACH DAY, K IN A YEAR

The energy yield of the solar panel in day k, $E_{ylddav(\mathrm{k})}$ is computer as expressed in Equation 1;

$$E_{ylddav(\mathrm{k})} = W_{pvarray}\left(PSH_{(k)}\right)\left[\left(f_{dc/ac}\right)\left(\mathrm{f_{temp}}\right)\right] \quad (1)$$

Where $W_{pvarray}$ is the rated power of the PV array, $0<\mathrm{f_{temp}} \leq 1$ and $0<f_{dc/ac} \leq 1$ and $PSH_{(k)}$ is the peak sun hour in day k given in Equation 2 as;

$$PSH_{(k)} = \frac{G_{(k)}}{G_{STC}} = \frac{G_{(k)}}{1\ \mathrm{kW/m2}} \quad (2)$$

Then, de-rating factor due to cell temperature, $\mathrm{f_{temp(k)}}$ is computer as expressed in Equation 3;

$$\mathrm{f_{temp(k)}} = 1 + \beta\left(T_{c(k)} - 25\right) \quad (3)$$

Where the day k cell temperature, $T_{C(k)}$ is is computer as expressed in Equation 4;

$$T_{c(k)} = T_{a(k)} + \left(\frac{NOCT-20}{800}\right) G_{(k)} \quad (4)$$

where $T_{a(k)}$ is the day k atmospheric temperature in °C; $G_{(k)}$is the day k the solar radiation in W/m^2 and NOCT denotes nominal operating cell temperature.

2.2.2 SIZING OF THE PV ARRAY

Let the full load daily energy demand be E_{fLd} and the fraction used for the sizing be δ_{fLd}, Hence, the daily energy demand used for the sizing is E_{lddmnd}, where the PV array wattage that can deliver the required E_{lddmnd} is computed using Equation 5;

$$W_{pvarray} = \frac{E_{lddmnd}}{(PSH)\left(f_{dc/ac}\right)\left(\mathrm{f_{temp}}\right)} \quad (5)$$

Where PSH denotes the peak sun hour used, $\mathrm{f_{temp}}$ denotes the de-rating factor based on temperature, and the two parameters, PSH and $\mathrm{f_{temp}}$ are analytically determined for a given value of $G_{(k)}$ = Gref and $T_{a(k)} = TaRef$. The E_{lddmnd} is given in Equation 6 as;

$$E_{lddmnd} = E_{fLd}\left(\delta_{fLd}\right) \quad (6)$$

Let the power rating of each PV module be denoted as W_{pv}, then if W_{pv} is individual PV panel power rating, then, the required number of PV panels given as N_{pvT} and it is computed using 7;

$$N_{pvT} = \left\lceil \frac{W_{pvarray}}{W_{pv}} \right\rceil \quad (7)$$

Where ⌈.⌉ denoted rounding up to higher integer. Let V_{syt} and V_{pv} be the system nominal voltage and PV panel voltage respectively, then the number of series $\left(N_{pvS}\right)$ and parallel $\left(N_{pvP}\right)$ connected PV panels given as follows;

$$N_{pvS} = \frac{V_{syt}}{V_{pv}} \quad (8)$$

$$N_{pvP} = \frac{N_{pvT}}{N_{pvS}} \quad (9)$$

2.2.3 SIZING OF THE BATTERY BANK

The capacity of the battery bank, C_{batBnk} in Ah is computed based on E_{lddmnd}, the DoD (which is depth of discharge),, η_{bat} (which is the efficiency of the battery). Dy_{aut} (denotes days of autonomy) and V_{bat} (denotes the voltage of the battery). The value of C_{batBnk} is determined using Equation 10;

$$C_{batBnk} = \frac{\left(E_{lddmnd}\right)\left(Dy_{aut}\right)}{(\mathrm{DoD})\left(V_{bat}\right)\left(\eta_{Bat}\right)} \quad (10)$$

With the capacity of each battery unit as Cap_{bat}, then the number of series $\left(N_{batS}\right)$ and parallel $\left(N_{batP}\right)$ connected batteries in the battery bank are computed as given in Equations 11 and 12 where N_{batT} is the total number of battery in the battery bank computed using Equation 13;

$$N_{batS} = \frac{V_{syt}}{V_{bat}} \quad (11)$$

$$N_{batP} = \frac{N_{pvT}}{N_{pvS}} \quad (12)$$

$$N_{batT} = \left\lceil \frac{C_{batBnk}}{Cap_{bat}} \right\rceil \quad (13)$$

Where V_{bat} is the individual battery voltage. Let E_{batMX} denote the maximum energy that can be stored in the battery bank which is as expressed in Equation 14;

$$E_{batMX} = (C_{batBnk})(V_{bat})(\eta_{Bat}) \quad (14)$$

Let $E_{batAvaLd}$ denote the maximum energy that can be delivered from the battery bank to the load given the DoD and battery capacity and the $E_{batAvaLd}$ is expressed in Equation 15 as;

$$E_{batAvaLd} = (E_{batMX})(\mathrm{DoD}) \quad (15)$$

Let $E_{batRsev}$ denote the maximum energy that must be reserved in the battery and hence cannot be delivered from the battery bank to the load given the DoD and battery capacity and the $E_{batRsev}$ is expressed in Equation 16 as;

$$E_{batRsev} = (E_{batMX})(1 - \mathrm{DoD}) \quad (16)$$

2.3 THE ALGORITHM FOR SIZING OF THE SOLAR PANEL ARRAY, SIZING OF THE BATTERY BANK AND DETERMINING THE BATTERY ENERGY DELIVERY CONFIGURATION

The algorithm for sizing of the solar panel array, sizing of the battery bank and determining the battery energy delivery configuration is given as Module 1 Procedure.

Module 1 Procedure:

1. Start

   // *Sizing of the solar panel array*
2. Input $\beta, NOCT, f_{dc/ac}, E_{lddmnd}$
3. Input $G_{(k)}$ and $T_{a(k)}$ for k = 1 to 365
4. Input Gref and $TaRef$
5. Input δ_{fLd}, E_{fLd} or $E_{lddmnd}, V_{syt}, V_{pv}, W_{pv}$
6. Compute $PSH_{(k)}$ from Equation 2 for k = 1 to 365
7. Compute $T_{c(k)}$ from Equation 4 for k = 1 to 365
8. Compute $f_{temp(k)}$ from Equation 3 for k = 1 to 365
9. Compute E_{lddmnd} from Equation 6
10. Compute PSH from Equation 2 using $PSH = \frac{\text{Gref}}{1\ \text{kW/m2}}$
11. Compute $TcRef$ from Equation 9 using $TcRef = TaRef + \left(\frac{NOCT-20}{800}\right)\text{Gref}$
12. Compute f_{temp} from Equation 8 using $f_{temp} = 1 + \beta(TcRef - 25)$
13. Compute $W_{pvarray}$ from Equation 5
14. Compute N_{pvT} from Equation 7
15. Compute N_{pvS} from Equation 8
16. Compute N_{pvP} from Equation 9

' *Sizing of the battery bank*

17. Input DoD, $\eta_{bat}, Dy_{aut}, V_{bat}, Cap_{bat}$
18. Compute C_{batBnk} from Equation 10
19. Compute N_{batS} from Equation 11
20. Compute N_{batP} from Equation 12
21. Compute N_{batT} from Equation 13

' *Determine the battery energy delivery configuration*

22. Compute E_{batMX} from Equation 14
23. Compute $E_{batAvaLd}$ from Equation 15
24. Compute $E_{batRsev}$ from Equation 16
25. Stop

2.4 ANALYSIS OF THE IMPACT OF THE METEOROLOGICAL DATASET AND DAYS OF POWER AUTONOMY USED ON THE PV ARRAY AND THE BATTERY BANK

The solar radiation and atmospheric temperature data for 21 years were used in the study acquired for the site located with latitude (4.6370226) and longitude (7.919093). The scatter plot of the feature scaled or normalized daily mean solar radiation and atmospheric temperature dataset is presented in Figure 2. The descriptive statistical analysis of the solar radiation dataset is presented in Table 5 while that of the temperature dataset is presented in Table 6. The solar radiation has annual mean value of 63447 kW-hr/m^2/day (Table 5) and the temperature has annual mean of 26.856 °C (Table 2). The study examined the influence of days of power autonomy and the solar radiation value used in the sizing calculations on the PV array and the battery bank. First the annual mean solar radiation value of 63447 was used while the days of autonomy was varied from 1 to 7 and later, the 3 days of autonomy was used while some selected range of values of solar radiation values were used for the sizing. The results of each of the two sets of experiments are captured and presented in section 3.

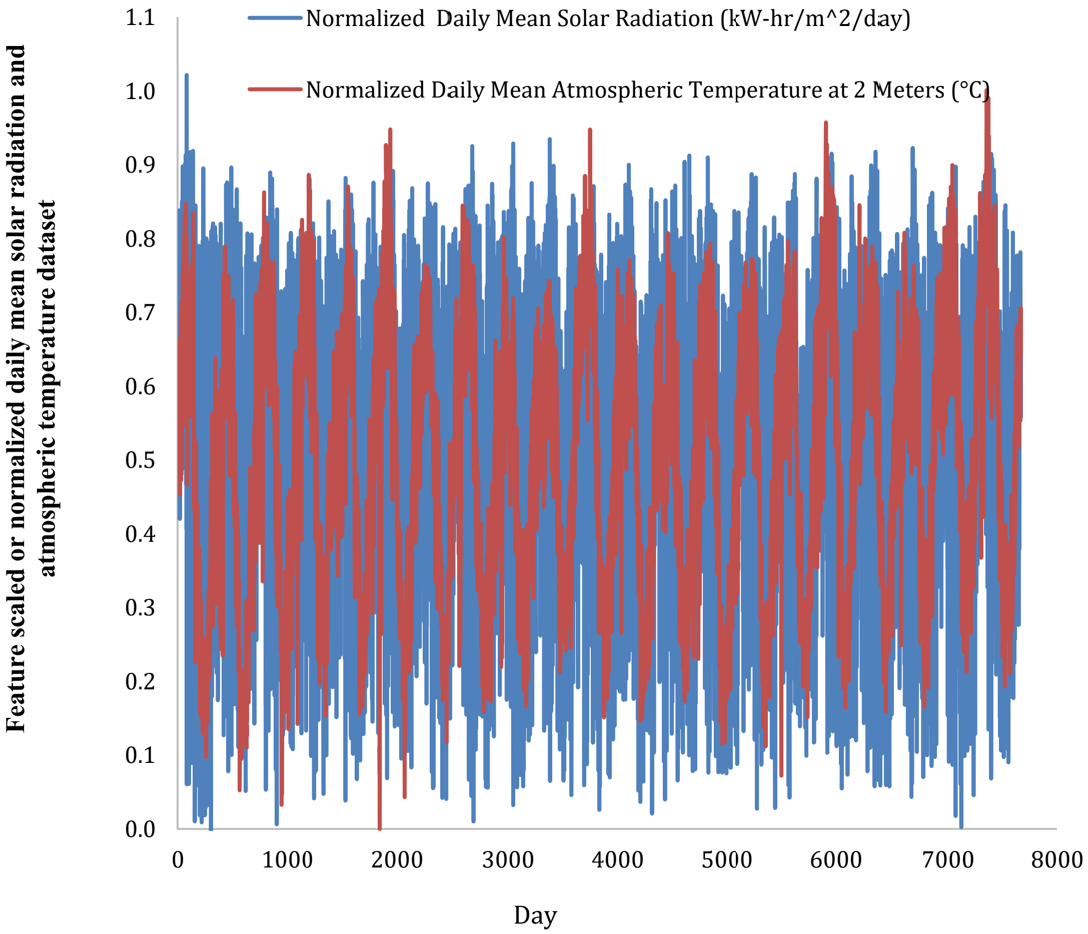

Figure 2 The scatter plot of the feature scaled or normalized daily mean solar radiation and atmospheric temperature dataset

Table 5 The descriptive statistical analysis of the solar radiation dataset

Groups	Daily Mean Peak Sun Hour ($kWh/m^2.day$)
Number of observations	365
Number of missing values	0
Minimum	4.9007
Maximum	7.482
Range	2.5813
Mean ($\bar{x}$)	6.3447
Standard Deviation (S)	0.5894
Variance (S^2)	0.3473
Q1	5.9487
Median	6.4138
Q3	6.8198
Interquartile range	0.871
Skewness	-0.4084

Table 6 The descriptive statistical analysis of the atmospheric temperature dataset

Parameter Description	Atmospheric Temperature at 2 Meters (°C)
Number of observations	7,671
Number of missing values	0
Minimum	24.08
Maximum	29.62
Range	5.54
Mean ($\bar{x}$)	26.856
Mode	27.48 (appears 55 times)
Mean Confidence Interval	95% CI [26.834, 26.878]
Standard Deviation (S)	0.978
Q1	26.04
Median	26.93
Q3	27.65
Interquartile range	1.61
Skewness	-0.0726

3. Results and Discussion

3.1 The results for varying the days of power autonomy at constant peak sun hour (PSH)

The study considered the effect of varying the days of power autonomy on the PV system while keeping the PSH constant. The results showed that the PV array capacity and number of required PV modules remained the same while the battery bank capacity and the number of battery units required varied with the variations in the days of power autonomy, as shown in Table 7 and Figure 3. The battery units increased from 260 at 1 day of power autonomy to 1810 at 7 days of power autonomy. Also, the battery capacity increased from 51,701 Wh at 1 day of power autonomy to 361912 at 7 days of power autonomy, as shown in Figure 4. The solar fraction also increase for the overall load (in Figure 6) from 95.3 % at 1 day of power autonomy to 96.0 at 7 days of power autonomy. Also, the Priority 1 and 2 solar fraction were steady at 100 % (in Figure 5) but priority 3 solar fraction increased from 72.22% at 1 day of power autonomy to 76.83% at 7 days of power autonomy. The normalized missing energy dropped from 4.7 % at 1 day power autonomy to 4 % at 7 days power autonomy whereas the normalized unused energy increased from 25.6 5 at 1 day power autonomy to 35.8 % at 7 days power autonomy.

Table 7 The results for the battery bank capacity (Ah) for PSH =6.3447 at various days of power autonomy

PSH	PV Array Unit Size (Wp)	Total number of PV Array	Total Power Rating of PV Array	Mean Daily Energy Demand (kW/h day)	Mean Daily Available Energy (kW/h day)	Mean Daily Energy Yield (kW/h day)	Days of Power Autonomy	Battery Unit Capacity (Ah)	Total Number of Battery Unit	Battery Bank Capacity (Ah)
6.3447	100	564	56400	333.846	528.675	357.3628	1	200	260	51701.79
6.3447	100	564	56400	333.846	617.418	357.3628	2	200	518	103403.6
6.3447	100	564	56400	333.846	691.562	357.3628	3	200	776	155105.4
6.3447	100	564	56400	333.846	732.327	357.3628	4	200	1034	206807.2
6.3447	100	564	56400	333.846	732.327	357.3628	5	200	1294	258509
6.3447	100	564	56400	333.846	732.327	357.3628	6	200	1552	310210.7
6.3447	100	564	56400	333.846	732.327	357.3628	7	200	1810	361912.5

Table 8 The results for the missing energy and unused energy for PSH =6.3447 at various days of power autonomy

Days of Power Autonomy	PSH	Daily Available Energy /Demand Ratio)	Daily Energy yield /Demand Ratio)	Solar fraction for Priority 1 load	Solar fraction for Priority 1 load	Solar fraction for Priority 1 load	Solar fraction for all the load	Unused Energy Fraction	Missing Energy fraction
1	6.3447	1.42020	0.96000	1.00000	0.96523	0.72222	0.95265	0.25608	0.04735
2	6.3447	1.65860	0.96000	1.00000	0.96529	0.74109	0.95539	0.31084	0.04461
3	6.3447	1.85778	0.96000	1.00000	0.96586	0.75924	0.95813	0.34318	0.04187
4	6.3447	1.96728	0.96000	1.00000	0.96860	0.76825	0.96000	0.35826	0.04000
5	6.3447	1.96728	0.96000	1.00000	0.96860	0.76825	0.96000	0.35826	0.04000
6	6.3447	1.96728	0.96000	1.00000	0.96860	0.76825	0.96000	0.35826	0.04000
7	6.3447	1.96728	0.96000	1.00000	0.96860	0.76825	0.96000	0.35826	0.04000

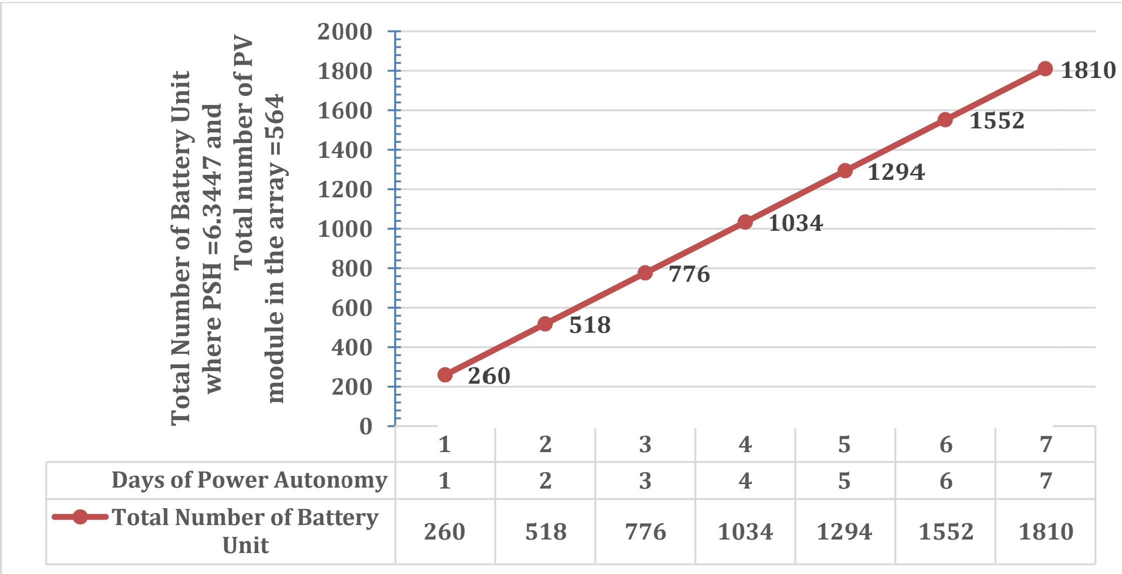

Figure 3 Total Number of Battery Unit where PSH =6.3447 and Total number of PV module in the array =564

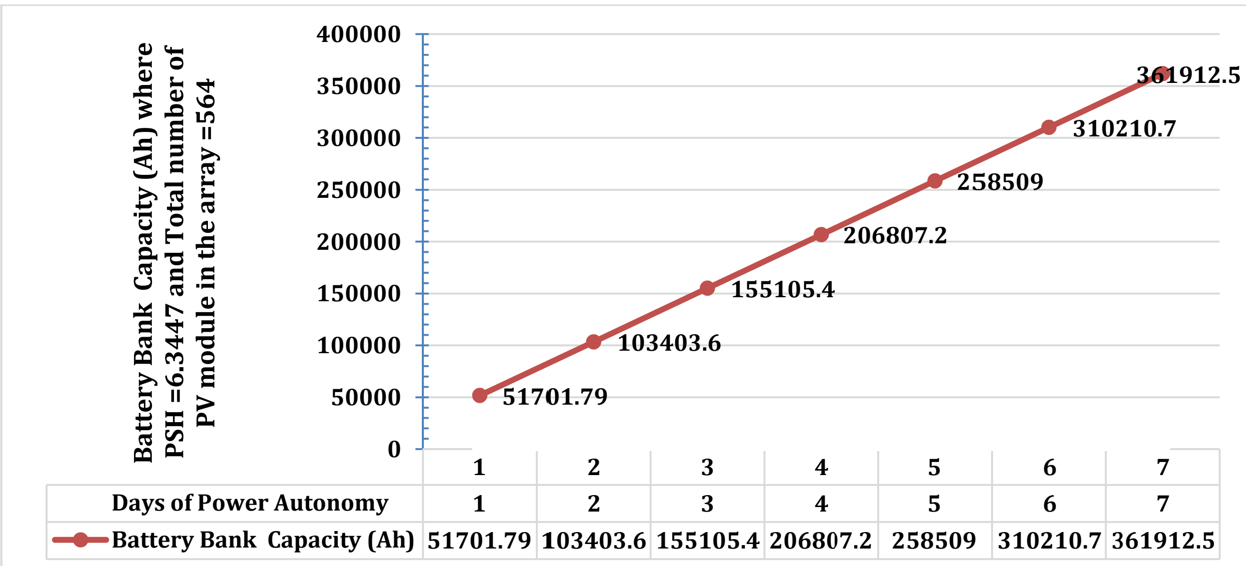

Figure 4 The Battery Bank Capacity (Ah) where PSH =6.3447 and Total number of PV module in the array =564

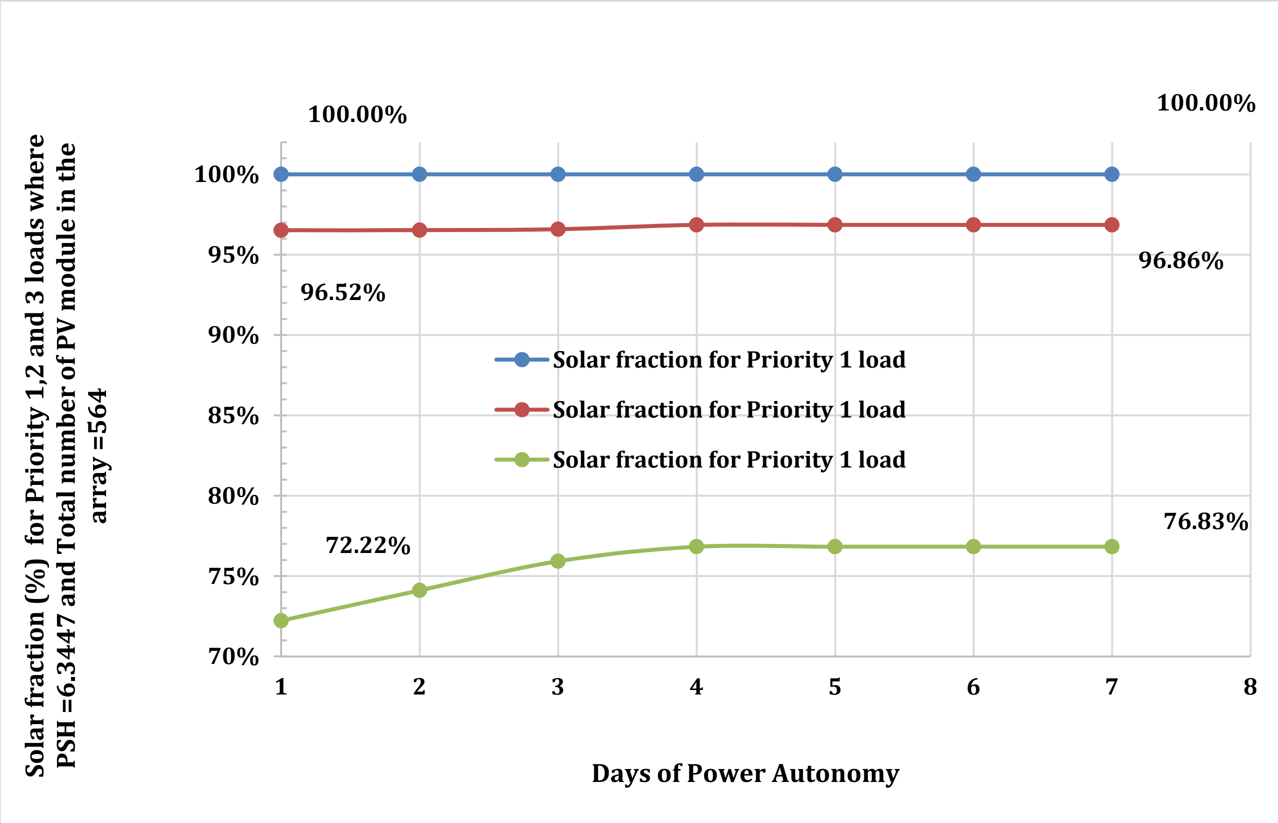

Figure 5 Solar fraction (%) for Priority 1,2 and 3 loads where PSH =6.3447 and Total number of PV module in the array =564

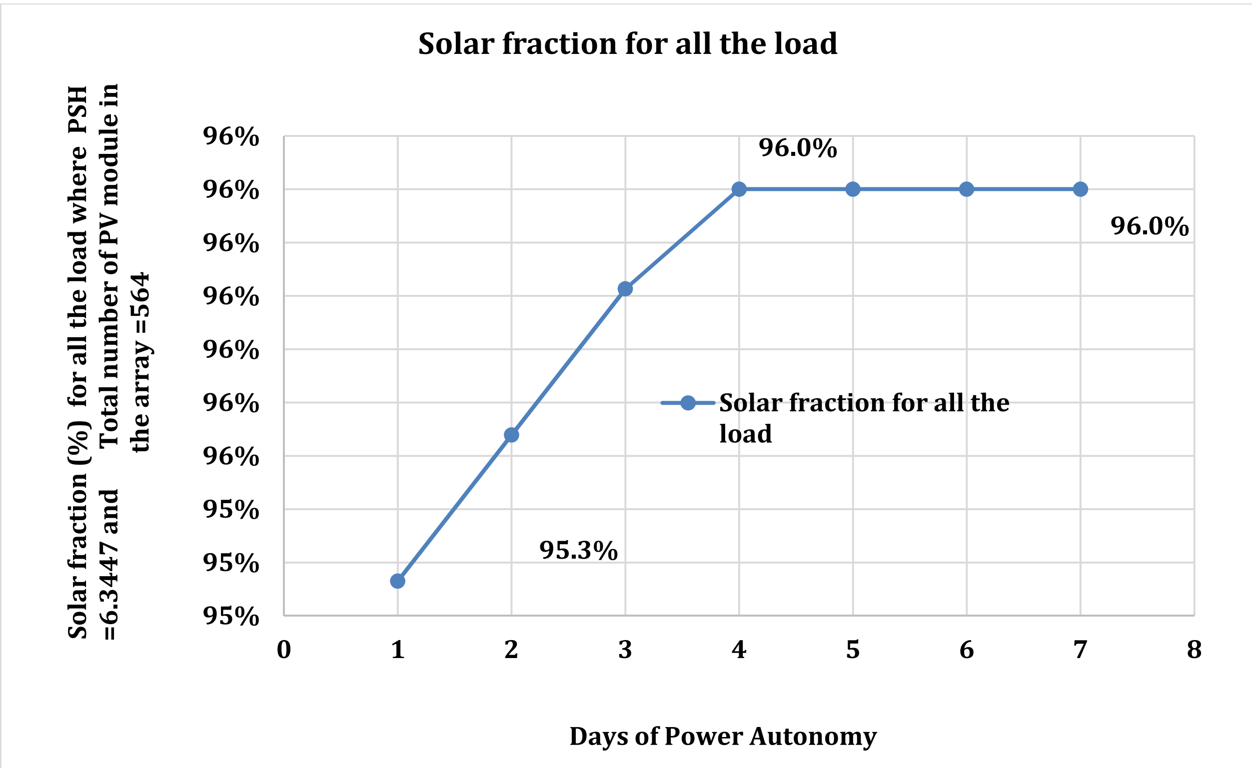

Figure 6 Solar fraction (%) for all the load where PSH =6.3447 and Total number of PV module in the array =564

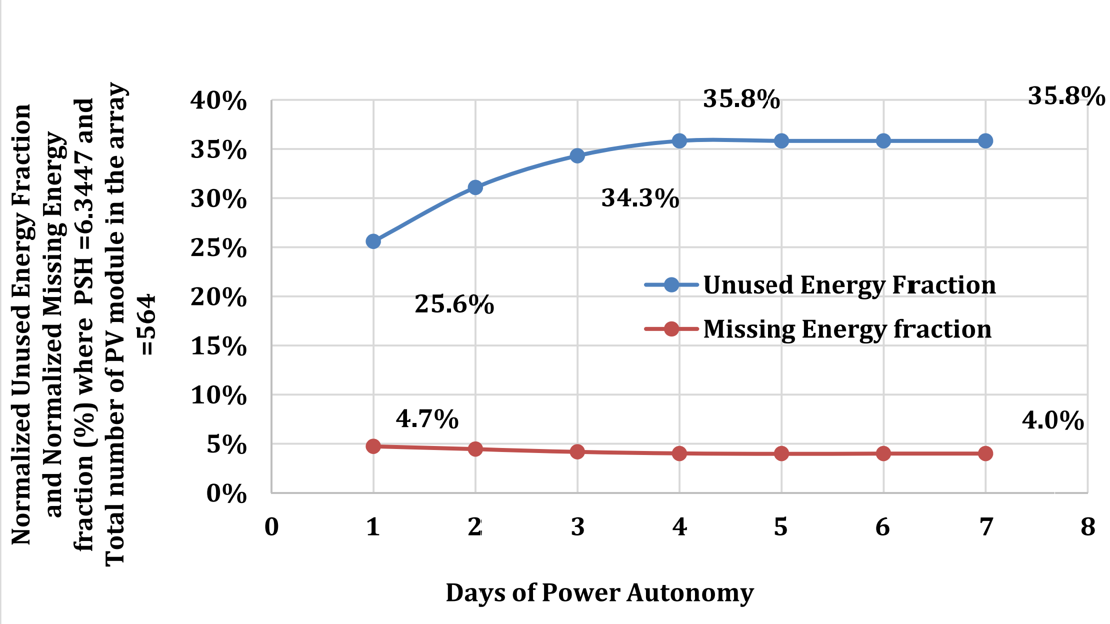

Figure 7 Normalized Unused Energy Fraction and Normalized Missing Energy fraction (%) where PSH =6.3447 and Total number of PV module in the array =564

3.2 The results for varying the peak sun hour at constant days of power autonomy

The study considered the effect of varying the PSH on the PV system while keeping the days of power autonomy constant. The results showed that the battery bank capacity and number of required battery units remained the same while the PV array capacity and number of required PV modules required varied with the variations in the PSH, as shown in Table 9 and Figure 8. The PV modules decreased from 728 at PSH of 4.901 to 562 at PSH of 6.82. Also, the power rating of the PV array decreased from 72800 at PSH of 4.901 to 56200 at PSH of 6.82, as shown in Figure 9. The solar fraction also decrease for the overall load (in Figure 11) from 100 % at PSH of 4.901 to 89.3 % at PSH of 6.82. Also, the Priority 1 solar fraction were steady at 100 % (in Figure 10) but priority 3 solar fraction decreased from 40 % at PSH of 6.82 and priority 2 solar fraction decreased from 90.5 % at PSH of 6.82. The normalized missing energy increased from 0 % c to 10.7 % at PSH of 6.82 whereas the normalized unused energy decreased from 74.5% at PSH of 6.82 to 0.3 % % at PSH of 6.82.

Table 9 The results for the PV array capacity (Ah) for 3 days of power autonomy at various peak sun hour

PSH Value Rank	Days of Power Autonomy	PSH	Daily Available Energy /Demand Ratio)	Daily Energy yield /Demand Ratio)	Solar fraction for Priority 1 load	Solar fraction for Priority 1 load	Solar fraction for Priority 1 load	Solar fraction for all the load	Unused Energy Fraction	Missing Energy fraction
Minimum	3	4.9007	4.09263	1.24287	1.00000	1.00000	1.00000	1.00000	0.74467	0.00000
Q1	3	5.9487	3.06436	1.02391	1.00000	0.99358	0.87795	0.98110	0.55815	0.01890
Mean (x̄)	3	6.447	1.23958	0.94477	1.00000	0.95546	0.68209	0.94477	0.14580	0.05523
Median	3	6.4138	1.38048	0.94966	1.00000	0.95903	0.71066	0.94966	0.19801	0.05034
Q3	3	6.8198	0.89638	0.89313	1.00000	0.90483	0.40017	0.89313	0.00304	0.10687

Table 10 The results for the missing energy and unused energy for 3 days of power autonomy at various peak sun hour

PSH Value Rank	PSH	PV Array Unit Size (Wp)	Total number of PV Array	Total Power Rating of PV Array	Mean Daily Energy Demand (kW/h day)	Mean Daily Available Energy (kW/h day)	Mean Daily Energy Yield (kW/h day)	Days of Power Autonomy	Battery Unit Capacity (Ah)	Total Number of Battery Unit	Battery Bank Capacity (Ah)
Minimum	4.901	100	728	72800	333.846	1,521.044	461.9203	3	200	776	154856.1
Q1	5.949	100	602	60200	333.846	1,140.215	380.9867	3	200	776	155036.9
Mean (x̄)	6.447	100	556	55600	333.846	461.491	351.7349	3	200	776	155123.1
Median	6.414	100	558	55800	333.846	513.929	353.5425	3	200	776	155117.3
Q3	6.820	100	526	52600	333.846	333.858	332.6457	3	200	776	155187.5

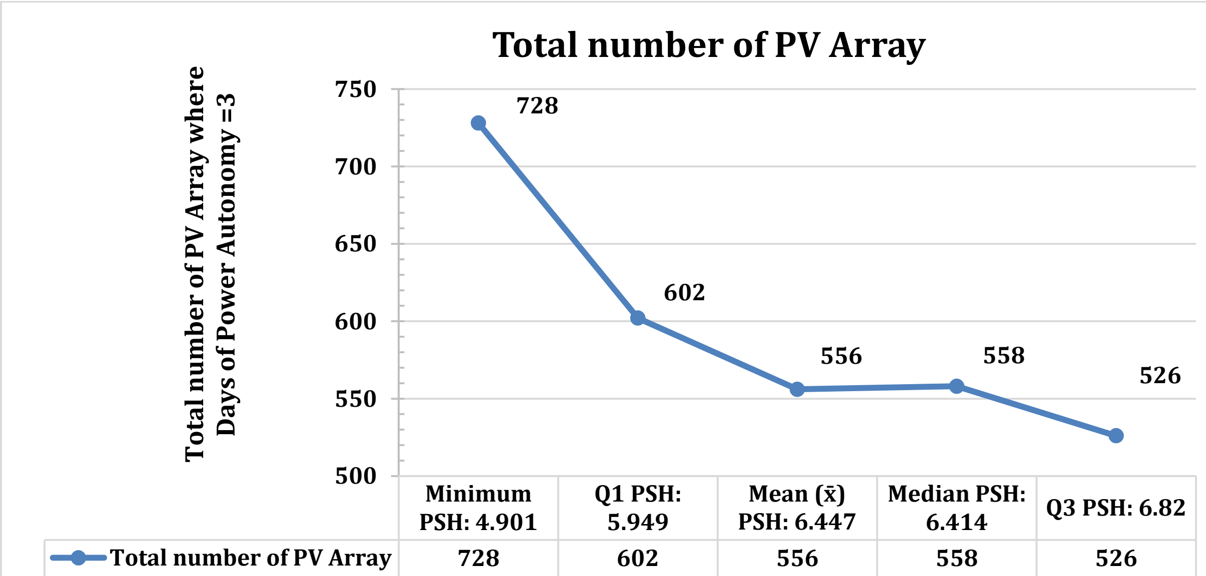

Figure 8 Total number of PV Array where Days of Power Autonomy =3

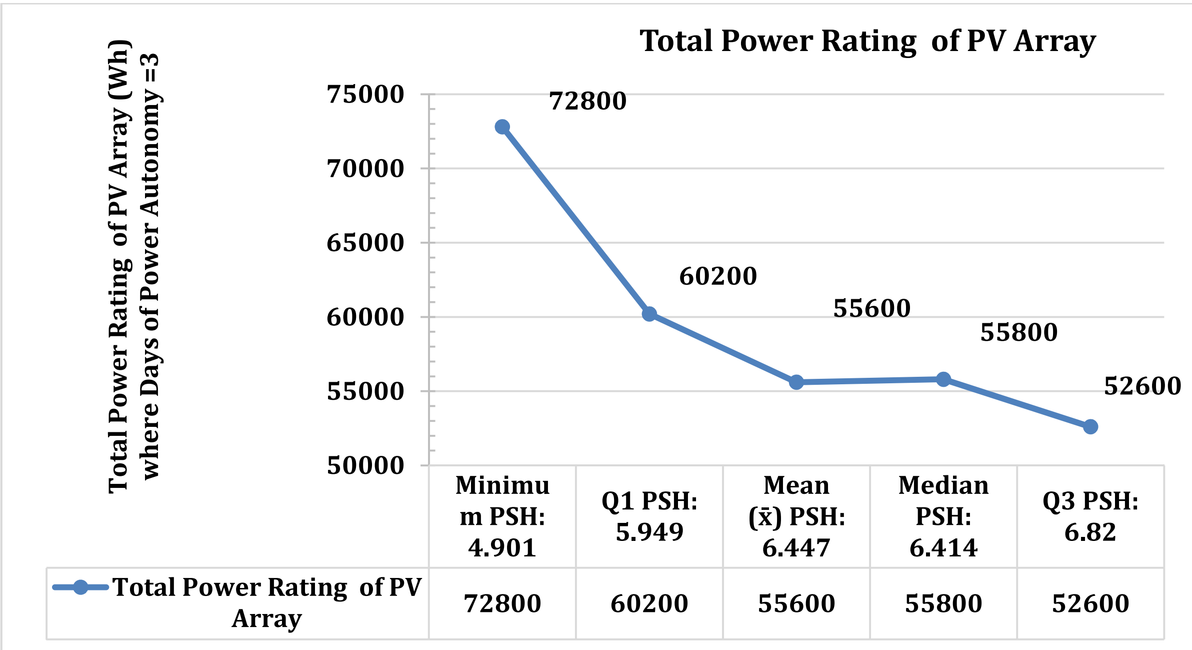

Figure 9 Total Power Rating of PV Array (Wh) where Days of Power Autonomy =3

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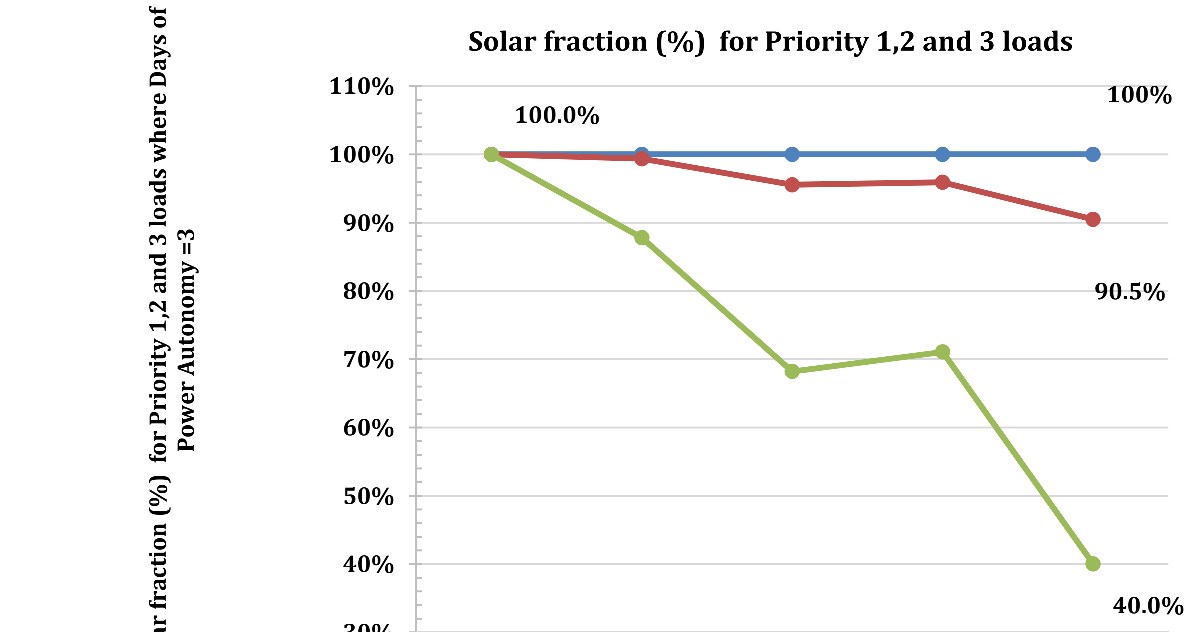
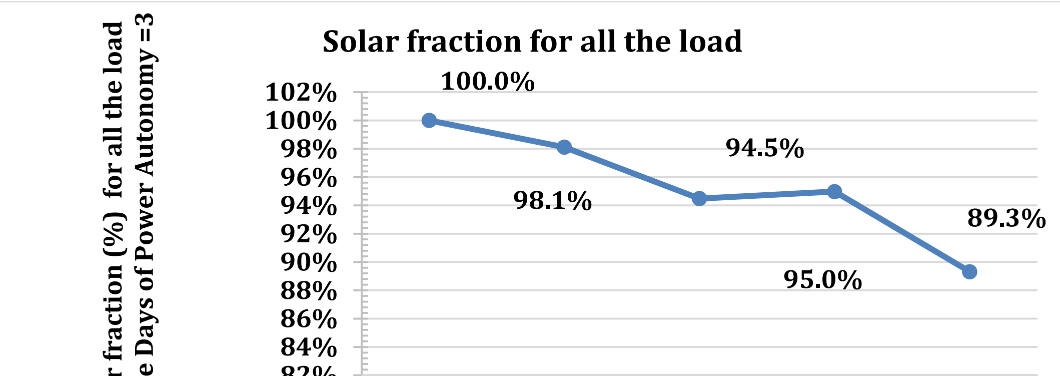


	Minimum PSH: 4.9007	Q1 PSH: 5.9487	Mean (x̄) PSH: 6.447	Median PSH: 6.4138	Q3 PSH: 6.8198
Solar fraction for Priority 1 load	1.000	1.000	1.000	1.000	1.000
Solar fraction for Priority 1 load	1.000	0.994	0.955	0.959	0.905
Solar fraction for Priority 1 load	1.000	0.878	0.682	0.711	0.400

Figure 10 Solar fraction (%) for Priority 1,2 and 3 loads where Days of Power Autonomy =3



	Minimum PSH: 4.9007	Q1 PSH: 5.9487	Mean (x̄) PSH: 6.447	Median PSH: 6.4138	Q3 PSH: 6.8198
Solar fraction for all the load	1.000	0.981	0.945	0.950	0.893

Figure 11 Solar fraction (%) for all the load where Days of Power Autonomy =3

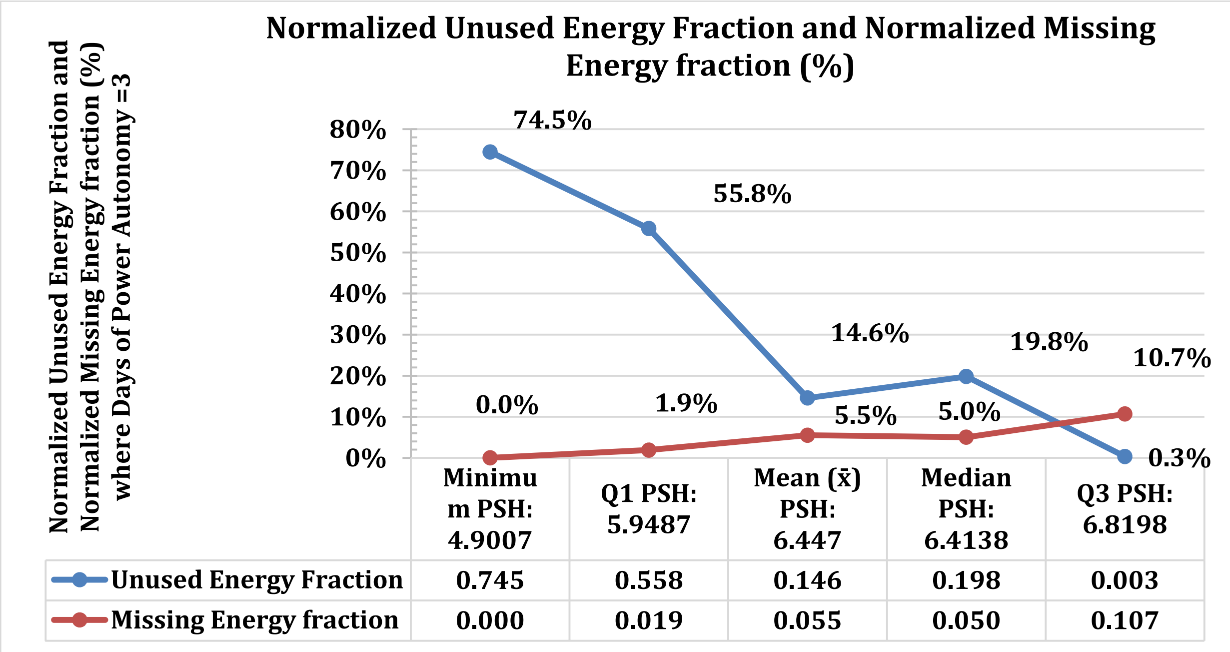


Figure 12 Normalized Unused Energy Fraction and Normalized Missing Energy fraction (%)

4. Conclusion

The approach used for sizing the solar power system deployed for powering a health facility is presented. The focus is on the evaluation of the effect of days of power autonomy and the peak sun hour on the sizing of the PV power plant is presented. The study considered standalone PV power plant focusing on the impact of the solar radiation on the PV array power rating and the number of PV required for a given load. It also examined the impact on the n\battery bank capacity and the number of battery units required. In addition, the impact of the number of days of power autonomy on the PV array and battery bank were also evaluated. In all, the results showed that increasing the days of power autonomy increases the battery bank capacity and number of battery units required while the PV array is not affected. On the other hand, increasing the solar radiation decreases the PV array power and number of PV modules required while the battery bank is not affected.

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