

# Off-Grid Photovoltaic System Design for Haiti School Project

Wentao Feng, Ziya M. Slameh

Department of Electrical Engineering, University of Massachusetts Lowell, Lowell, USA  
Email: [ziyad\\_salameh@uml.edu](mailto:ziyad_salameh@uml.edu)

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## Abstract

**In this paper a Photovoltaic (PV) system was designed for the Port-Margot School Solar Project in Haiti. This off-grid system consists of PV panels, inverter, battery storage and other components such as fuses, dc/ac disconnects and transformers [1]. Sizing the PV to fit on the roof was determined. The battery storage and inverter were chosen to be installed in the school building. The expected energy production was compared with data file from NASA website. The KW PV system was chosen to be the most effective and demonstrating renewable technologies and reducing the electrical load of the school.**

## Keywords

Haiti, Photovoltaic, Battery, Controller, Inverter, Layout

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## 1. Introduction

This project is led by the Ministries of Aides International Organization, and its partners United Solar Associates, LLC, Solar World Co. will deliver donations at the most appropriate facility. University of Massachusetts Lowell's Renewable Energy Department is implementing the solar solution.

Solar electricity will allow for much improved cooling and ventilation in the offices and classrooms. Given the tropical temperatures averaging mid to high 90 degrees Fahrenheit, this is a problem in that overhead fans are inoperable due to intermittent electricity. As a result, the learning environment is adversely impacted with student concentration levels reduced. Also, the steady flow of electricity will provide power to the administrative offices and improve productivity with peripherals such as computers, copiers, printers, etc. Additionally, students and local residents will benefit from use of the same devices in the computer learning center.

According to the client's requirement, there are 6 perspectives in PV system model selection: Data collection, Electric appliance load calculation, Battery packs selection, PV array selection, Spacing between rows and Con-

troller and Inverter selection.

## 2. Methotology [2]

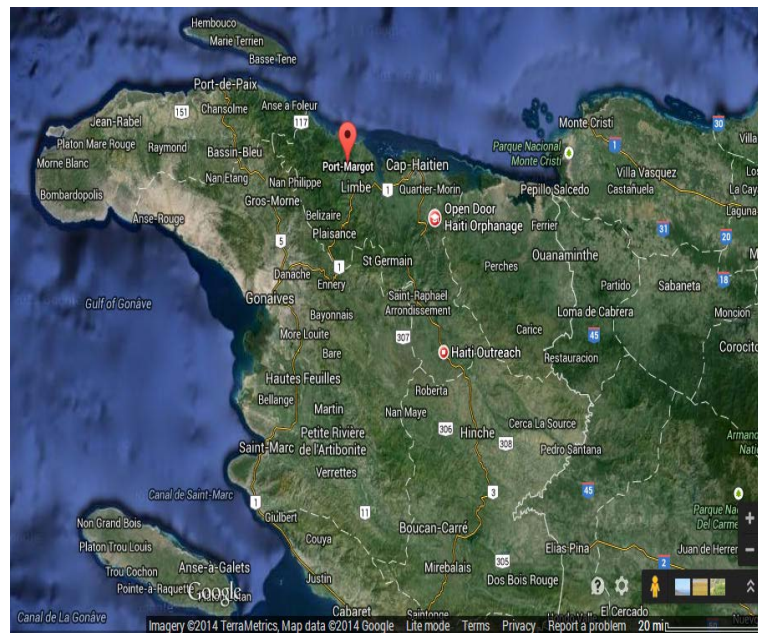
The school located in Port-margot where is not far from cap-haitien. The following is the school's geographic location which shows in **Figure 1**. and the roof structure form the top view is shows in **Figure 2**. Grid Location: 19 degrees 45' North, 72 degrees 26' West.

Measurements: 21.85 meters (71.69 feet) in length.

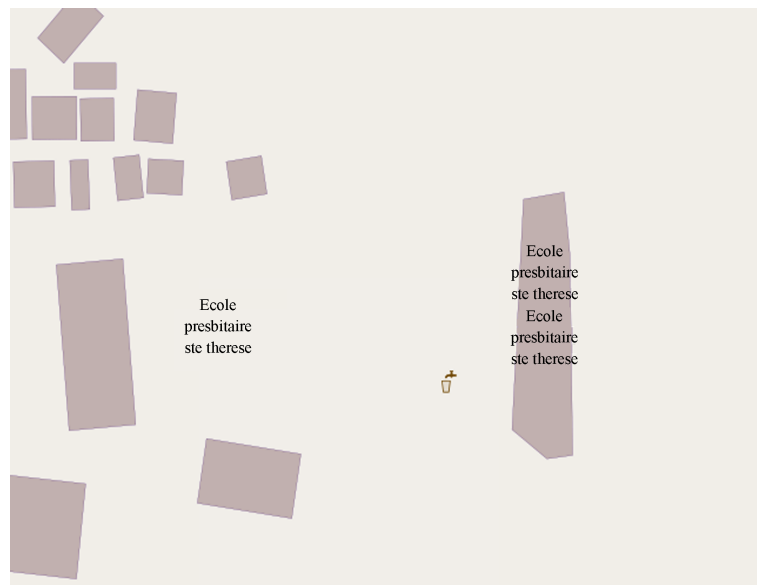
The front is 5.65 meters (18.54 feet) in width.

The back is 4.8 meters (15.74 feet) in width.

### Step 1. Data collection [3]



**Figure 1.** Geographic location [13].



**Figure 2.** Top view [12].

**Step 2. Load Calculation [4]**

Illumination (Lux) = light output lumen × lights number × 0.563/Area (m<sup>2</sup>)

$$500 = 3000 \times \text{number} \times 0.563 / (3 \times 2.5)$$

$$\text{Number} = 2.22 \approx 3$$

So we choose 3 for each classroom in the calculation after.

According to the Load Evaluation Table present in **Table 1**, the Total electrical power is 10,241 w, and the daily electricity consumption is 29.92 kW·h, on the basis of simultaneously utilized rate we get the total power is 6144.6 w, and daily electricity consumption is 17.95 kW·h.

**Step 3. Battery Sizing [5]**

Equivalent Autonomy Days (No-Sun or Black Days)

Take Autonomy days for 3, and DOD for 80%

Average Discharge Rate calculate formula:

Weighted average load work time:

$$\sum \text{Energy} / \sum \text{Power} = 17950 / 6144.6 \text{ w} = 2.92 \text{ h}$$

Average Discharge Rate(h)

$$= (\text{Autonomy days} \times \text{weighted average load work time}) / \text{DOD} \tag{1}$$

$$= (3 \times 2.92) / 0.8 = 10.95 \text{ h}$$

Battery Capacity Calculation Formula:

$$\text{CAP} = (D \times L) (\text{DOD} \times \eta_{\text{out}} \times V) \tag{2}$$

$$= (3 \times 17.95 \text{ kW} \cdot \text{h}) / (0.8 \times 0.9 \times 48 \text{ V}) \approx 1558 \text{ Ah}$$

CAP: Battery Capacity, Ah;

D: Autonomy days;

L: Daily electricity consumption, kW·h;

$\eta_{\text{out}}$ : Total efficiency; Take inverter efficiency for 0.92 and charge controller for 0.98. So  $\eta_{\text{out}} = 0.92 \times 0.98 = 0.9$ .

**2.1. Battery Number**

In parallel: 1558/130 = 12

In series: 48/12 = 4

Total: 12 × 4 = 48

We choose TYPE: J150, 12 VOLT, 5-Hr Rate CAPACITY 120 Ah, 20-Hr Rate CAPACITY 150 Ah. Take 130 Ah [6].

**Step 4. PV Array Sizing:**

Choose SW 225 mono of SOLARWORLD Co. which temperature character is shown in **Figure 3**.

Current Output Calculation [7].

**Table 1.** Load estimate table.

Load Type	Numbers	Voltage	Current	Power	Service Time (h/day)	/wh
Computer	20	110	2	4400	3	13,200
Monitor	20	110	0.5	1100	3	3300
Copier Fax	3	110	8.8	2904	1	2904
Ceiling Fans	12	110	0.7	924	6	5544
Refrigerator	1	110	2	220	10	2200
Lighting	3*6	110	0.35	693	4	2772
Total Power		10,241 w			Total Energy	29,920
Simultaneously Usage Rate	0.6	6144.6 w				17,950

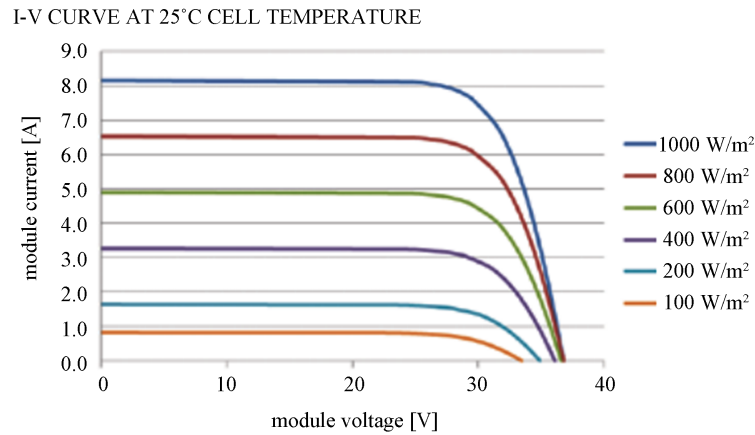


Figure 3. PV panel I-V curve.

$$\text{PV Array Output Current } I = L / (V \times \eta_1 \times \eta_2 \times h) = 17.95 \text{ kW} \cdot \text{h} / (48 \text{ V} \times 0.9 \times 0.7 \times 4.8 \text{ h}) \approx 123.6 \quad (3)$$

L: Daily electricity consumption, kW·h;

$\eta_1$ : Line Loss, 0.9;

$\eta_2$ : Battery Discharge efficiency, 0.7;

h: Average sunshine hours, h; [8]

According to this current, PV panels in parallel should be  $123.6/8.17 = 15.13 \approx 15$ .

Number in series = System Voltage/panel voltage

=  $48 \text{ V} / 29.7 \text{ V} = 1.61 \approx 2$ .

PV Array power output calculation:

$$\begin{aligned} \text{Output} &= \text{Daily electricity consumption} / \text{Minimum sunshine time} \\ &= (17.95 \text{ kW} \cdot \text{h}) / 4.8 \text{ h} \approx 3.73 \text{ Kw} \end{aligned} \quad (4)$$

Surplus capacity: 10% - 20%, take 0.15

Battery efficiency: 0.9

Temperature loss factor: 0.9

Dust loss factor: 0.9

Controller efficiency: 0.85

$$\begin{aligned} \text{Safe factor} &= (1 + \text{Surplus capacity}) / (\text{Battery efficiency} \times \text{Temperature} \\ &\quad \text{loss factor} \times \text{Dust loss factor} \times \text{Controller efficiency}) \\ &= (1 + 0.15) / (0.9 \times 0.9 \times 0.9 \times 0.85) = 1.85 \end{aligned}$$

Output \* Safe factor =  $3.1 * 1.77 = 6.92 \text{ W}$

According to this output, temporarily design PV array capacity:  $6.92 \text{ kW} > 6.14 \text{ kW}$

PV Array series-parallel design

$$\begin{aligned} \text{Total Numbers} &= \text{PV Array power output} / \text{Maximum power for each panel} \\ &= 7 \text{ kW} / 225 \text{ W} = 30.7 \approx 30 \end{aligned}$$

## 2.2. Verification

Numbers in parallel

= daily electricity consumption / (columbic efficiency × panel output × attenuation factor)

=  $(17.95 \text{ kW} \cdot \text{h} / 48 \text{ V}) / [0.9 \times (225 \text{ W} \times 5.79 \text{ h} / 36.8 \text{ V}) \times 0.9]$

$\approx 373.95 \text{ A} \cdot \text{h} / 28.67 \text{ A} \cdot \text{h} \approx 11.7 < 15$

Numbers in series and parallel are according to system voltage and current [10]. We assumed for this 6.92 kWp system, using 30 bucks of 225 Wp-PV panels which 15 in parallel and 2 for series, system open circuit voltage is 110.4 V; short circuit current is 81.7 A; operating voltage 88.5 V, operating current is 76.3 A.

But as the actual working temperature (about 60°C) rise will lead the MPPT voltage decrease, the coefficient is  $-0.43\%/^{\circ}\text{C}$  ( $-16.6\text{ V}$ ); meanwhile, in low irradiance circumstances the operating voltage would decrease too, normally down to 92% ( $-9\text{ V}$ ); in addition, in the wire and the connections between appliances there are voltage drops about 1V, so actual operating voltage is close to the charging voltage for battery, which is about 60 V.

Charging current is about 76 A (Which is smaller than Constant voltage charging current limiting value:  $10\%C = 155\text{ A}$ ), as an ideal charging setting.

1) Battery bank and PV array design verification

Battery daily discharge rate = daily load/battery capacity =  $((17.95\text{ kW}\cdot\text{h}/48\text{ V})/1558\text{ Ah}) \approx 0.24 < 0.8(\text{DOD})$

So the battery bank would not over discharge;

2) Maximum charging rate = Battery capacity/PV Array current =  $1558\text{Ah}/(7.63\text{A} \times 10) \approx 20.4\text{ h} > 10.25\text{ h}$

(Maximum charging current:  $10\%C = 155\text{ A}$ )

PV array would not overcharge the battery;

**Step 5. Spacing between rows [11]**

Take the worst situation of the year for calculation that is in December the solar angle is  $47^{\circ}$  at noon when the sun is the highest in the sky using Figure 4 to illustrate.

$$D_1 = X \cdot \text{COS}\beta = 1675\text{ mm} \times \text{COS}20^{\circ} = 1574\text{ mm}$$

$$H = X \cdot \text{SIN}\beta = 1675\text{ mm} \times \text{SIN}20^{\circ} = 573\text{ mm}$$

$$D_2 = H \cdot \text{TAN}(\delta_m + L) = 573 \times 2.36 = 1352\text{ mm}$$

$$D_T = D_1 + D_2 = 2926\text{ mm}$$

With  $\delta_m = 47^{\circ}$  indicates the declination at the winter solstice (December 21), that is the time when the sun is at the lowest elevation and L is the latitude of the site which is  $19.5^{\circ}$ . In order to account for times before and after noon when the sun's angle is lower, a common distance greater should be used. It was decided that a spacing of 3000mm would be acceptable and the whole frame work is shown in Figure 5.

**Step 6. Inverter and Charge Controller: [14]**

According to Solar world website. Solar World makes good use of the longstanding experience of SMA, the German market leader with respect to efficiency, durability, cost effectiveness and service.

Solar World solar power systems are optimally enhanced by SMA inverters. The SMA inverters are a perfect fit for Solar World's definition of quality.

Solar World uses Inverters (besides SMA) and Charge Controllers of STECA, a leading supplier for regulation and control of solar energy systems. Its long lasting experience, high quality standards and cost effectiveness match to Solar World's demands primarily for off-grid systems [15].

$$\text{Inverter capacity} = \text{Load Power}/0.8 = 6144\text{ W}/0.8 = 7.68\text{ W}$$

In this system we use SMARTFORMER FOR SUNNY ISLAND inverter.

$$\text{Controller current} = \text{System capacity}/\text{voltage} * \text{loss factor} = 6.92\text{ KW}/48 * 0.85 = 122.4\text{ A}$$

For charge controller we use Steca Tarom 4140 [16].

### 3. Power System Simulation and Performance Result

Simulation by PVsyst [17] is presented in Figure 6.

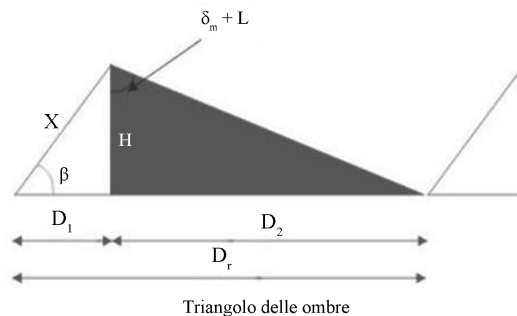


Figure 4. Distance between the rows of panels.

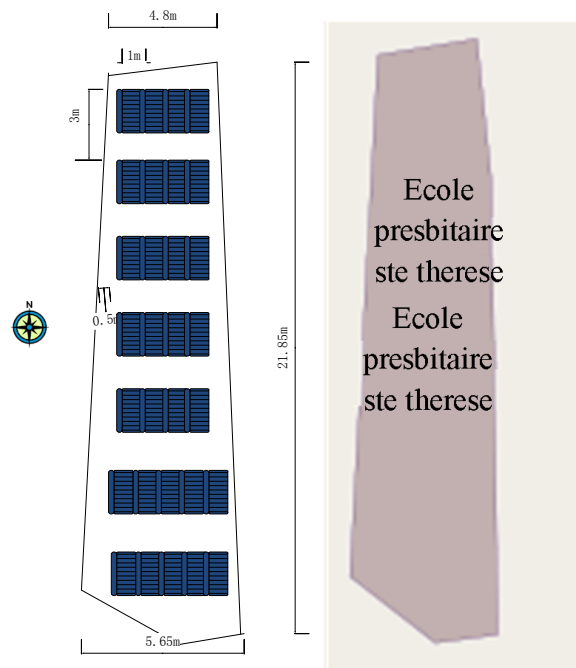
## 4. Market Analysis

### 4.1. Estimation Cost

#### 1. System Investment Content

This PV system has installed capacity of 6.92 kW, investment include PV panels, off-grid inverter, batteries, charge controller, AC circuit breaker, wires, PV panel mounting rack, power shed, labor fees and so on which are presented in **Table 2** and **Table 3**.

#### 2. Project budget



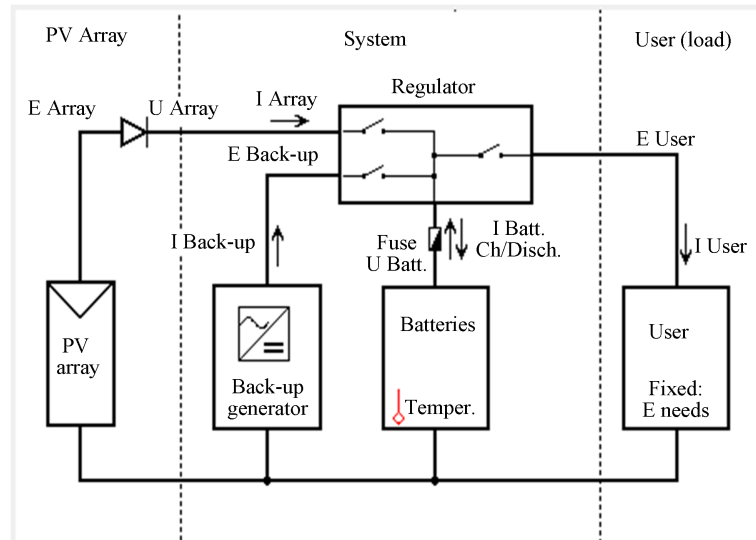
**Figure 5.** PV panels layout [9].

**Table 2.** Project contents.

#	Title	Supplier	Standard	Amount	Unit Price
1	PV Panels	Solarworld	SW 225	24	350
2	Inverter	SMA	SMARTFORMER	1	1800
3	Controller	Steca	POWER TAROM 4140	1	2000
4	Batteries	Trojan	J150	48	220
5	Mounting	Self-collect			
6	Breaker	Self-collect			
7	Wires	Self-collect			

**Table 3.** Project cost.

Wood or metallic frame installation	$\$2.5 \times 225 \times 30 = 16,875\$$
Batteries	$\$220 \times 48 = 10,560\$$
PV panels	$\$350 \times 30 = 10,500\$$
Inverter	$\$1800$
Controller	$\$2000$



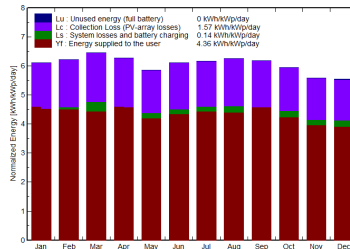
Stand Alone System: Main results

Project : Stand Alone Project at haiti  
 Simulation variant : haiti

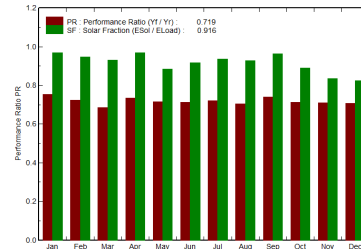
Main system parameters		System type	Stand alone	
PV Field Orientation		tilt	20 deg	azimuth 0 deg
PV Array		Nb. of modules	28	Pnom total 6.3 kWp
Battery		Model	GY112 - Starting	Technology vented, vehicle starting
battery Pack		Nb. of units	48	Voltage / Capacity 48 V / 1560 Ah
User's needs	Daily household consumers	Constant over the year		global 10.95 MWh/year

Main simulation results		Available Energy	10.34 MWh/year	Specific prod.	1641 kWh/kWp/year
System Production	Used Energy	10.02 MWh/year	Excess (unused)	4.7 kWh/year	
Loss of Load	Performance Ratio PR	71.9 %	Solar Fraction SF	91.6 %	
	Time Fraction	8.2 %	Missing Energy	925 kWh	

Normalized productions (per installed kWp): Nominal power 6.3 kWp



Performance Ratio PR and Solar Fraction SF



haiti  
Balances and main results

	GlobHor kWh/m2	GlobEff kWh/m2	E Avail kWh	EUnused kWh	E Miss kWh	E User kWh	E Load kWh	SoFrac
January	153.4	184.7	886.4	0.252	28.4	901.4	929.8	0.969
February	151.2	189.9	808.2	0.371	44.8	795.1	839.8	0.947
March	189.1	184.7	931.4	0.192	63.6	866.2	929.8	0.932
April	191.7	182.7	886.4	0.155	27.9	871.9	899.8	0.969
May	196.8	175.9	857.0	1.200	108.6	821.2	929.8	0.883
June	205.8	177.1	855.6	0.770	75.5	824.3	899.8	0.916
July	210.8	185.0	899.3	0.920	60.4	869.4	929.8	0.935
August	203.4	187.9	903.7	0.135	68.0	861.8	929.8	0.927
September	181.2	180.5	887.5	0.141	33.3	886.5	899.8	0.963
October	166.2	179.8	869.6	0.061	101.3	828.5	929.8	0.891
November	140.4	163.1	786.0	0.037	148.8	751.1	899.8	0.835
December	136.4	167.0	809.3	0.510	164.1	765.7	929.8	0.823
Year	2126.4	2148.4	10340.4	4.746	924.7	10023.2	10947.8	0.916

Legends: GlobHor Horizontal global irradiation  
 GlobEff Effective Global, corr. for IAM and shadings  
 E Avail Available Solar Energy  
 EUnused Unused energy (full battery) loss  
 E Miss Missing energy  
 E User Energy supplied to the user  
 E Load Energy need of the user (Load)  
 SoFrac Solar fraction (EUsed / ELoad)

Figure 6. Simulation result.



According to the latest edition of *Tracking the Sun*, an annual PV cost tracking report produced by the Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab). The report indicates that the median installed price of PV systems completed in 2012 was \$5.30/W for residential and small commercial systems smaller than 10 kilowatts (kW) in size. It fell by 0.90\$ per Watt in 2013. For developing country the labor is cheaper, take India for reference, its rate is around 2.5\$ per Watt for installation [18].

$$\text{Total} = 16,875 + 10,560 + 10,500 + 1800 + 2000 = 41,732\$$$

All of these cost items are variable costs, so the cost will increase with total installed capacity and if there is expansion in the future.

## 4.2. Assumptions

- 1) The total installed capacity of 6.92 kWp, the total cost is 41,735\$;
- 2) The project is completed in 2014 (from the proposal been accepted);
- 3) The total investment donated is tentatively scheduled for 70%;
- 4) Through simulation software estimation, the first year of the project the system will generate about 14,712 kW·h in total, take the annually decay rate by eight thousandth, within 25 years of life cycle the total generation is 334,563.4 kW·h, plus a roughly annual cost of \$3325 for maintenance, the average price is about 0.35 \$/kW·h.

The payback period is easy to get then by following. As we know in Haiti the cost of electricity produced by the electric grid company is about 0.23\$/kW·h, and take the first year production which will lead to \$3383 value. So the payback time of this system is 10.71 year, compared to the average payback time for the developing countries, which is 6.76 years.

## 5. Conclusions

This Photovoltaic system is designed for SOLARWORLD donated Haiti school project. The off-grid PV system can produce total energy of 14,000 kW·h per year with total cost of \$41,735 dollars.

Without electricity and distribution system has been erected in remote regional, independent photovoltaic system become a very effective application which has broad prospects. When designing of a stand-alone PV system, PV array and the battery capacity is the basic design. In this thesis, through studying examples of stand-alone PV systems, the stand-alone PV system design steps are summarized as well as solve the real problem. In addition, discusses the independent photovoltaic Array design and battery capacity calculation problem. For the capacity design, besides load cases, fully consideration about the environmental conditions is very important: include the site location, solar radiation, climate, topography and surface features and so on. Summarized steps can be used for other stand-alone PV system design.

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