Alternative Energy

Chapter 5 Part 2: Load Assessment and System Sizing

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Chapter Description

- Expected Outcomes
  - To calculate load assessment
  - To design PV stand-alone system

- References
  - Stand-alone Solar Electric Systems: The Earthscan Expert Handbook for Planning, Design and Installation by Mark Hankins, Earthscan, 2010.

Step to design a PV stand-alone system

1. Calculation of the load energy demand and determine the system voltage
2. Survey of solar resource and the selection of PV modules
3. Sizing and selection of battery
4. Sizing and selection of inverter, charge controller and other BOS

1. Calculation of the load energy and determine the system voltage

✓ There have two type of load assessment:

- AC load
- DC load

✓ Daily requirement for electricity

– Unit of consumption for electricity

$$E_{req\_daily} = P_{appliance} \times H_{use}$$

E_{req_daily} is daily energy requirement (Wh per day)

$P_{appliance}$ is power of appliance

H_{use} is expected daily use of appliance (hours per day)

1. Calculation of the load energy and determine the system voltage

Example: AC load(Wh/day)

Appliances	Appliances Power (W)	Expected daily use (hour per day)	Electrical requirement (Wh per day)
TV	50	5	250
Fan	50	8	400
Refrigerator	120	24	2880
4 x Fluorescents (20W)	80	6	480
Electric Kettle	1000	0.5	500
Electric Cooker	3000	1	3000
		Total	**7510**

Load Assessment Cont..

Example: DC load(Wh/day)

Appliances	Appliances Power (W)	Expected daily use (hour per day)	Electrical requirement (Wh per day)
Laptop	20	5	100
CD player	15	2	30
6 x LED light(12W)	72	12	864
Battery charger	30	6	360
Phone charger	20	0.5	10
Digital Clock	5	24	120
		Total	**1484**

1. Calculation of the load energy and determine the system voltage

Estimate system losses

There are concerns about two types of efficiency:

- **General System Efficiency**: the efficiency of cables, the battery and the charge controller. This can be taken to be 80 per cent (meaning 20 per cent of the energy is lost).
- **Inverter Efficiency**: a good inverter, one designed for use in stand-alone PV systems for example, will be about 85 per cent efficient under average loads.

1. Calculation of the load energy and determine the system voltage

$$E_{req\_daily\_rev} = E_{req\_DC} + \left(E_{req_{DC}} \times LOSS_{DC}\right) + E_{req\_AC} + \left(E_{req_{AC}} \times \eta_{inv}\right)$$

where

$E_{req\_daily\_rev}$ is revised energy required daily

E_{req_DC} is the DC load energy

$LOSS_{DC}$ is the general system efficiency

E_{req_AC} is AC loads energy

η_{inv} is inverter efficiency

System Voltage

- 'System voltage' is the nominal voltage at which the batteries, charge regulator and solar array operate.
- Also, system appliances often operate at the system voltage.
- In general, PV_SA system voltage (SV) is : 12V, 24V or 48V DC.
- It is recommended to use SV:

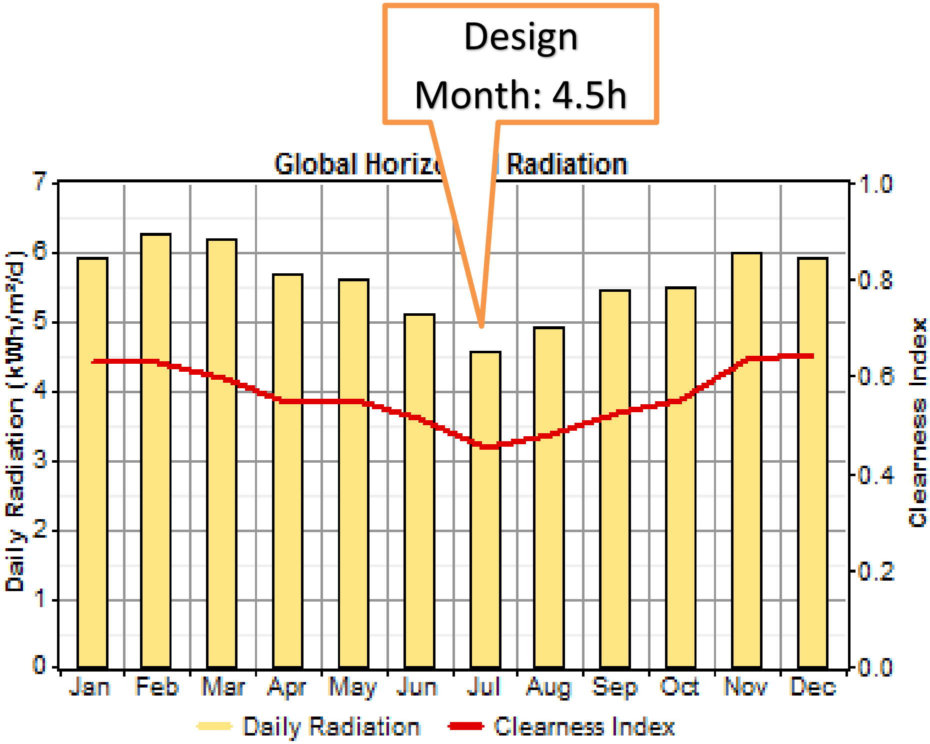
Condition	Recommended system voltage
$E_{required\_daily} \leq 1$ kWh	12 V_{DC}
1 kWh $\leq E_{required\_daily} \leq 4$ kWh	24 V_{DC}
$E_{required\_daily} \geq 4$ kWh	48 V_{DC}

- Most small stand-alone PV systems (especially solar home use $12V_{DC}$ as their system voltage.
- For AC power, an inverter is used to convert the electricity from the battery to AC voltage.
- If the system 24 or 48 V_{DC} Voltage is used - the batteries and PV modules should be wired in series or series-parallel so that they voltage become 24 or 48V, and 24 or 48V charge regulators and inverters must be used
- Such systems have less voltage drop in wire runs, so they are often selected to save on cable costs (48 V_{DC} System are common in stand-alone telecom systems).

- MPPT charge controllers accept electricity from the array at a range of voltages (i.e. from 15 to over 100V) and deliver it to the battery at 12 or 24V.
- Many charge controllers and inverters can operate at either at the system voltage of 12 V_{DC} or 24 V_{DC}. The system voltage can be sensed and adjusted automatically.
- In addition, one of the general limitations is that, the **maximum continuous current** being drawn from battery should be **no greater than 120 A**.

2. Survey or solar resource and the selection of PV modules

- Next, check which month has **the lowest mean daily insolation**.
- This is called the **design month** and it is used to size the array for stand-alone systems.
- Most off-grid PV system are designed for the month of the year with the lowest insolation so that when the sun is least available, the system will work.



3. Sizing and selection of battery

There are several calculation to determine sizing of the system:

1. PV module sizing
2. Battery sizing

Daily system charge requirement

- Divide the revised daily total system energy requirement, $E_{req\_daily\_rev}$ by the system voltage, SV to get the daily system charge requirement in amp-hours.
- This is the charge in amp-hours that the module(s) will have to provide each day to meet the load requirements.

$$C_{daily\_req} = \frac{E_{req\_daily\_rev}}{SV}$$

Sizing and Choosing the PV Module(s)

PV module sizing.

- Daily output from one module:

$$\left[\begin{array}{c}\textit{Current at load or}\\ \textit{other current}\\ \textit{specification}\\ \textit{of module}\\ (A)\end{array}\right] \times \left[\begin{array}{c}\textit{Daily insolation}\\ (\textit{Peak} - \textit{hours/day})\end{array}\right] \times \left[\begin{array}{c}12\\ (V)\end{array}\right] = \left[\begin{array}{c}\textit{Daily output}\\ \textit{of one module}\\ (\textit{Wh/day})\end{array}\right]$$

Sizing and Choosing the PV Module(s)

Example:

In Malaysia, the average daily PSH is 4kwh/m2. The module with the maximum current of 3.2A under STC is to be used. Calculate daily energy output from that module.

3.2 x 4 x 12 = 153.6 Wh/day at 12 V

Calculate the system design charging current

- The module(s) in a system must be chosen so that their energy output matches the total daily system energy requirement. For your solar electric system to succeed over the long term, the average daily energy output of the modules must equal the average daily energy requirements.
- This is the '**system design charging current**' - the charging current the array must produce to meet your energy requirements. You need enough modules to produce this current at your system voltage.

Calculate the system design charging current

$$I_{charging\_module} = \frac{C_{daily\_req}}{PSH_{design}}$$

where

$I_{charging\_module}$ is the system design charging current

PSH_{design} is the design solar insolation value

Example

From the previous example, the average daily energy output from one module is 153.6 Wh/day at 12 V. The daily requirement of the appliances for home considered in the example DC load table in previous slide which is 1484 Wh/day. How many module are needed? (consider 80% of average charging efficiency of the battery)

$$\frac{1484}{153.6 \times 80\%} = 12.08 \approx 13\, modules \text{ (round up)}$$

Battery sizing and Selection

Choosing the battery

- Choice of battery will be limited by what is on the market and how much you have to spend. Remember, buy a good battery if you can afford it – it will pay off over the years.
- Identify the available batteries, list important characteristics that can fit within your budget
- Calculate the required capacity of your battery. The capacity of the battery required depends on three primary factors;
  - The daily system charge requirement, C_{daily_req} (Ah) that must be supplied to the loads each day.
  - The maximum allowable depth of discharge factor (DOD_{max}). This is the deepest depth of discharge that is ordinarily allowed with the battery. Shallow cycle batteries, for example, should not he cycled below 20 per cent depth of discharge, while deep discharge batteries can regularly handle 50 per cent discharges.
  - The reserve storage factor, or the number of days of storage needed (system autonomy). This varies with site and is higher for site with cloudy weather.

Battery sizing and Selection

- Remember, over-sizing the battery is not recommended, especially where there are long cloudy periods and where load management is not strict.
- Most system designers compromise between cost and reliability by selecting a battery with a capacity of between two (in very sunny locations) and five (locations with cloudy periods) times the daily system charge requirement. If appliances are mostly used during the day (when the sun is shining) then the need for battery capacity is reduced.

Battery sizing and Selection

Calculating capacity of required system battery:

$$C_{batt\_req} = \frac{C_{daily\_req} \times T_{res\_days}}{DOD_{max}}$$

C_{batt_req} is the capacity of required system battery

C_{daily_req} is the daily system charge requirement

T_{res_days} is the reserve storage factor (system autonomy)

DOD_{max} is the maximum depth of discharge

Minimum number of Battery, $N_{\min\_batt}$

$$N_{\min\_batt} = \frac{C_{batt\_req}}{C_{batt\_12V} \times DOD_{max}}$$

C_{batt_req} *is theTotal usable capacity needed (Ah at 12 V)*

C_{batt_12V} is theFull capacity specified for one 12 V baterry (Wh/day at 12 V)

Determine the configuration of your battery set

- Batteries should be configured at the system voltage. Make a drawing of your battery configuration. Get advice if you are unsure how to do this.
- Small off-grid PV systems usually use 12 V_{DC} as their system voltage and 12V batteries. If more than one 12V battery is used, they are configured in parallel.
- If 2V DC or 6V DC batteries are used, they are configured in series so that their total equals the system voltage (i.e. at a system voltage of 12 V_{DC}, two 6V batteries would be configured in parallel).

Example

The daily requirement of the electrical appliances for a home considered in the example DC loads table in the previous slide which is 1484 Wh/day. The batteries selected for this system each has a capacity of 110 Ah (lead-acid batteries) intended for deep-cycle(the percentage of charge used on each cycle of a battery) operation and can be discharged to a depth of 60%. What is the smallest number of batteries that can be used?(the typical autonomy value of 5 days is chosen).

4. Sizing and selection of inverter and charge controller

Before choosing a charge controller:

1. Decide the controller size (current rating)
2. Decide controller features

Controller need to be sized according to the system voltage (either 12V, 24V or 48V)

4. Sizing and selection of charge controller

Step 1: select the charge controller size

- The controller must be sized to handle both the maximum short-circuit current from the array and the maximum demand of the load.
- Charge controller sizes range from 5 to 50 amps or larger.

4. Sizing and selection of charge controller

- Note that many charge controllers have the same `charge' and 'load output' rating (i.e. a l0A controller is sized to accept l0A of charge from the array and to provide a maximum of 10A load output).
  a. To determine the array current size, calculate the maximum short-circuit current of the array and multiply it by 1.25.
  b. To determine the maximum DC load output current, calculate the maximum power consumption of all DC (not AC) appliances. Divide this by the system voltage to get the maximum DC load and multiply by 1.25. This is the load output current rating in amps.

4. Sizing and selection of inverter

Step 1: is an inverter needed?

Many small off-grid PV system operate 100% on 12V and do not require inverters.

If the system is below 100Wp and you ran procure' all of your appliances in 12V, at 12V DC system without an inverter may be the best choice.

Step 2: do you need an inverter-charger?

If an inverter is needed, decide whether it will function only as an inverter (i.e.. DC to AC only) or it is also need, an Integrated battery-charger. Inverter-chargers (usually for systems above 500Wp only accept power from generators (or the mains grid in the case of back-up system) and can charge the batteries when the solar resource is low.

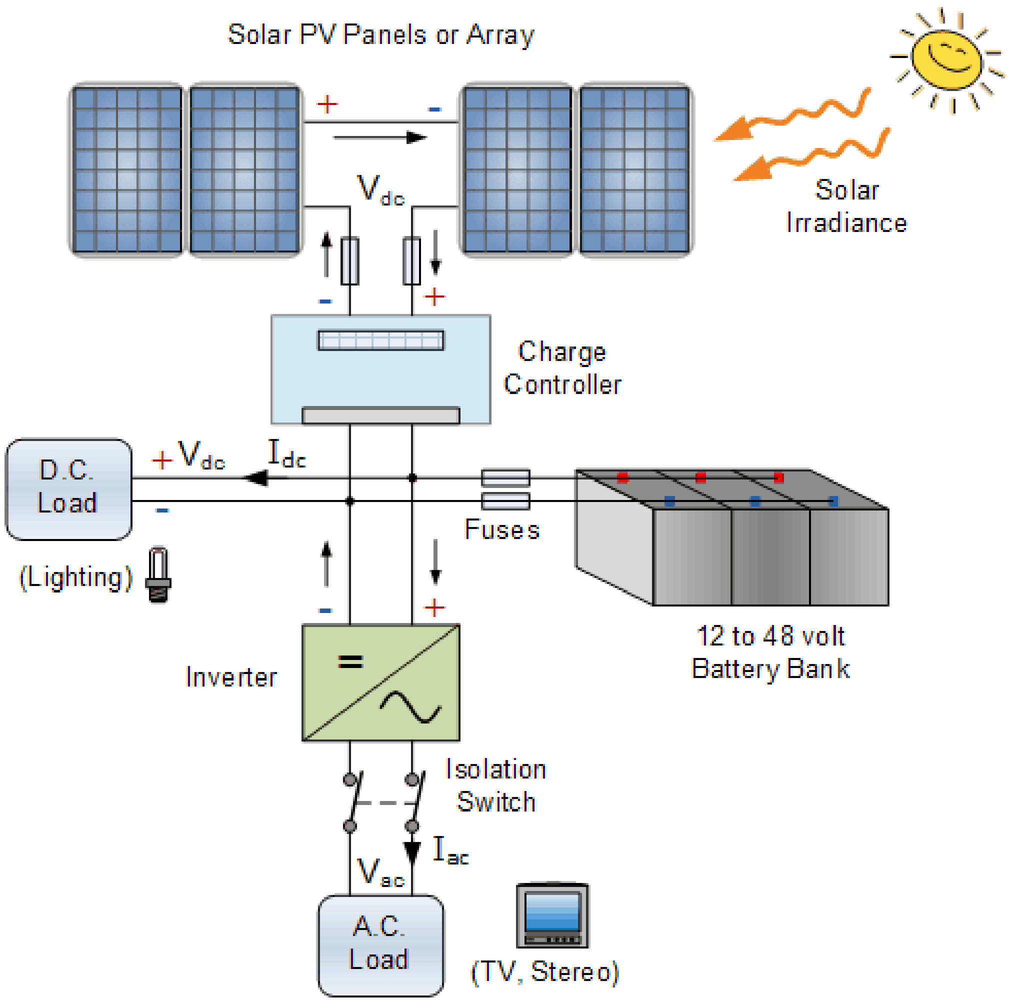
4. Sizing and selection of inverter

Step 3: inverter rating

The inverter must deliver the maximum AC load that you expect from AC devices. Total up the power of the AC devices and multiply this by 1.25. This is the recommended inverter rating.

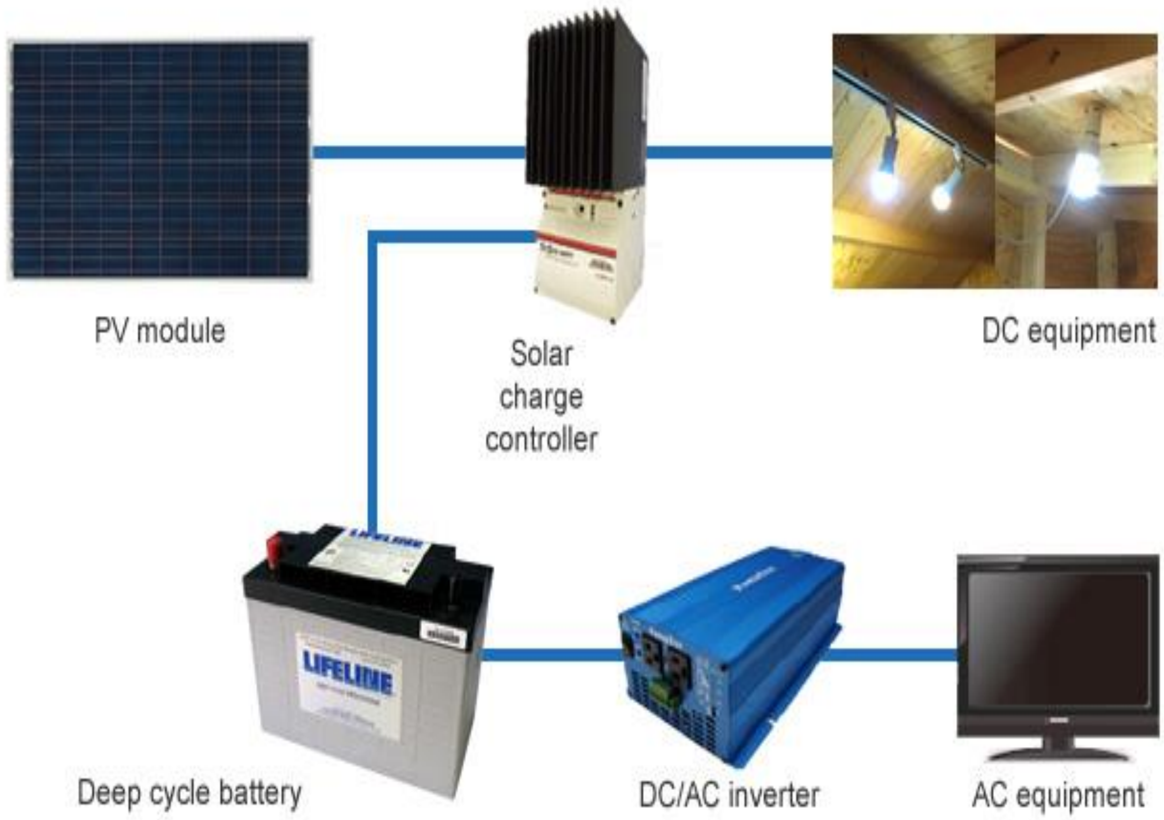
Step 4: select desired inverter features

Decide the desired features of the inverter you need. Make sure the wave-shape of the inverter matches the needs of your appliances.

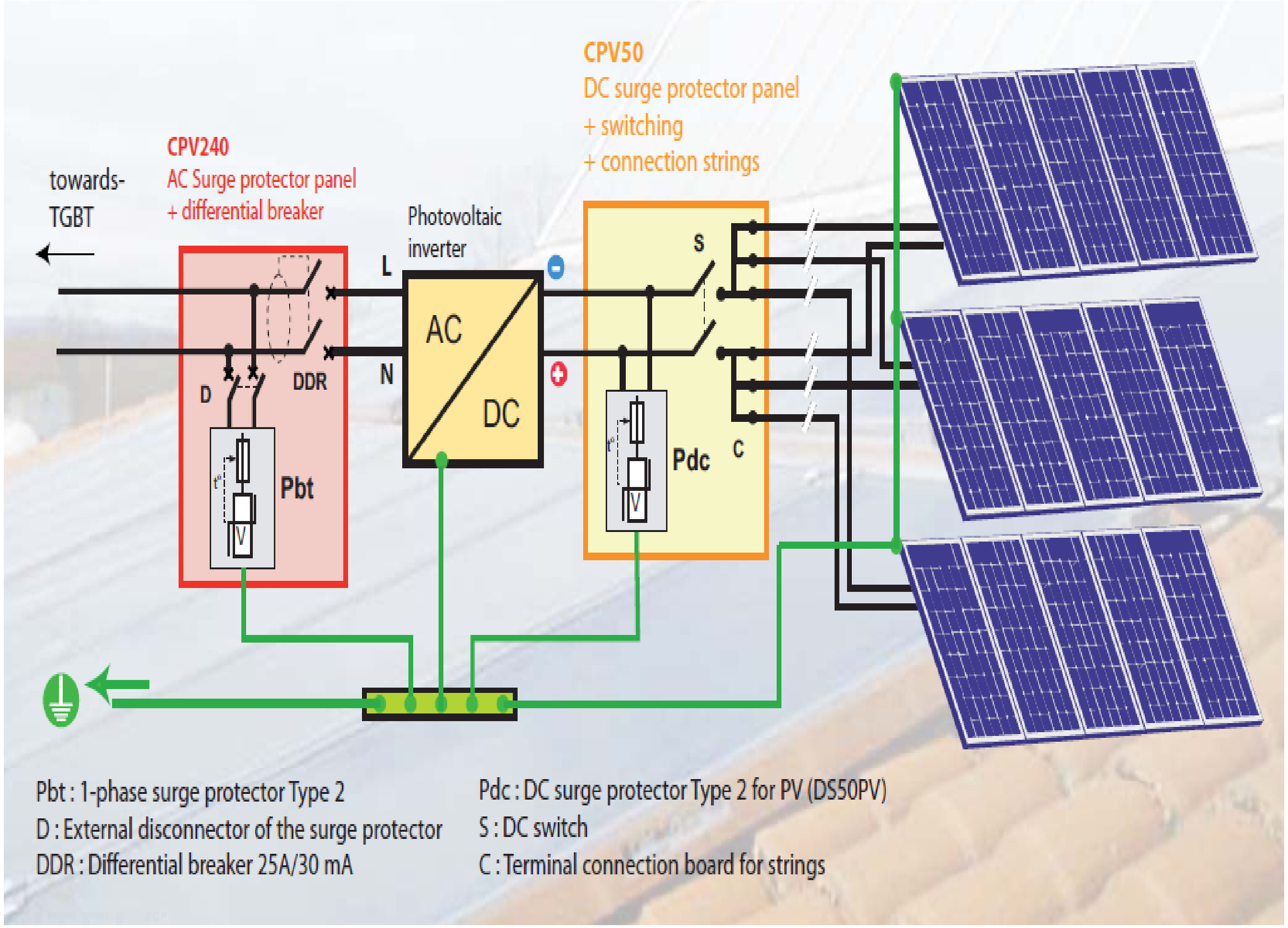


Solar PV Panels or Array
+
-
V_{dc}
-
+
Solar
Irradiance
Charge
Controller
D.C.
Load
+ V_{dc}
I_{dc}
-
(Lighting)
Fuses
-
+
12 to 48 volt
Battery Bank
Inverter
=
Isolation
Switch
I_{ac}
V_{ac}
A.C.
Load
(TV, Stereo)

System Block Diagram



PV System Protection



System Protection

Surge protection:

- DC network
- AC network

AC Surge Protection Device (SPD)

DC Surge Protection Device (SPD)

Thank You