Standalone PV Systems

Ahmad El Khateb

Contents

Introduction

- The energy issue
- Overview of electricity generation
- Renewable energy options
- Why photovoltaics?

The energy issue

Most obviously relevant for developing countries

1.5 billion people do not have access to electricity (what would happen if they all could plug in next week?

Crucial for such “basic” things as:

- Water (drinking, farming ..)
- Education (lights for studying)
- Health Care (refrigeration for medicine etc..)

Access to electricity seeks to greater urbanization and Poverty can be reduced through all of the above.

The energy issue

Important for Developed Countries

- Energy independence/security
- Emissions due to energy generation leading cause of pollution and carbon dioxide in the atmosphere – Global warming
- Energy choices are strongly influenced by policy – compare U.S. with Germany or Denmark
- Problems with maintaining and increasing supply are multiplying – will only get worse and more expensive
- Concerns over environmental impacts of extracting – drilling for oil.

Newark, DE, USA

Generation

Methods of energy generation

• Most common electricity production is via conversion of mechanical energy to electrical energy via turbines or generators

• Source of mechanical power typically thermal expansion/ compression cycle via a generator; can also use turbines or other types of engines

• Different “fuels”:

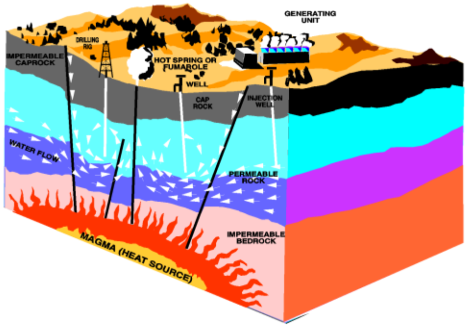
- Coal, Nuclear, Solar Thermal, Gas

• Other sources of mechanical power: Hydro, wind, tidal, geothermal, wave

• New forms of energy conversion are direct e.g. photovoltaics the sunlight is converted directly to electrical energy, Seebeck effect converts heat directly to electricity

Alternatives/Renewables

- Geothermal: very site specific



- Wind Energy: Site issues

- Solar Thermal: good in deserts
- Wave/Tidal: limited capacity/site issues

Why Photovoltaic?

• Other factors like politics make PV attractive due to such things as global warming.

• Photovoltaics is reliable, portable..

– Perfect for remote applications

– Solar is most cost effective solution for many remote or distributed power applications

– Can easily increase capacity

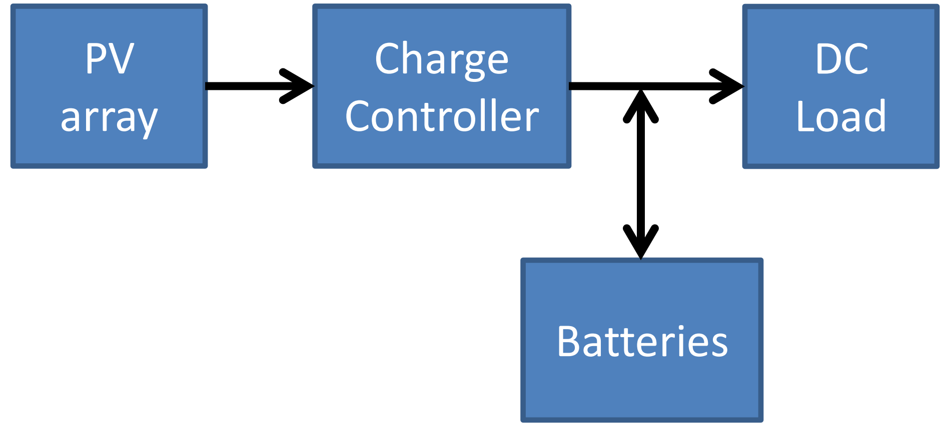
– Minimum maintenance required

– Can even be integrated into existing buildings (and new ones)

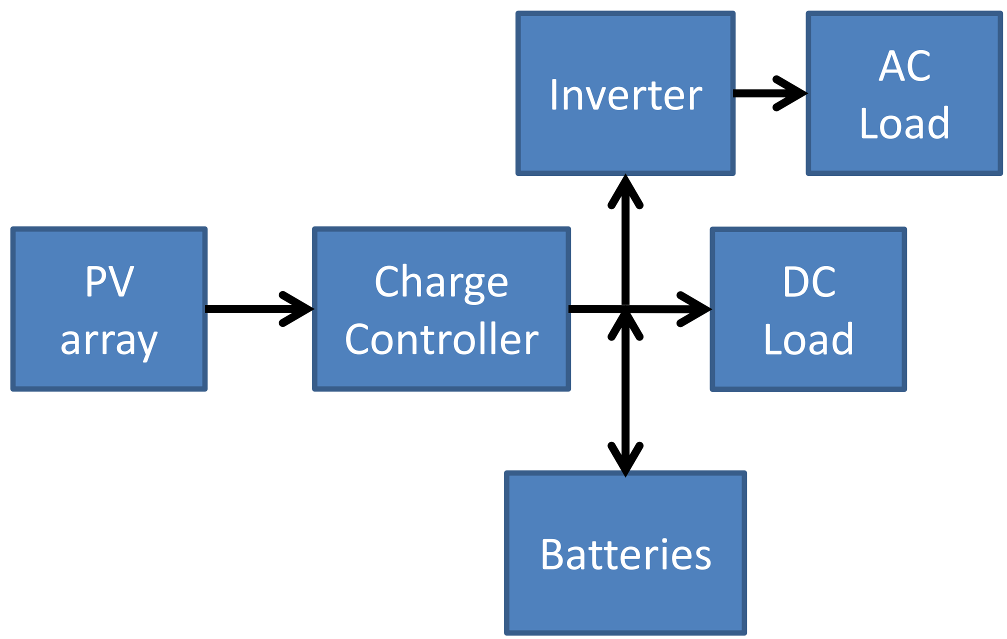
Grid-Connected vs. Standalone
GC vs. SA

- Very different design philosophy
- <u>**SA: availability key issue**</u>
  - Very complicated analysis, design, operation
  - Worst case, longest cloudy period
  - Loss of Load Probability (LLP)
    - LLP(%)= 100 - (% availability)
  - Key parameter: Amp-hours @VBAT
- <u>**GC: annual or daily peak power**</u>
  - Total annual or offset peak power
  - Key parameter: annual kW-hours
  - LLP no concern, grid is backup, no power if grid down

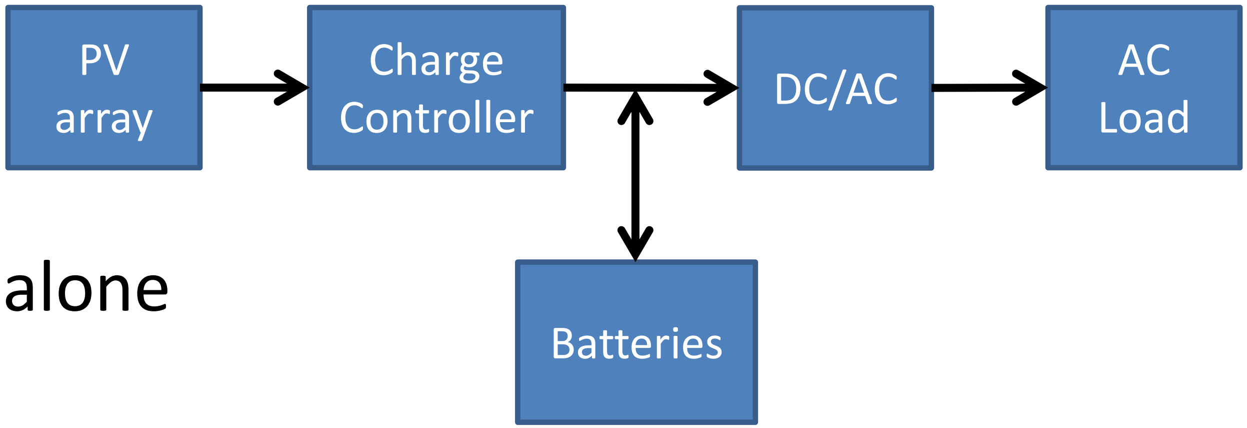
DC standalone System

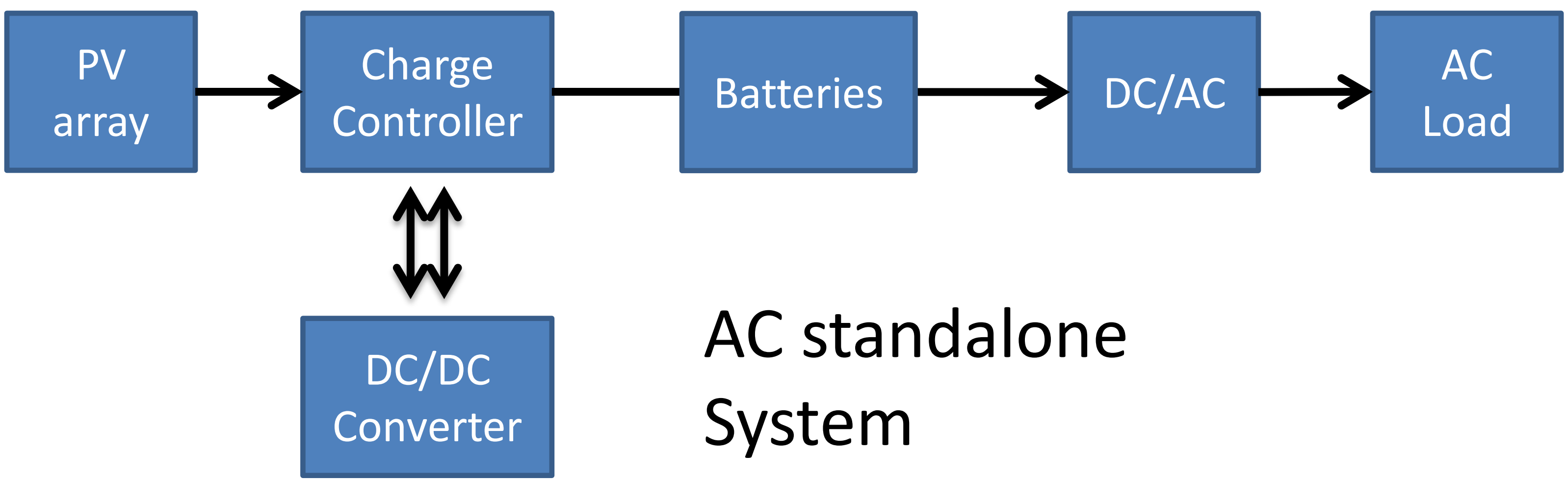


AC+DC standalone System

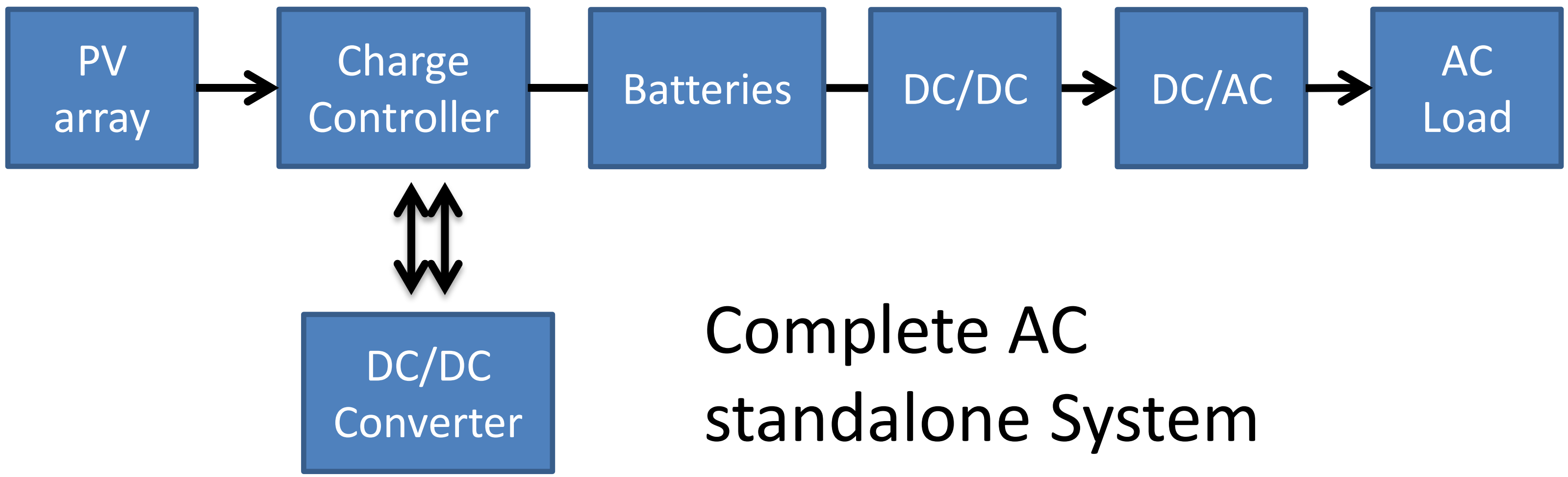


AC standalone System

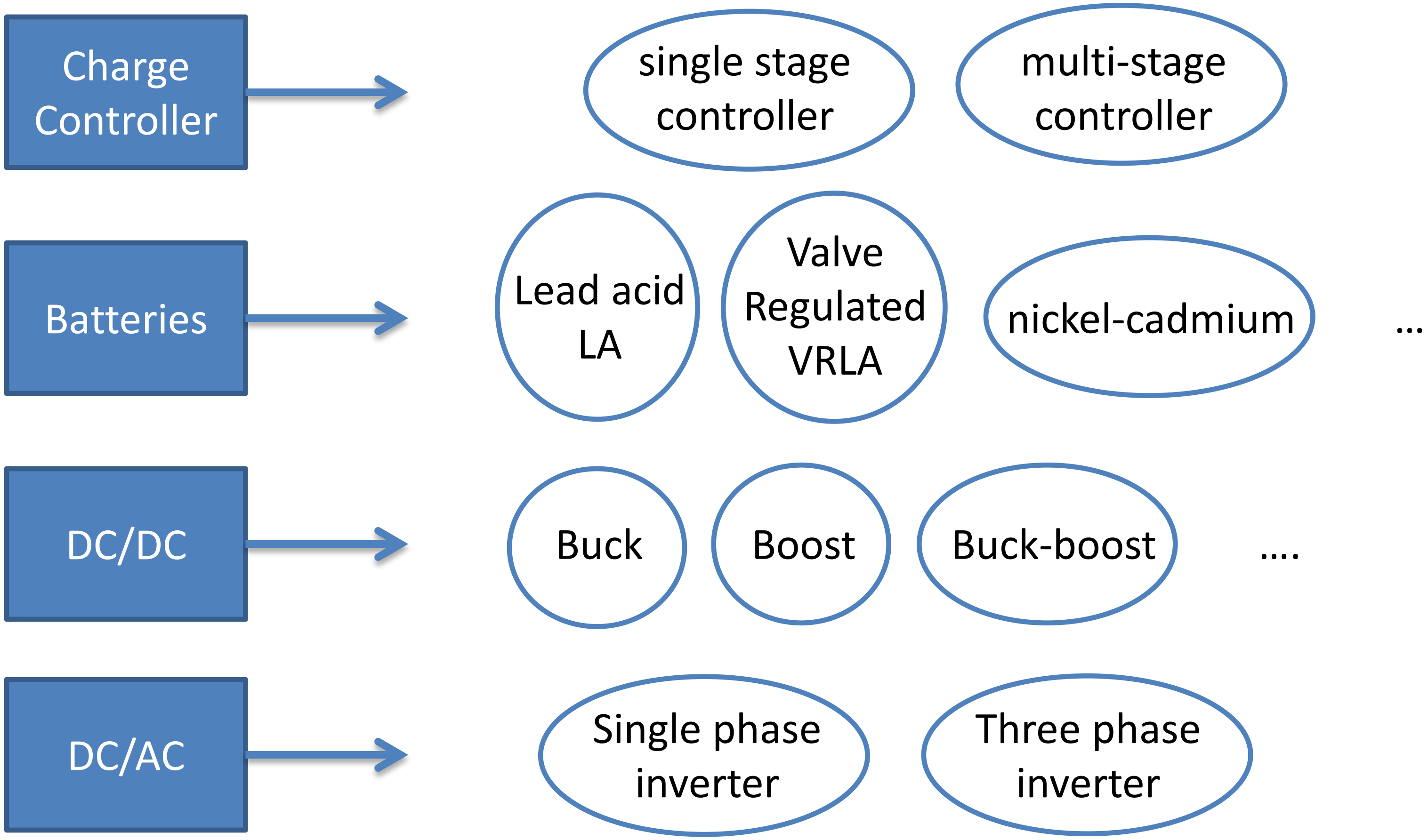




AC standalone System

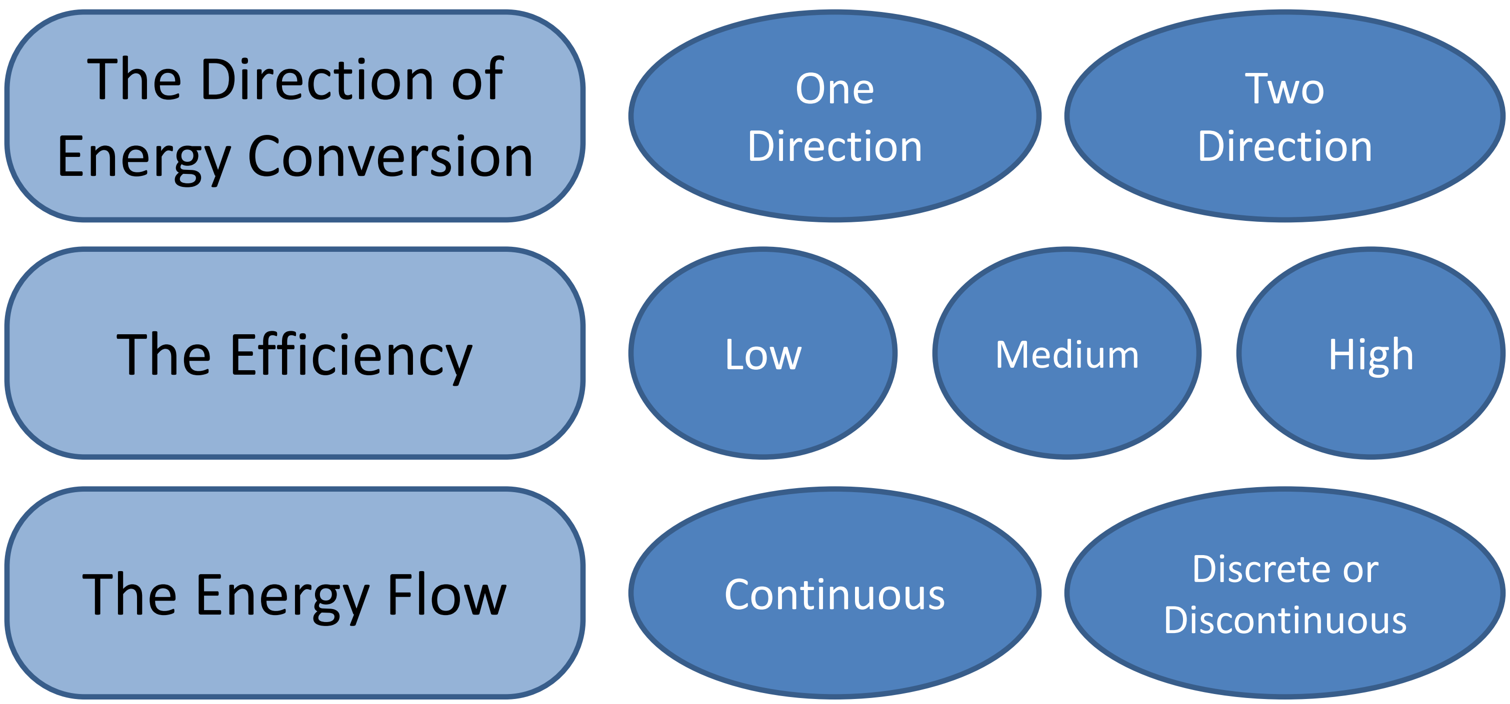


Complete AC standalone System


Charge Controller
single stage controller
multi-stage controller
Batteries
Lead acid LA
Valve Regulated VRLA
nickel-cadmium
....
DC/DC
Buck
Boost
Buck-boost
....
DC/AC
Single phase inverter
Three phase inverter

The DC-DC Converters

Features of DC-DC Converters



The DC Converters

- Boost
- Buck
- Buck-boost
- SEPIC
- Ćuk
- ....

- Convert the energy in one direction
- Low Efficiency
- Moderate Efficiency
- ---------

- High Efficiency
- Discontinuous input energy flow
- Continuous input energy flow
- ---------

Energy vs. Power

- *Power:* output of module or array in Watts (W), kilowatts (kW) or megawatts (MW) under Standard Test Conditions (STC)
- STC = “1 sun” or 1000 W/m2 at 25°C,
- A 200 W module produces 200W only under specific conditions
- Power is instantaneous output from the PV
- *Energy* output of module or array in kW-hrs is what you want
- Energy is power integrated over time
- Energy is what you pay for on the electric bill (2.23 cents/kW-hr)
- Energy is output over period of varying sunlight, angle, temperature
- Goal is to calculate daily/monthly/annual *energy* from module

Batteries

- <u>Batteries are required for the following reasons:</u>
  – Load doesn’t match solar radiation
  – Mitigate the effect of variability in solar radiation
- <u>The key issues for batteries:</u>
  – Why and how battery voltage and capacity change with system and battery parameters
  – Operating constraints on batteries; constraints of state of charge, charge/discharge rate, temperature
  – Lifetime and safety issues with batteries

Batteries

Battery characteristics

- Charging/discharging parameters: State of Charge (SOC), Depth of Discharge (DOD), discharge rate
- Capacity
- Efficiency
- Energy, volumetric and power density
- Other electrical parameters

Lead Acid batteries

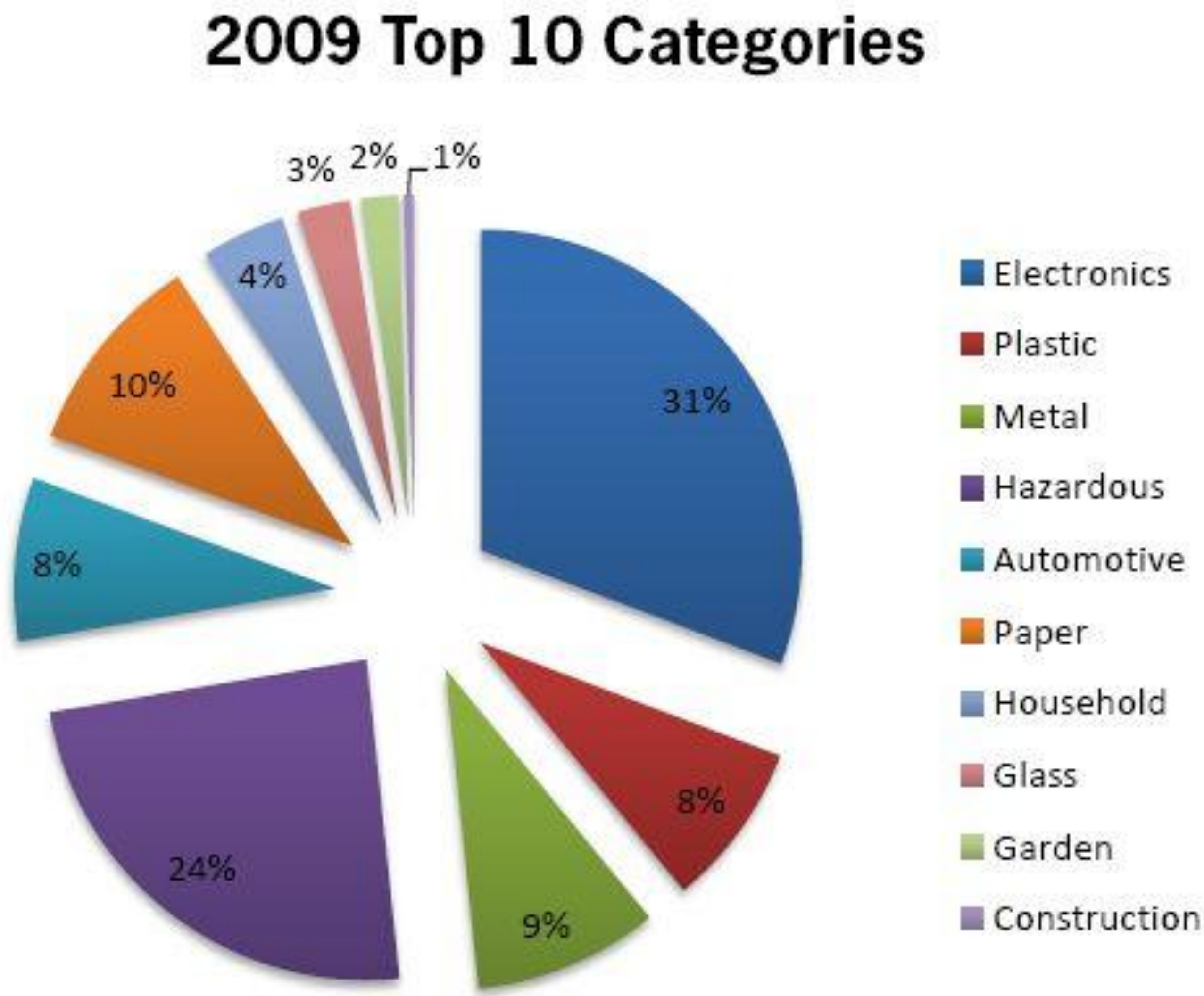
- Operation of lead acid batteries
- Lead acid battery characteristics
- Issues specific to lead acid batteries
- Potential problems – storage

Other battery systems

- Nickel-cadmium

Batteries

- The most recyclable



Batteries

Batteries

Battery capacity

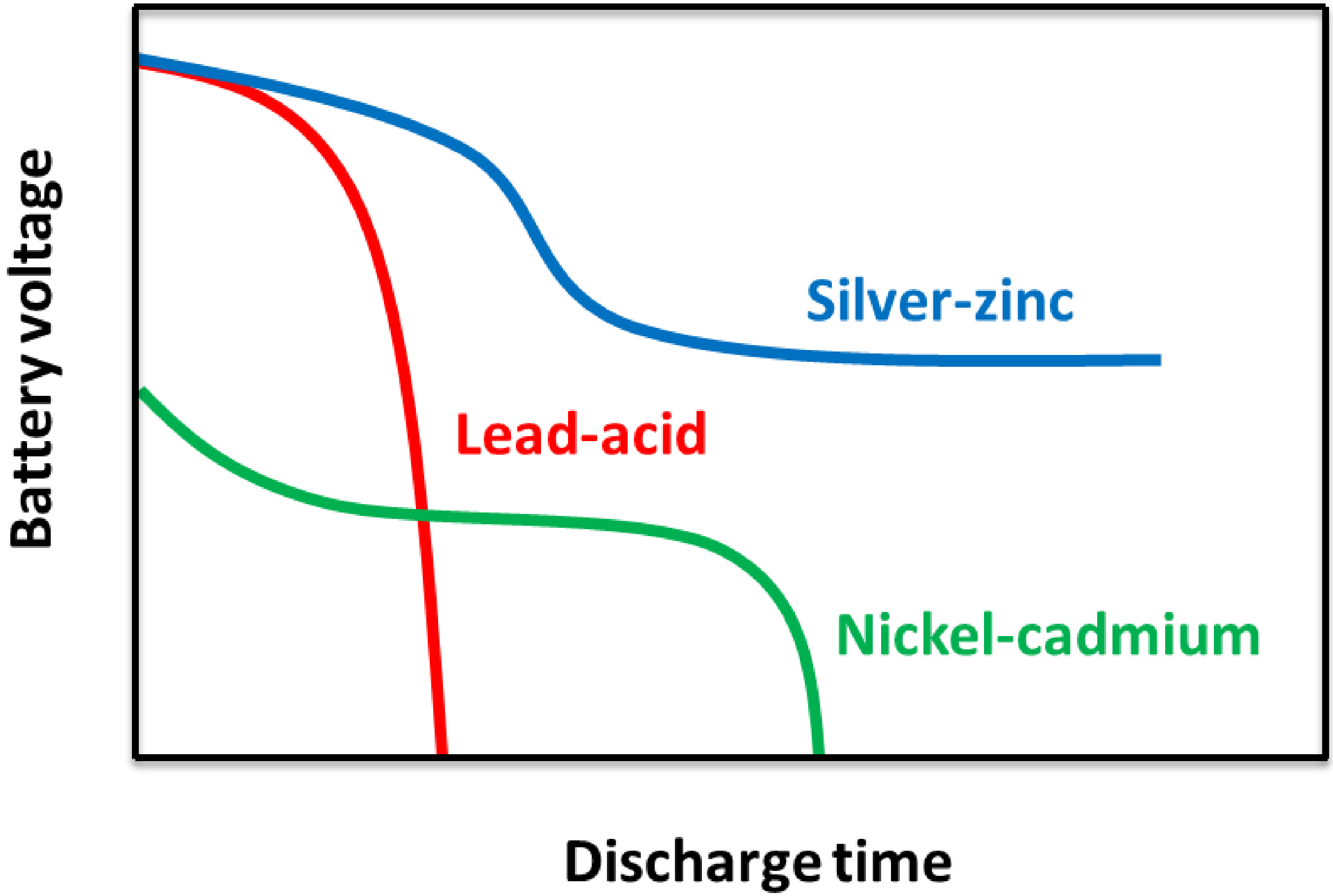
- Capacity(Ah) = Ampere × Hour
- Capacity(Ah) = $\frac{\text{Coulomb}}{\text{second}} \times 3600 \text{ seconds}$
- Capacity(Ah) = 3600 Coulomb (C)

- Energy Capacity = Ah × Battery Voltage

Battery Characteristics

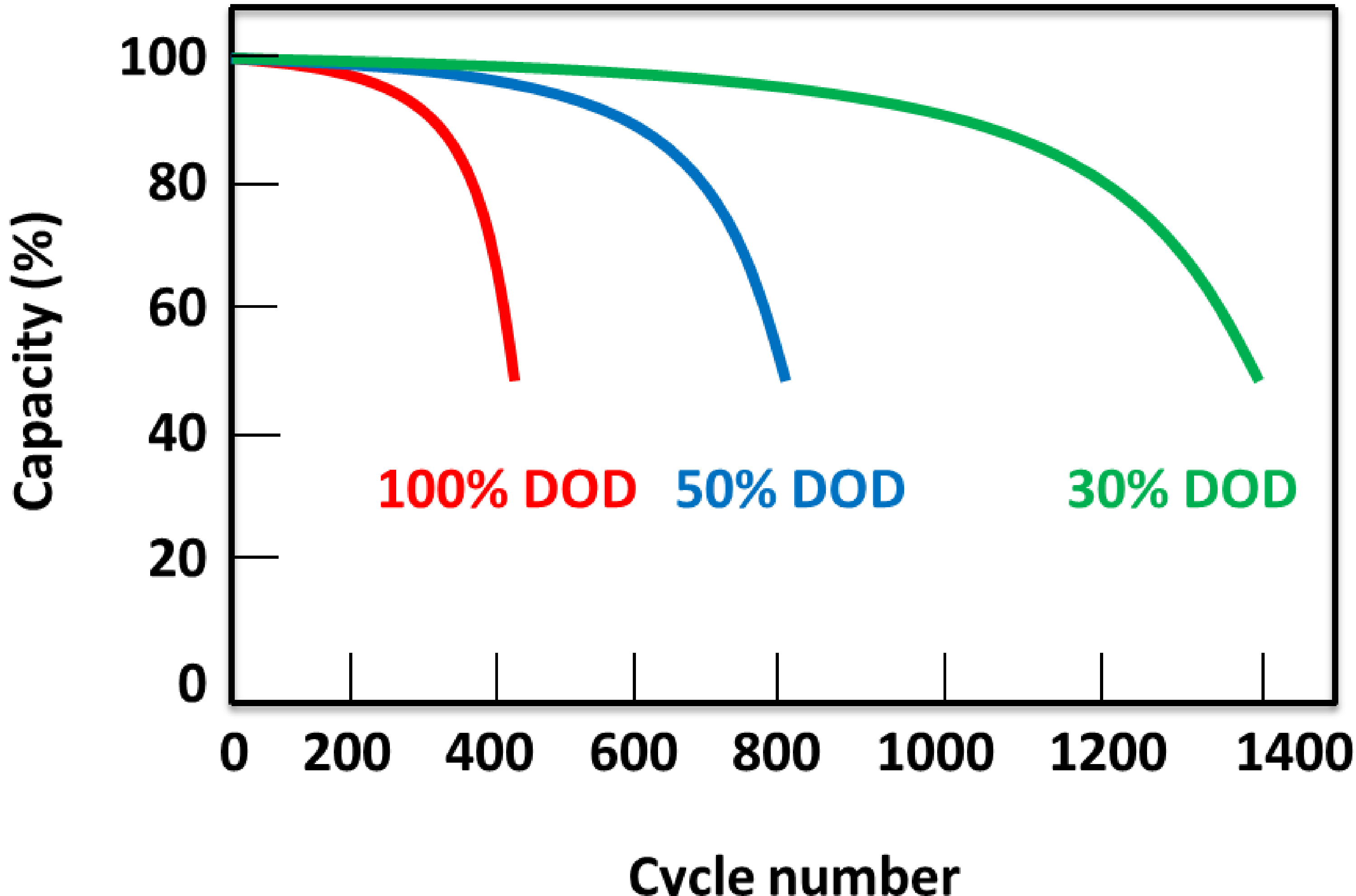
- Battery capacity
  - Measured in Amp-hours rather than conventional Watt-hours due to variation in battery voltage
  - Battery capacity depends on age of battery and the history
- Depth of discharge
- Battery lifetime: (number of discharges)
- Battery voltage and variation of voltage
- Effect of temperature

Battery Characteristics



Lead-acid batteries

Depth of discharge, lifetime and number of cycles



Power Conditioning

Power requirements and matching to PV module

- Functions of power conditioning:

– Keep the module operating at it's maximum power point (maximum power point trackers)

– Optimizing charging of the batteries to prevent damage to the batteries (battery charger)

– Prevent discharging of batteries through the solar cell module (blocking diode)

– Converting from DC to AC (inverter) for applications or feeding the grid

Battery Charging

- Batteries are very sensitive to charging parameters and the lifetime of batteries can be dramatically altered by improper battery charging or leaving the battery at low charge

- Function of battery charger is to provide appropriate charging conditions for the battery, particularly by preventing either over-charging or excessive discharging of the battery

- The type of battery regulator used must be matched to the battery used and a battery charger designed for one type of battery will not be effective for another type of battery

Battery Charging Challenge

- Issues in battery charging

– If charging current is too high, towards the end of the charging cycle tend to get a lot of electrolysis of the water, resulting in gassing rather than storage

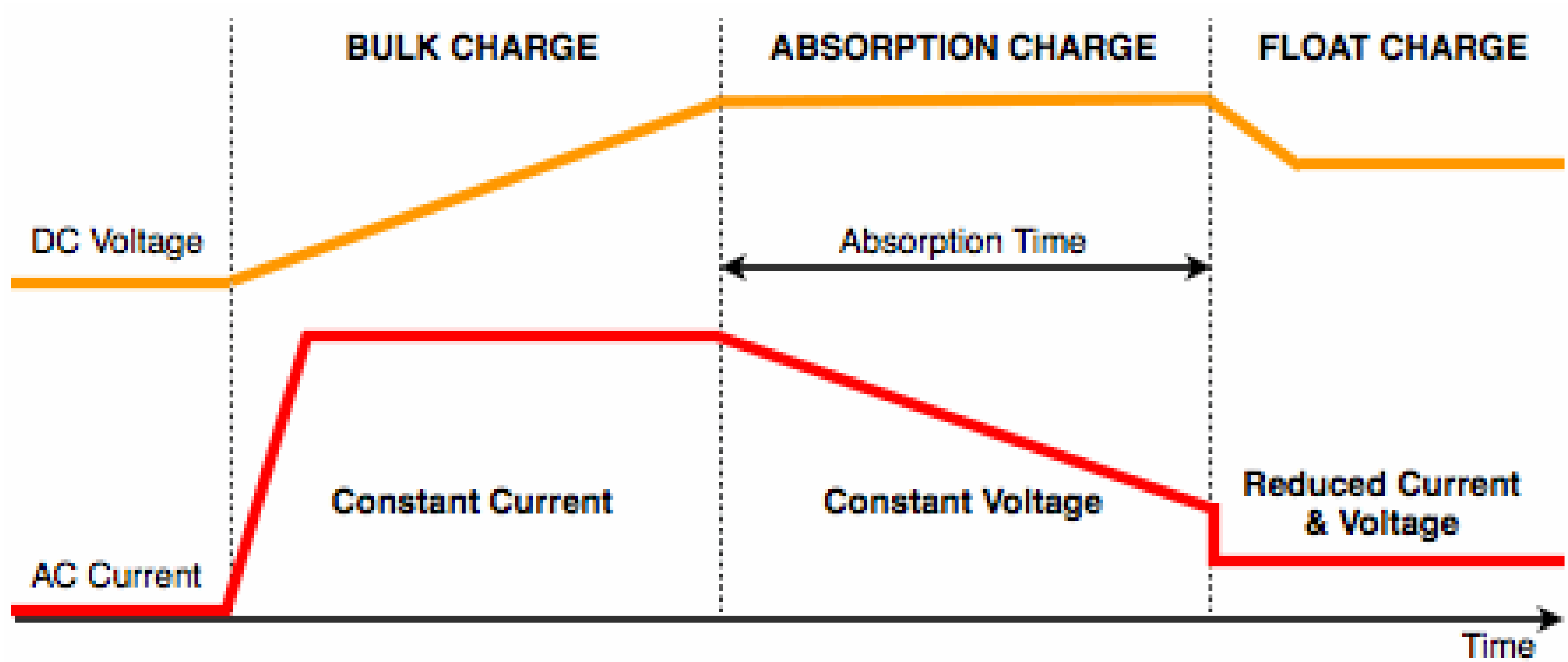
– Abrupt stopping of the charging, however, results in the batteries not reaching their fully charged state, if this happens regularly the battery capacity is reduced

– Solution is to taper the current as battery approaches full charge

– Charging too slowly also has disadvantages:

- Low charging current increases likelihood that power from solar module is used inefficiently
- Want to fully charge the batteries whilst sun light is available to us

Battery Charging Solution



Battery Charging

– Shunt regulator

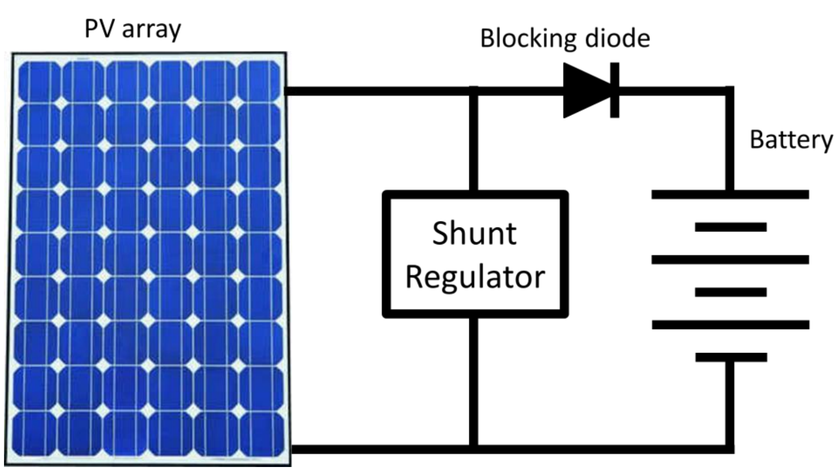
• When voltage reaches certain level shunt regulator is switched on and current diverted through it

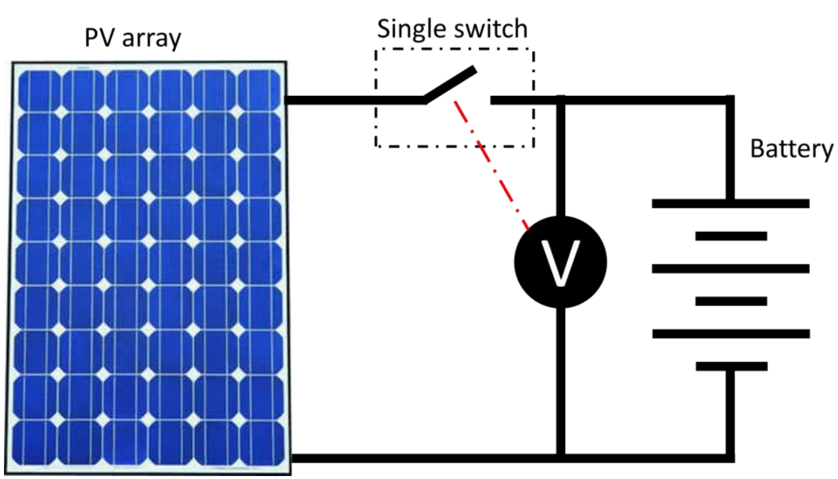
• Since shunt dissipates the power from the modules only used for small system where shunt can handle the array current

– Series regulator

• When a voltage is reached the series switch opens

• Doesn’t allow reduced currents as voltage rises, hence not optimal charging



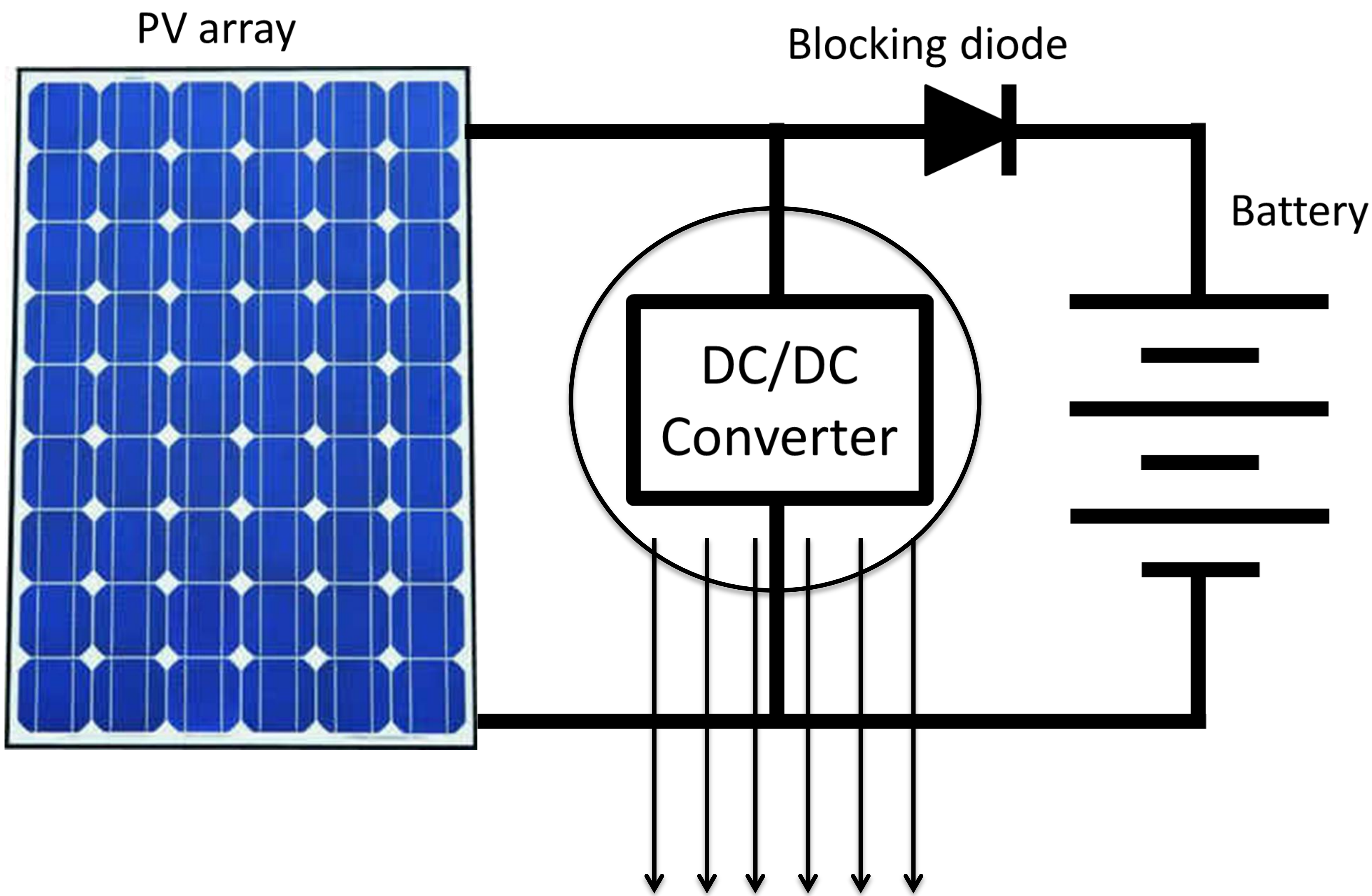


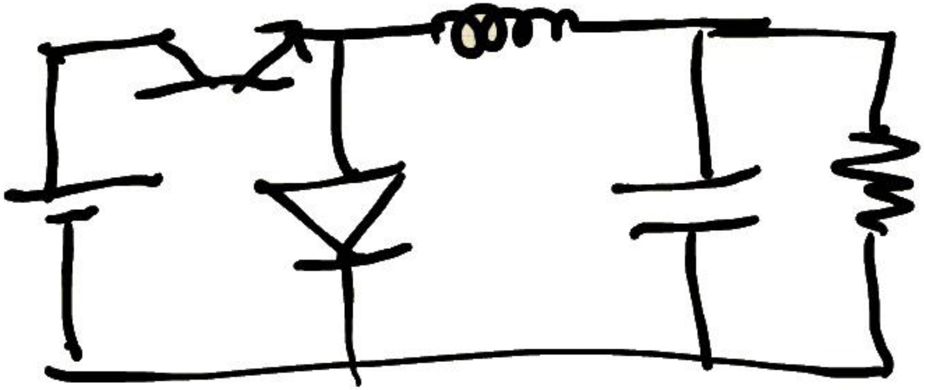
Battery Charging

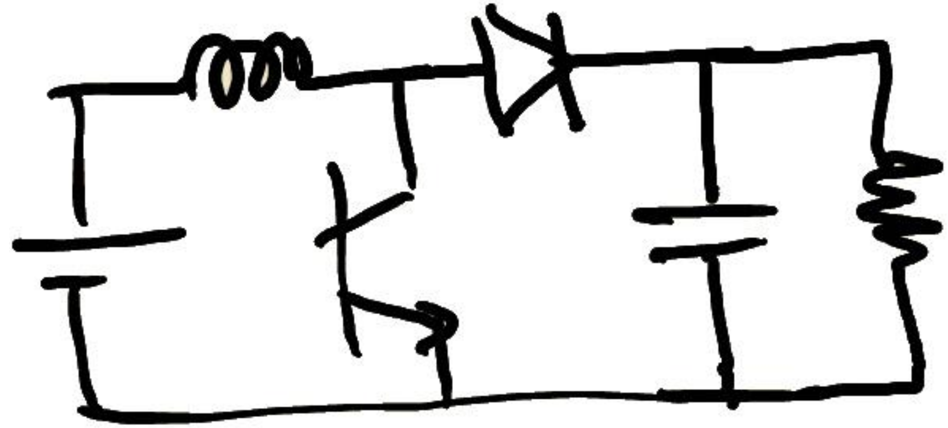
• Pulse Width Modulation Circuits
– A PWM circuit is used to provide a variable voltage, which allows greater control over types of charging methods
– Requires more complex circuitry than shunt or series-switch circuits

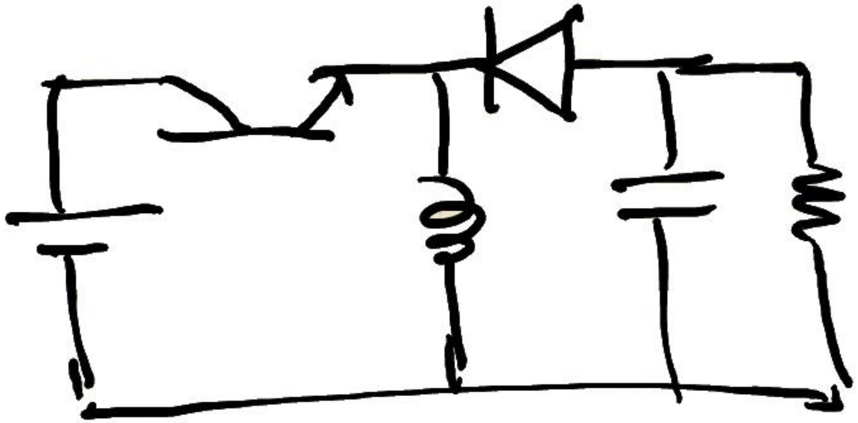
• Amp-hour meters and controllers
– Battery charge measures and controls the amps flowing into and out of the batteries and continuously determines the state-of charge of the batteries
– Allows potentially more precise information about the BSOC but requires periodic calibrations

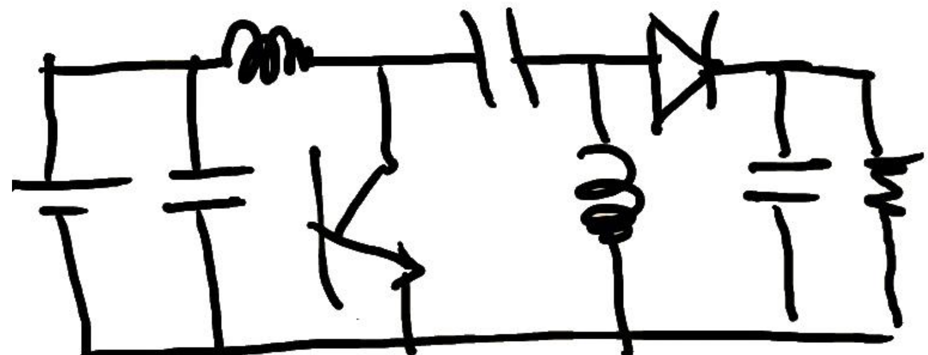
Battery Charging

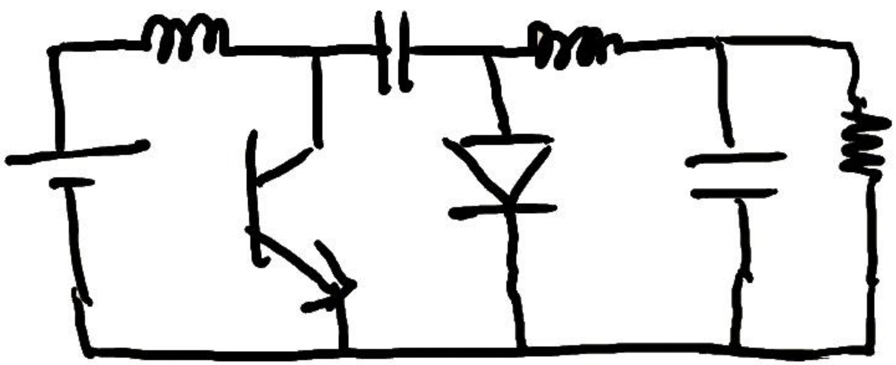


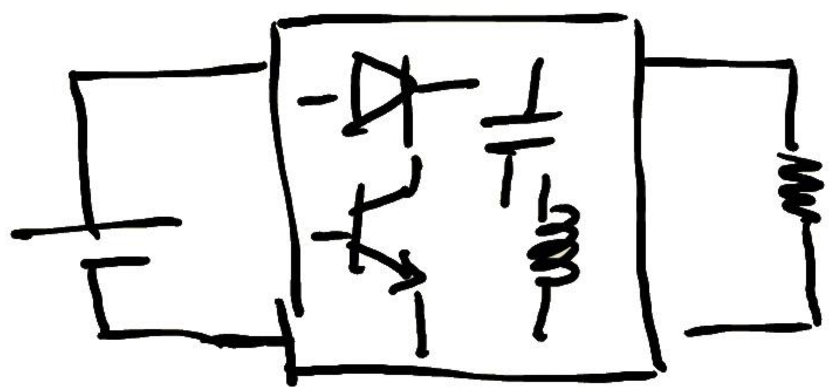




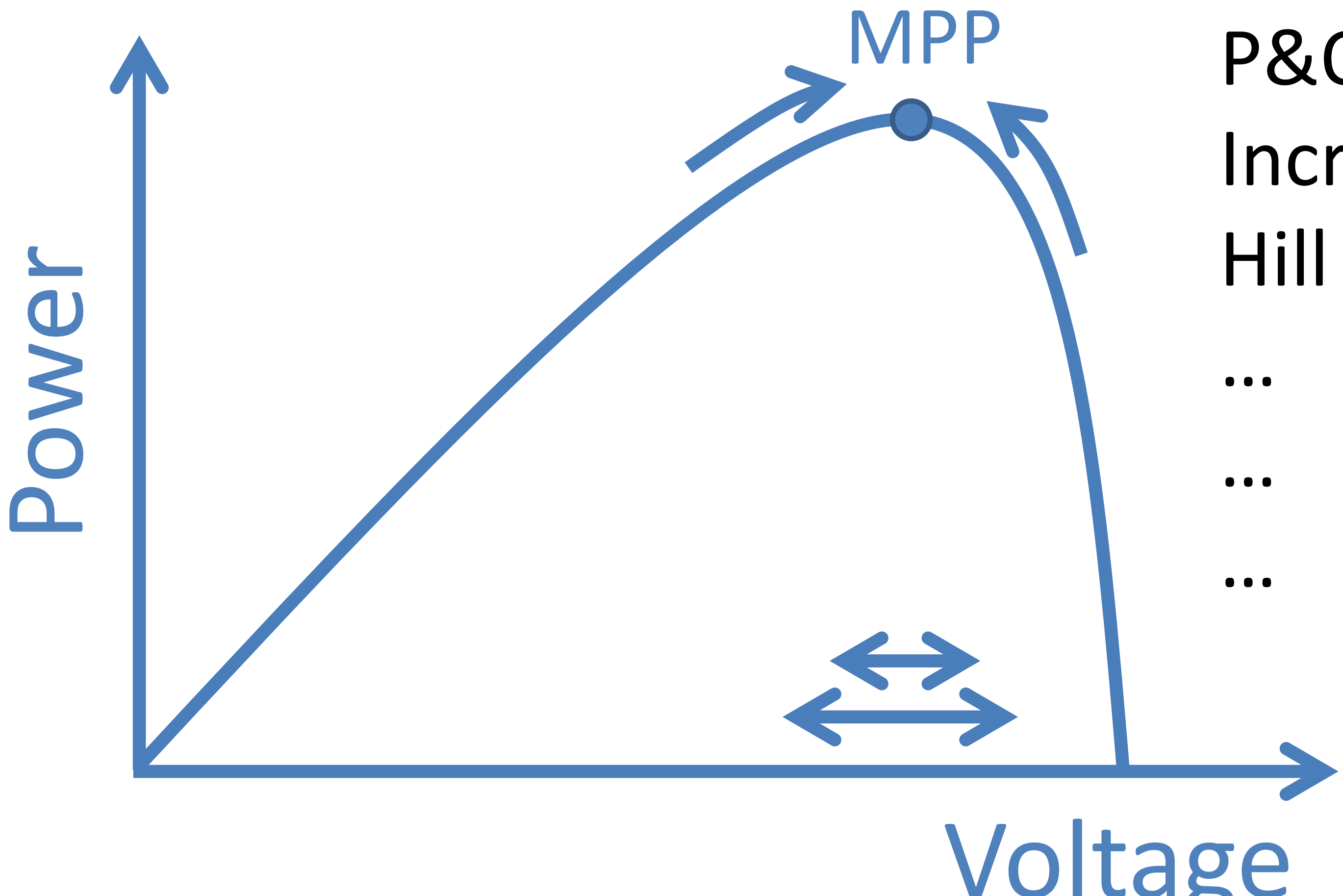








Maximum Power Point Tracking (MPPT)



P&O
Incr. Cond.
Hill climbing
...
...
...

Energy Balance

- The controller operates the system in four operation states owing to the battery state of charge, the load, and the available power.
- The available PV power < the load power. The battery supplies the load automatically.
- The available PV power > the load power, and then, the undue power charges the battery.

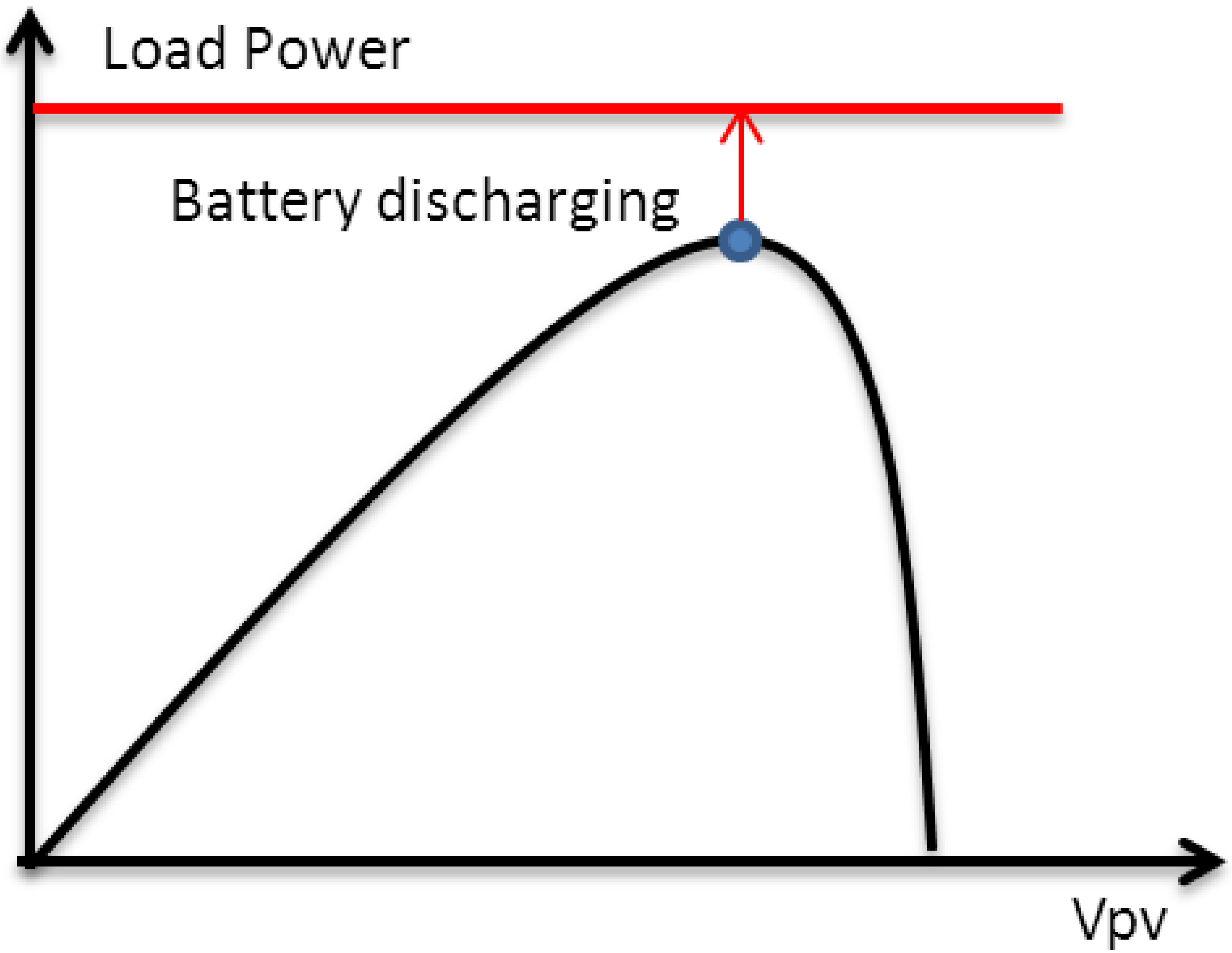
  In the previous two states, the battery current supposedly cannot reach its reference current, but the signal generated by the battery current PID controller which is supplied with the most available power will generate zero-error signal.

- The available PV power > battery + load power. In this case, the battery current will reach its reference current. As a result, the PV module will shift the reference voltage to a higher level than the MPPT voltage. Furthermore, the generated PV power will balance the load and the charging, as well.
- The battery voltage < the level that can supply the load,

  and the available PV power is not sufficient to supply the load.

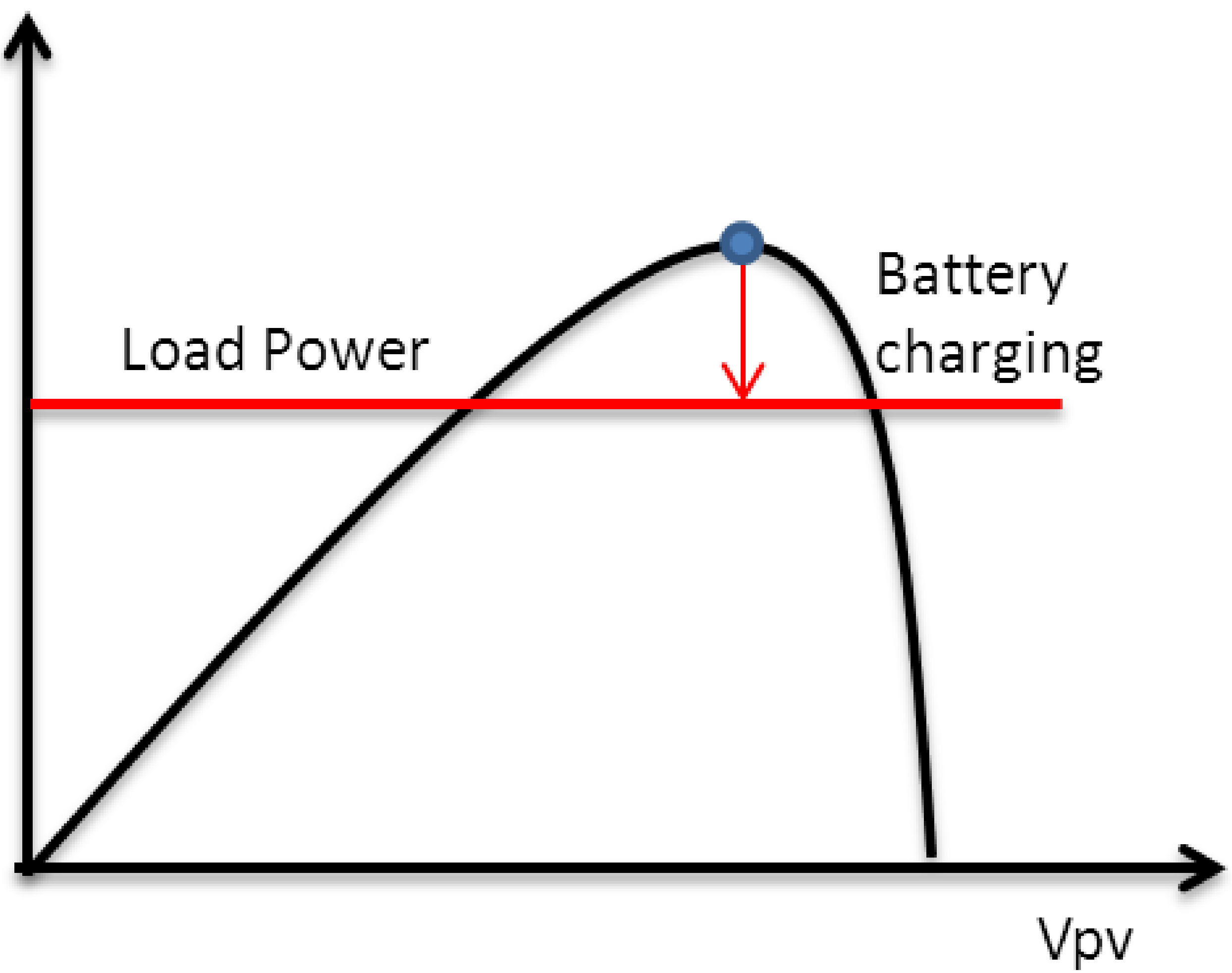
  In this case, a simple comparator switch is used to disconnect the load and reconnect if the battery voltage is larger than the lowest level of batteries.

Energy Balance



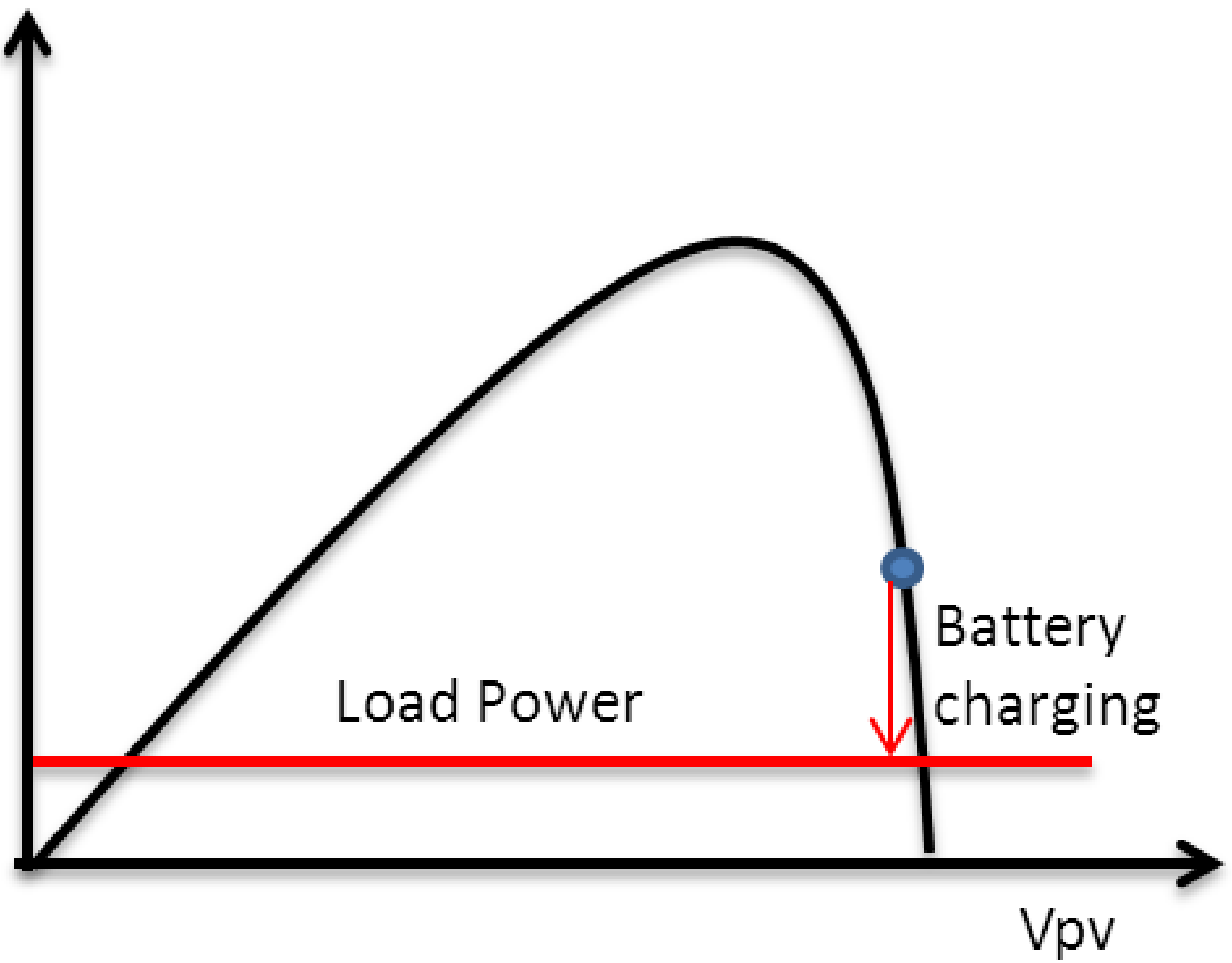
The available PV power < the load power

Energy Balance



The available PV power > the load power

Energy Balance



The available PV power > battery + load power

Design

1. Make initial choice of system topology

2. Calculate load for each month of the year in Ah

- The voltage used in these calculations must be the same as the system voltage

3. Pick a tilt angle, or calculate for several tilt angles

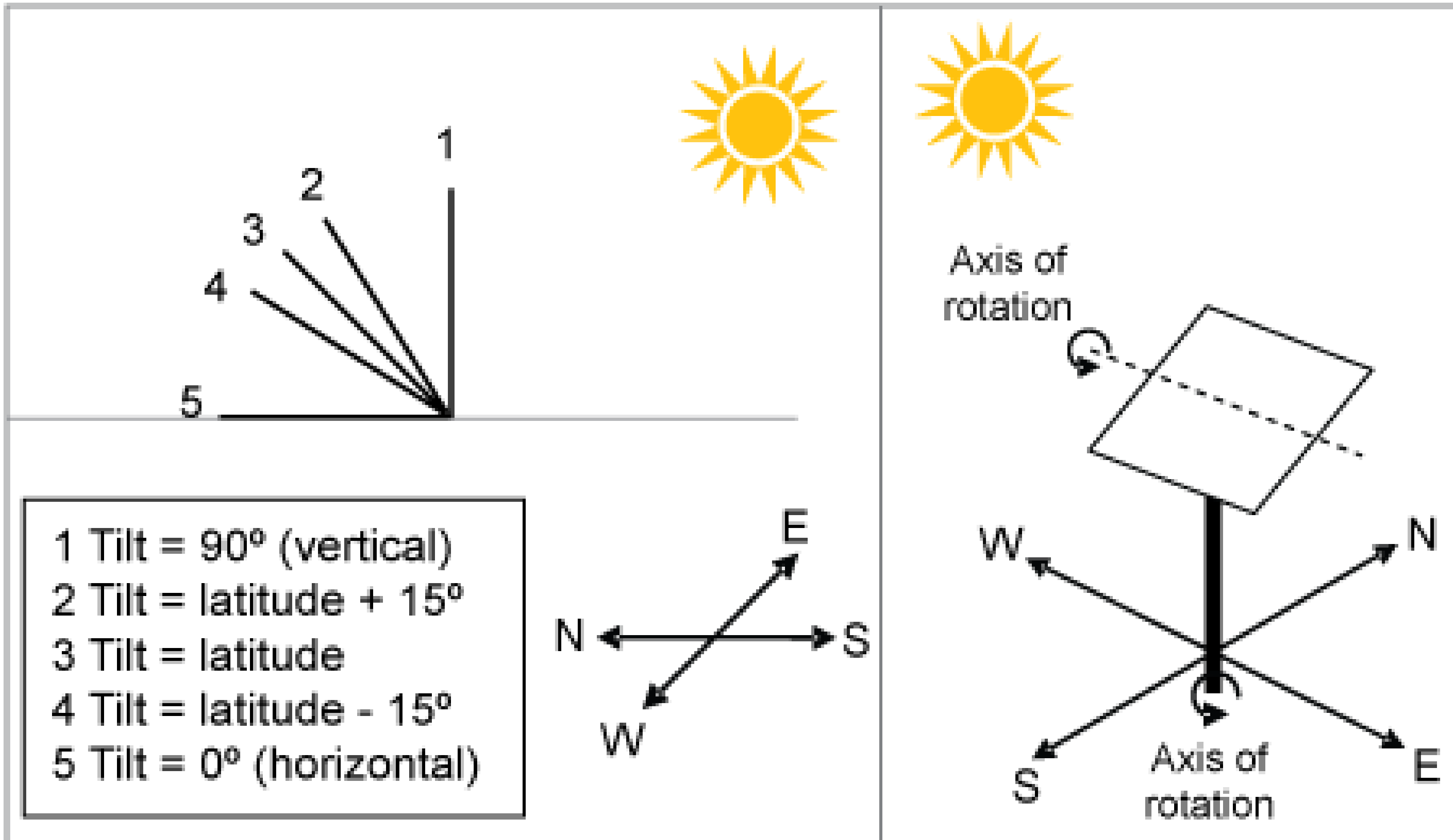
- For initial guess, look at load and pick tilt angle that maximizes solar radiation on array during month in which load is highest

- Array = latitude gives overall maximum power. Constant load or slightly higher load in summer

- Array = latitude + 15° : suited towards winter loads

- Array = latitude – 15° : suited towards summer loads

Design



South-facing PV panels with different tilts

2-axis tracking PV panels

Design

4. Find total current needed from array

Array current = $\frac{Load\ (Ah)}{Sun\ Hours\ (hr)}$

5. Find number of panels needed in parallel

Panels = $\frac{Array\ Current\ (A)}{Current\ from\ panel \times 0.9\ (A)}$

Current from panel is found by looking on manufacturers data sheet at maximum point current

Current from panel is at maximum power point and is derated (10%) to account for reduction in current due to dirt.. etc.

Design

6. Find total number of panels in series to meet system voltage requirements

Need to account for

- Output drops due to operating **temperature** as opposed to room **temperature** (at which panel is rated)
- Diode drops
- Changes in battery voltages due to **temperature** (unless maximum power tracker included)
- Battery voltage needs to be above 12V (should be ~14V) for a nominally 12V system
- Number of panels is number in series
- Total number of panels = # in series x # parallel

Design

7. Find battery size

- Estimate the number of days autonomy from statistical analysis of radiation data.
- Determine the depth of discharge (DOD) for battery from manufacturers data sheet of estimate from type of battery.
- Determine battery capacity in Ah

$$\text{Battery Capacity (Ah)} = \frac{load\ (Ah) \times Days\ Autonomy}{DOD}$$

- The load in the above equation is the corrected load which takes into account battery and inverter inefficiencies

Design

7. Find battery size

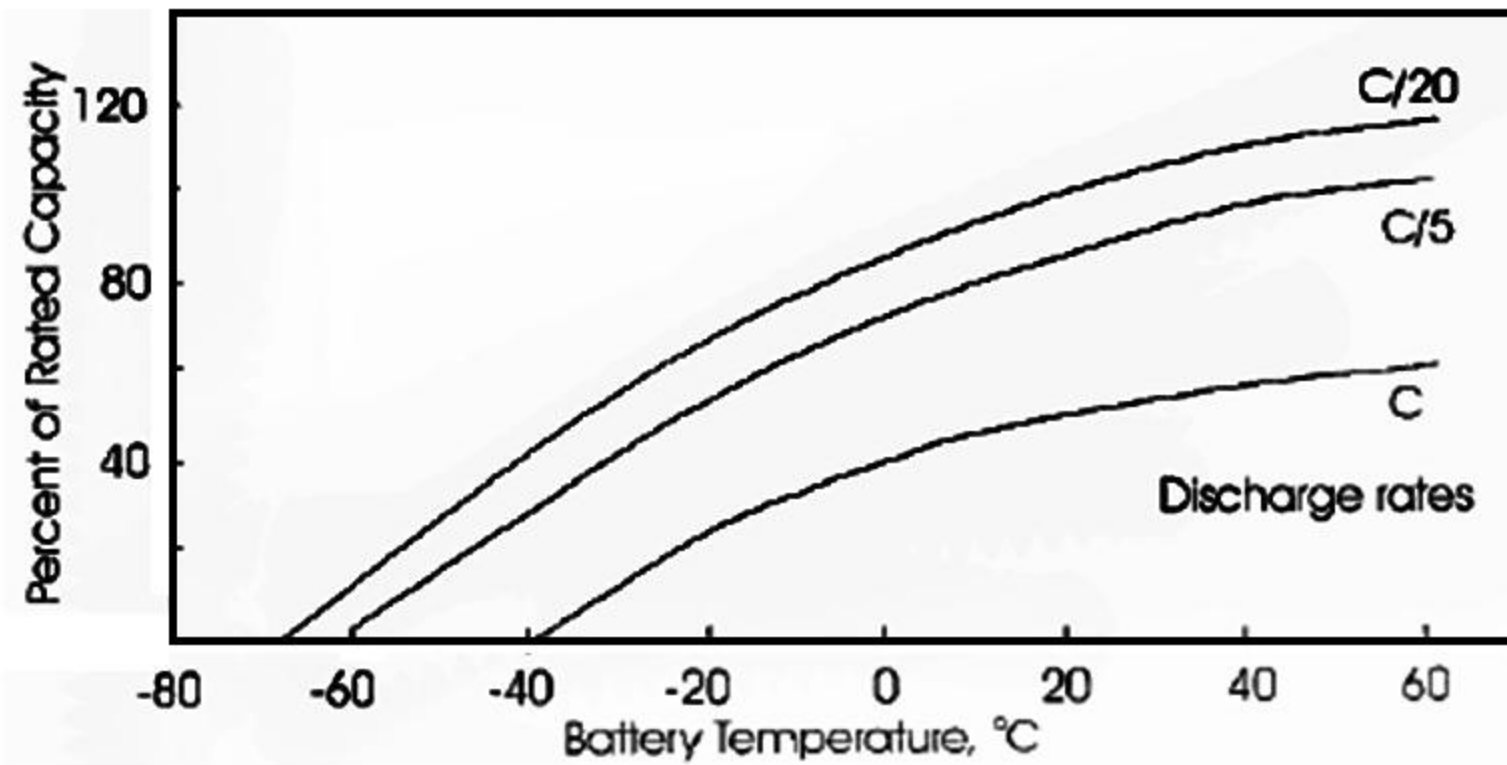
- Total number of batteries

  Batteries number =

$$\frac{System\ Voltage\ (V) \times Battery\ Capaity\ (Ah)}{Battery\ Voltage\ (V) \times Rated\ Battery\ Capaity\ (Ah)}$$

- Battery voltage and rated battery capacity are determined from manufacturers data.
- Check and adjust battery capacity based on temperature, discharge rates,

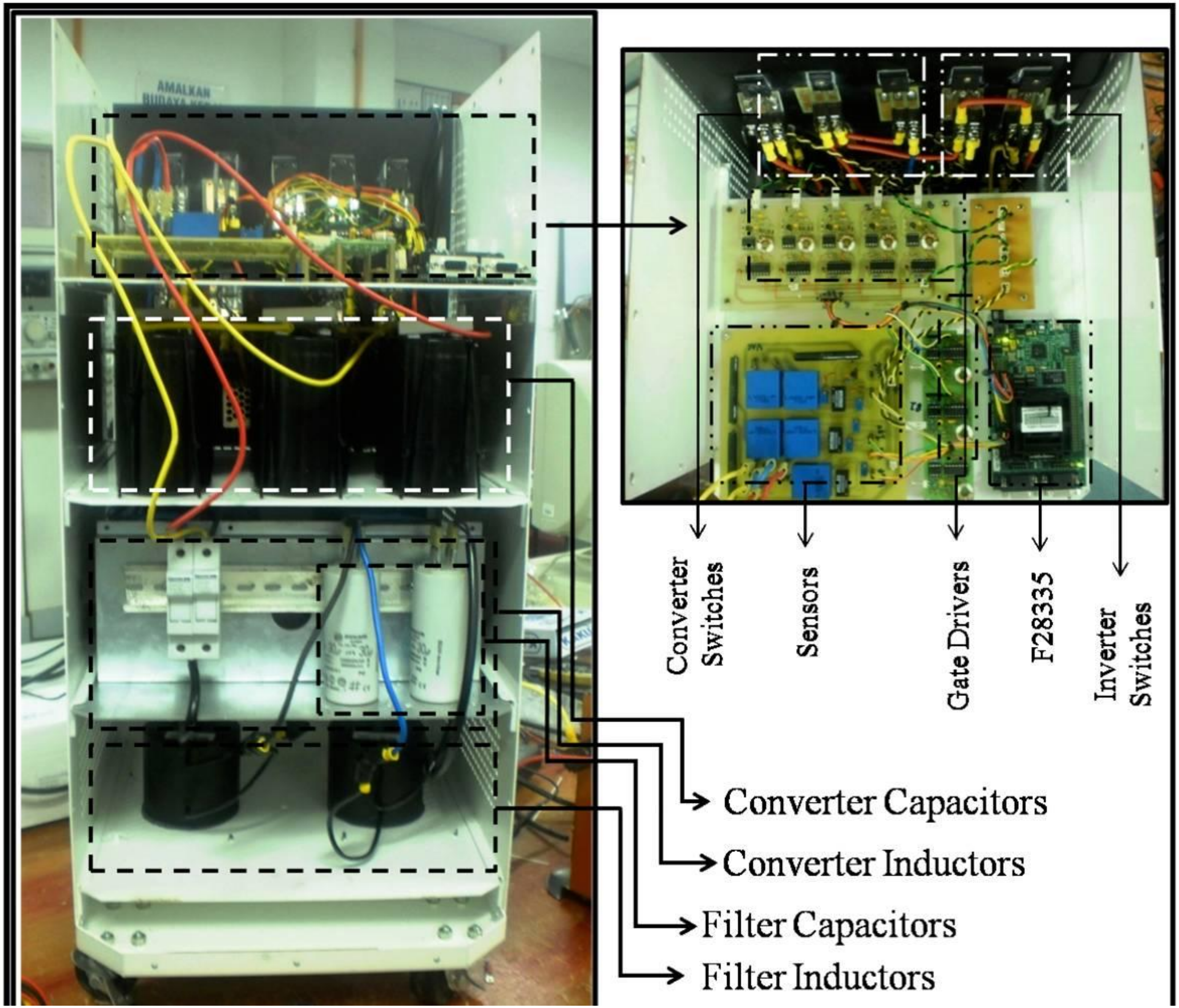
Design


C/20
C/5
C
Discharge rates
120
80
40
Percent of Rated Capacity
-80
-60
-40
-20
0
20
40
60
Battery Temperature, °C

Design

8. Specify other parameters

- Charge controller: handle maximum current and power from array, suited to type of batteries
- Inverter: rated power should be just under typical load



AMALKAN
Converter Switches
Sensors
Gate Drivers
F28335
Inverter Switches
Converter Capacitors
Converter Inductors
Filter Capacitors
Filter Inductors


RA12-100
[D,12V100AH/10HR]
VALVE REGULATED
RECHARGEABLE BATTERY (NONSPILLABLE)
Pb

Thank

You