Battery

- A battery is an electrochemical device, which is used to store energy.
- In PV systems, they store electrical energy generated by PV modules
- It can be used at night when there is no sunlight

Classification of batteries

» ***Primary batteries***

- Primary batteries irreversibly transform chemical energy into electrical energy. These batteries cannot be recharged once they go dead.

» ***Secondary batteries***

- Secondary batteries transform chemical energy into electrical energy and vice versa, and are easily recharged.

Battery types and technologies

» ***Lithium-ion battery***

- Most often used in high-end electronics such as laptops and mobile phones
- They are expensive
- They recently started to gain market share. An example of the increasing market share is the Tesla (electric vehicle)
- Relative to their size and weight, Li-ion batteries have a long lifespan and a high energy storage capacity.

Strength and weaknesses of Lithium-ion battery

Advantages	Disadvantages
• High energy density • Low self discharge • High efficiency • High cell voltage	• Moderate discharge current • High manufacturing costs • Susceptible to explosion due to mechanical, thermal or chemical stress • Requires built-in protective circuit to keep current and voltage within safe limits • Subject to ageing even when unused

Battery types and technologies

- » ***Lead-acid battery***
- The lead-acid battery is the most commonly available and widely used battery with photovoltaic systems in Nigeria.

Battery types and technologies

Lead Acid Battery

There are two types of Lead acid batteries:

- Starter
  - Very high discharge to start Car
  - Fast recharge with high current alternator
  - Minimal discharge
- Deep-cycle
  - Gradual discharge through out day/night
  - Comparatively slow recharge during the day
  - Daily Cycle
  - Used in PV systems

Battery Types and Technologies

Type of Electrolyte

Flooded Lead Acid Battery

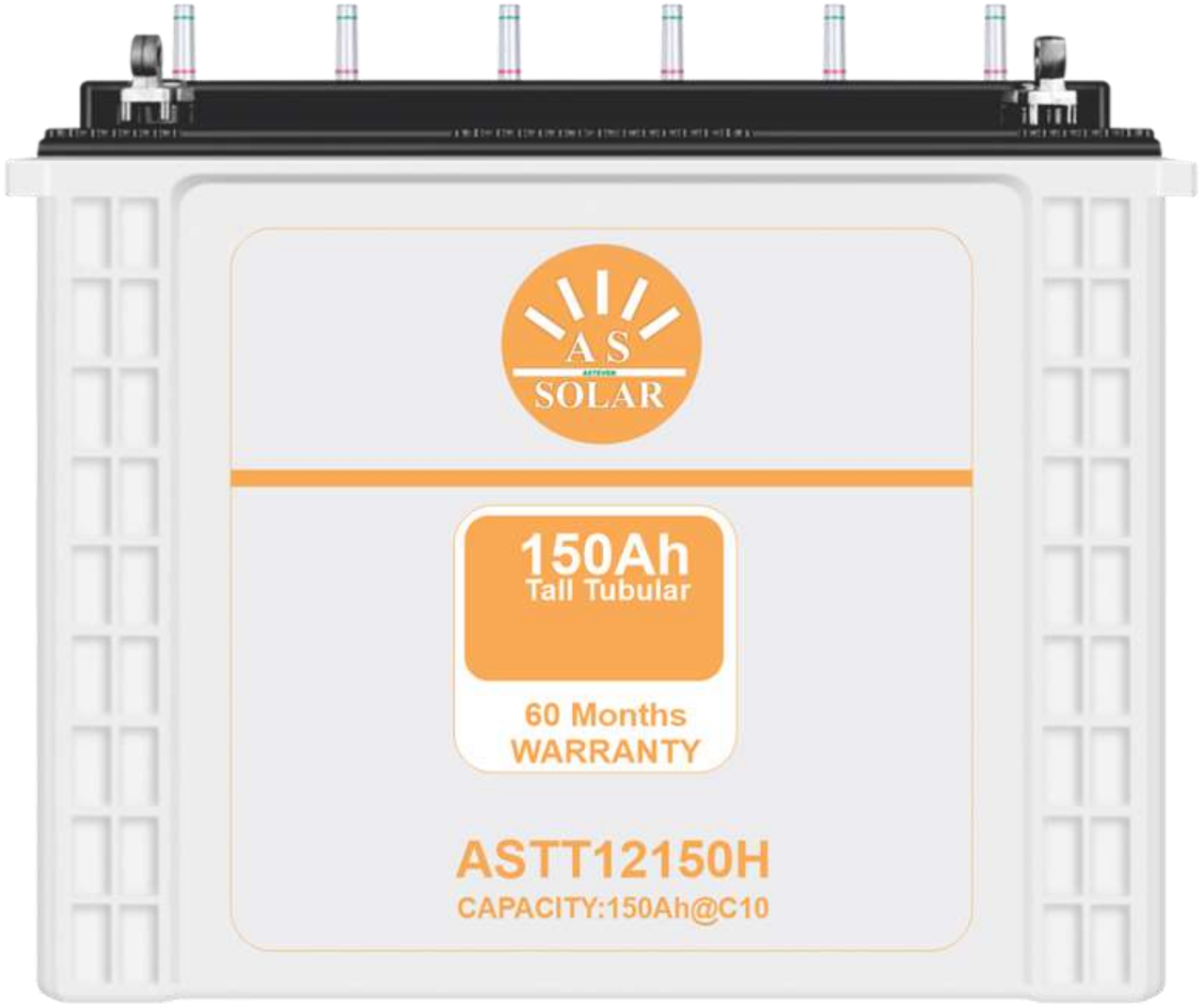
- Consists of lead anode and lead oxide cathode immersed in a liquid electrolyte (sulphuric acid)
- Most common type of battery available

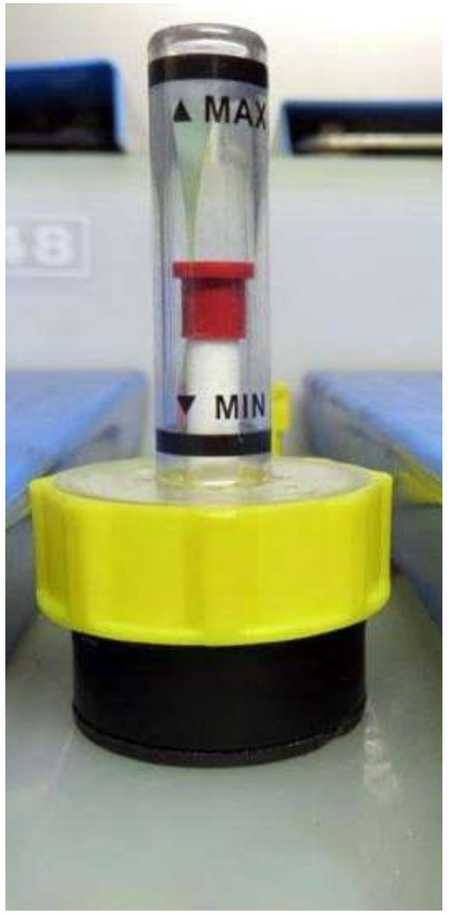
Valve-regulated lead acid (VRLA)

- Also known as sealed or dry cell battery
- Does not require topping off with distilled water
- Electrolyte is semi-solid

Battery Types and Technologies

Flooded Lead Acid Battery





Battery Types and Technologies

Types of Sealed Batteries

- **Absorbed Glass Mat(AGM) Battery**: Most common type of sealed battery in Nigeria
- **Gel Battery**: Have longer life cycles than AGM battery

Strength and Weaknesses

Advantages	Disadvantages
• Mature and dependable • Cost effective • Low self discharge • Low maintenance • Recyclable	• Heavy • Allows only a limited number of full discharge • Cannot be stored in discharge mode – The cell voltage should never drop below 2.10V

Lead-acid battery Vs. Lithium-ion battery

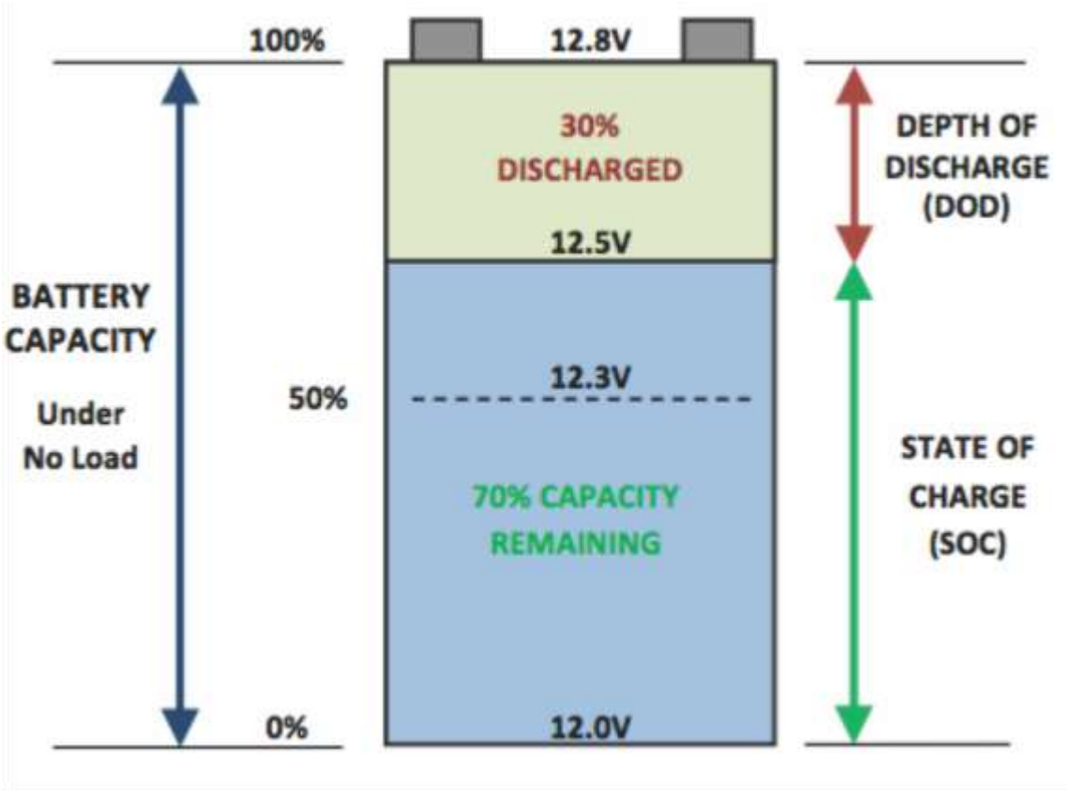
Lead-acid Batteries	Characteristics	Lithium-ion batteries
40Wh/kg	Energy density	95 – 140Wh/kg
Up to 70%	Charging Efficiency(%)	Up to 95%
1200 Cycles	Charge/discharge cycle	> 3000 Cycles
Gassing and water loss occur when charging	Emissions	Emission free(Zero gassing)
The voltage will constantly drop over its discharge	Voltage Stability	They are almost 100% in terms of voltage
Charging:50% in approx. 3h, 90% in approx. 6 – 7h	Fast charging capacity	Charging:90% In approx. 1.5 – 2h
Required	Maintenance	Not required

Interpreting Name plate

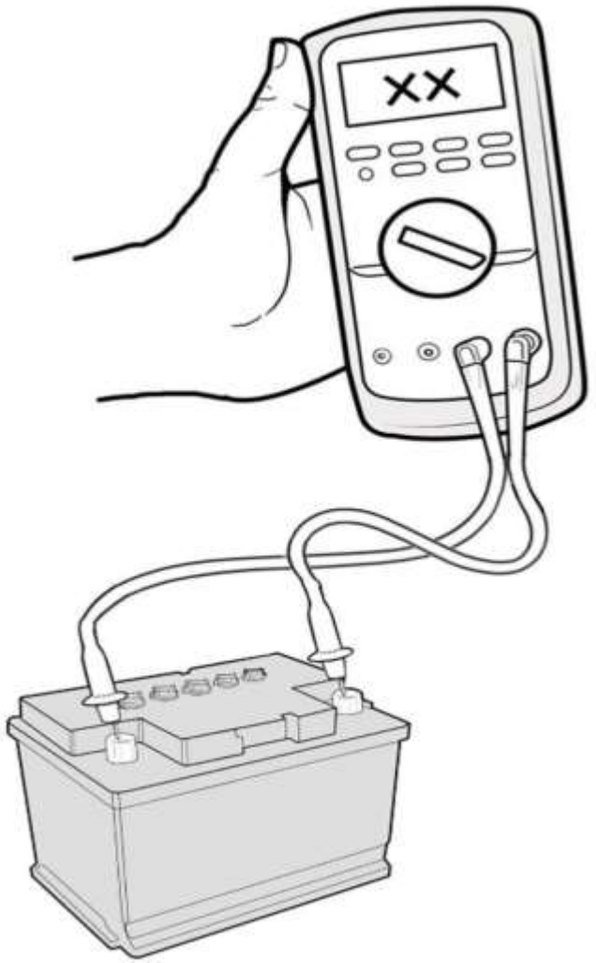
- Batteries are rated by their capacities in **Ah**
- The voltage across a battery is determined by the number of cells it possesses
- Energy stored by a battery(**Wh**) is a function of the battery capacity(**Ah**)
- Most batteries used in solar systems are 12V batteries.
- A 12V lead acid battery has 6 cells, each rated at 2V
- Due to inefficiency between a battery and inverter during discharging, **not all the stored energy in the battery can be used**

Battery state of charge (soc)

- The state of charge(SoC) describes the battery's charge level, i.e. fully charged or empty. The unit is %.
- Depth of discharge(DoD) describes how much of the battery capacity is discharged by using it. The unit is %.
- A fully charged battery has a 100% SoC and DoD of 0%. A half full battery has a 50% SoC and DoD of 50%. An empty battery has a 0% SoC and DoD of 100%.
- SoC can be determined by a voltage measurement, but is not always reliable.



Knowing the Charge Level of a Battery

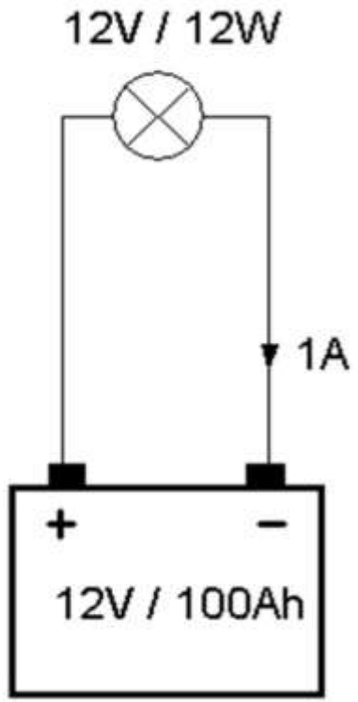


Expected Voltmeter reading for 12V Battery

SOC	GEL	AGM	WET CELL
100%	12.95V	>12.8 V	12.60 V
75%	12.74V	12.55 V	12.36 V
50%	12.54V	12.30 V	12.10 V
25%	12.34V	12.20 V	11.90 V
0%	12.10V	12.00 V	11.80 V

Charge/discharge rates

- Charge rate (C-rate) is how fast a battery is charged or discharged based on its Ah capacity,
- Ah capacity ÷ Amp charge or discharge = C-rate
  - 100Ah ÷ 5A = C/20
  - Battery will be 100% in 2Ohours
- If the bulb operates for 10hours, it will discharge 10 Ah from the battery. Given a 100 Ah battery, this discharge is 10% of the battery capacity. The DoD will be 10%. If the same bulb is operated for 50 hours, the DoD will be 50%.



Battery Cycle Life

- The process of discharging and recharging a battery is called a cycle.
- In solar PV systems, a cycle is usually one day, as the battery gets discharged at night and recharged during the day.
- Discharging only 10% of the capacity (DoD = 10%) is a shallow cycle. Discharging 100% of the capacity (DoD = 100%) is a deep cycle.
- Deep cycles are more harmful and shorten the battery life more than shallow cycles.

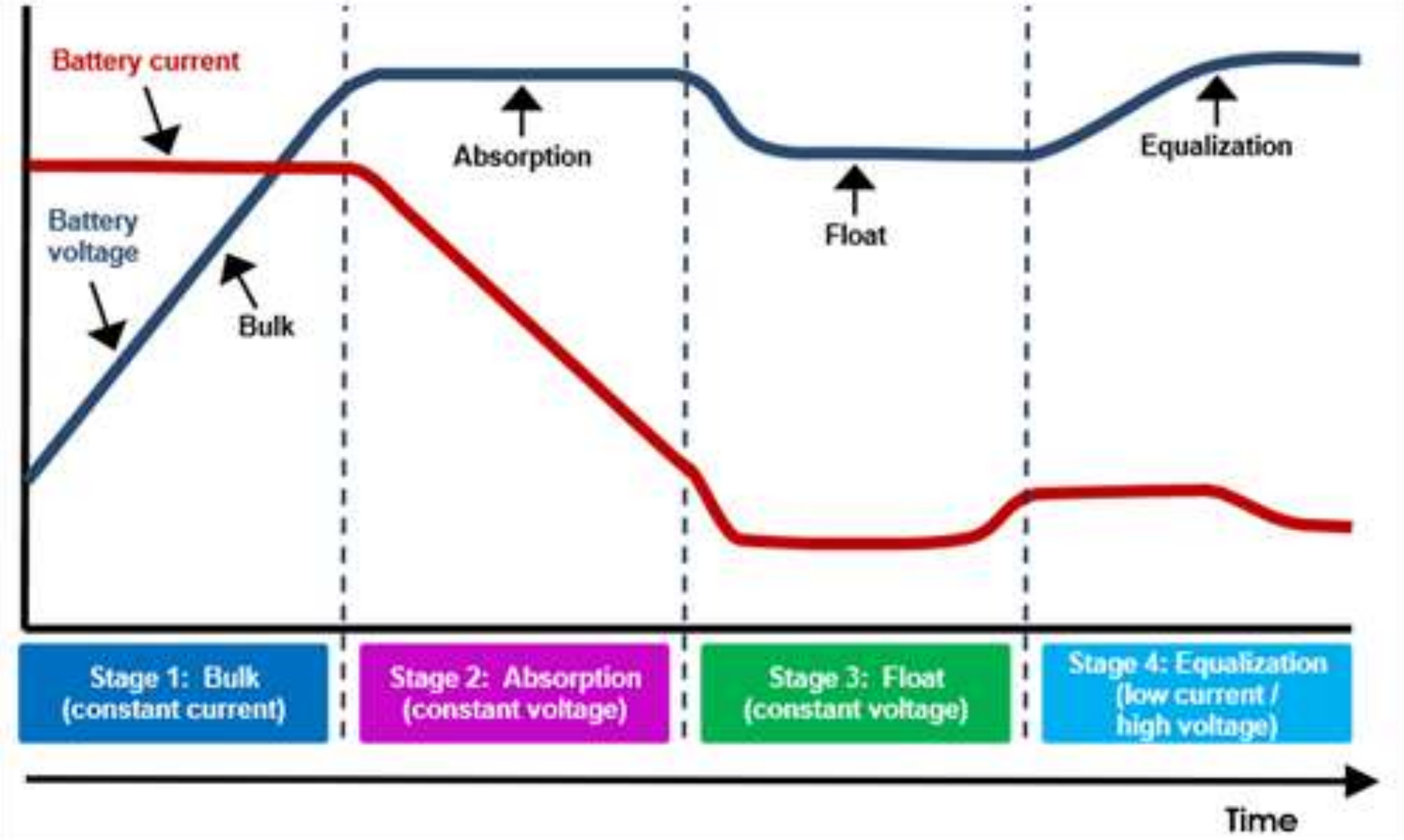
Battery cycle life

- Battery life is expressed in cycle life, meaning a battery can be used for a certain number of cycles or charges. After that it gets weak and loses its capacity.
- A 12 V/100 Ah battery, which has been used for many cycles may have a remaining capacity of only 50 Ah. It has essentially become a “smaller” battery.
- Even when a battery is just stored and not used, the useful lifespan is still “consumed”. This is called the **float life or shelf life. The float life depends** very much on the temperature at which the battery is stored and on its state of charge.
- A good quality gel battery can be stored up to 10 years at 20 °C but only 6 years at 30 °C. During storage, the state of charge (SoC) must always be kept at 100%. This requires regular recharging every three to four months or a constant ‘trickle charge’.

What the number of life cycle of a battery depends on

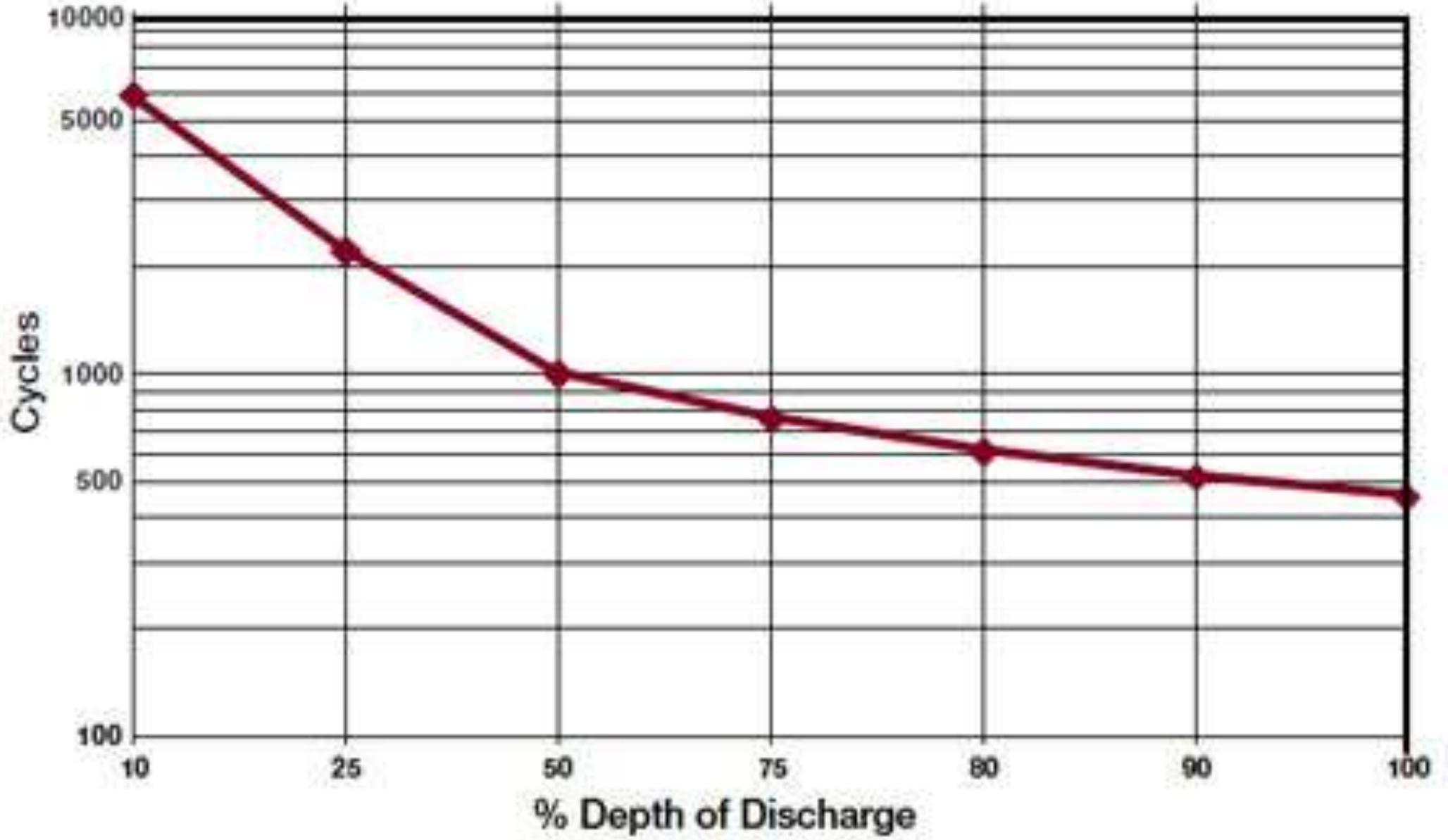
- Discharge frequency: Frequent discharging reduces the number of available cycles, making the battery smaller.
- Depth of discharge (DoD): Deep discharging causes the formation of crystals at the electrode, which reduces the area available for chemical reactions in the battery.
- State of charge (SoC): The battery’s charge state should be maintained at 100% whenever possible.
- Storage and operation temperature: Batteries have specific operating temperatures for optimum performance.

Charging Stages



Gel Cycle Life vs. Depth of Discharge

Based on BCI 2-hour Capacity at 25°C (77°F)



Battery Datasheet

- This information is usually stated in the battery's datasheet to indicate the expected lifespan of the battery

Electrolyte	*Immobilized H_2SO_4*
Positive Plate Alloy	**Arsenic and Cadmium Free Pb-Ca-Sn Alloy*
Positive Plate Type	*Flate pasted*
Type of Connection	*Bolted*
Type of Separator Material	*Absorptive Glass Matt*
Container material	**ABS**
Recommended Charging Method	*Constant Potential*
Shelf life at 27°C	*6 Months*
Self Discharge	*<1% Per Week*
Float Charge Voltage	*13.5V - 13.62V*
Boast Charge Voltage	*13.8V - 14.1V*
Charging time from 20% SOC TO 90% SOC	*6 - 8 Hrs*
Operating temperature range	*0°C to 50°C*
Design Life at 27°C	*10 years*
Cyclic Service Life(@27°C)	
At 20% DOD	*1400 Cycles*
At 50% DOD	*650 Cycles*
At 80% DOD	*300 Cycles*
Product Performance Conforms to	*JIS C 8702*

Self-discharge

- If batteries are left standing uncharged, all batteries lose charge slowly by a process called ‘self-discharge.
- The rate at which batteries self-discharge depends on the temperature, the type of battery, their age and condition. As batteries get older, self-discharge rates Increase.
- Dirty batteries (i.e. those with a high accumulation of acid mist and dirt on top) tend to have higher self-discharge rates, and high ambient temperatures increase the rate of self-discharge.
- To avoid self-discharge:
  - store the battery off the floor in a wooden battery box or non-metallic tray;
  - keep the top surface of the battery clean;
  - keep the terminals clean and greased.

Battery stratification and sulfation

- Battery stratification is caused when the sulfuric acid in the electrolyte mixture separates from the water and begins to concentrate at the bottom of the battery.
- This increased concentration of acid increases the formation of lead sulfate (sulfation).
- Sulfation reduces the performance of the battery and may cause premature battery failure.
- To prevent stratification, your battery should receive a periodic equalizing charge (increasing the charging voltage to 14.4 volts or above).

Battery Sulfation Causes

- Using chargers that have the wrong amp hour rating for the battery
- Undercharged batteries
- Going too long without recharging discharged batteries
- Low electrolyte levels – any battery plates exposed to air will sulfate

❖ The longer a battery goes without a recharge, the worse the sulfation damage will be.

Common mistakes made by owners of lead acid batteries

- **Undercharging** - Generally caused by not allowing the charger to restore the battery to full charge after use.
- **Overcharging** - Continuous-charging causes accelerated corrosion of the positive plates, excessive water consumption and in some cases, damaging temperatures within the battery.
- **Under-watering** - In lead acid batteries(wet cell) water is lost during the charging process. If the electrolyte level drops below the tops of the plates, irreparable damage may occur. Check your battery water level frequently.
- **Over-watering** - Excessive watering of a battery results in additional dilution of the electrolyte, resulting in reduced battery performance. Add water to your battery after it has been fully charged, never when the battery is partially discharged.

Buying Used Batteries

- Buying used batteries may sound like a good deal, but the truth is that it's generally not. Batteries are very powerful but delicate devices.
- Proper handling and maintenance procedures, temperatures, and discharging processes affect the life cycle of the battery dramatically.
- Unfortunately, there is no way to test the battery to figure out how many cycles are left. Even if the seller tells you that these batteries have never been used and they are good as new, then there is also a high probability that the batteries have been exposed to long periods of discharge as they self-discharge over time.
- **Buying used batteries is never a good idea. If you are low on budget, the best choice available is to select flooded type batteries and install a smaller PV system to cover only basic loads.**

Real Life Case Study

- Someone bought this solar battery loaded with concrete. So much for wanting an affordable battery, don't you think?
- How do we solve problems like this?

Batteries available in the market

- 2V 330Ah
- 2V 500Ah
- 2V 600Ah
- 2V 800Ah
- 2V 1000Ah
- 2V 1500Ah
- 2V 1890Ah
- 2V 2200Ah
- 6V 220Ah
- 6V 420Ah
- 6V 770Ah
- 6V 600Ah
- 12V 26Ah
- 12V 40Ah
- 12V 50Ah
- 12V 60Ah
- 12V 65Ah
- 12V 75Ah
- 12V 100Ah
- 12V 150Ah
- 12V 170Ah
- 12V 200Ah
- 12V 220Ah
- 12V 230Ah
- 12V 250Ah
- 48V 30Ah(lithium ion)
- 48V 100Ah(lithium ion)
- 48V 200Ah(lithium ion)
- 48V 30Ah(lithium ion)

Battery bank

- A battery bank is the result of joining two or more batteries together for a single application.

Interconnection of batteries

- When batteries are interconnected to form a bank, the total voltage and capacity of the battery bank is dependent on whether batteries are connected in series, parallel or both. There are three interconnection methods for batteries:

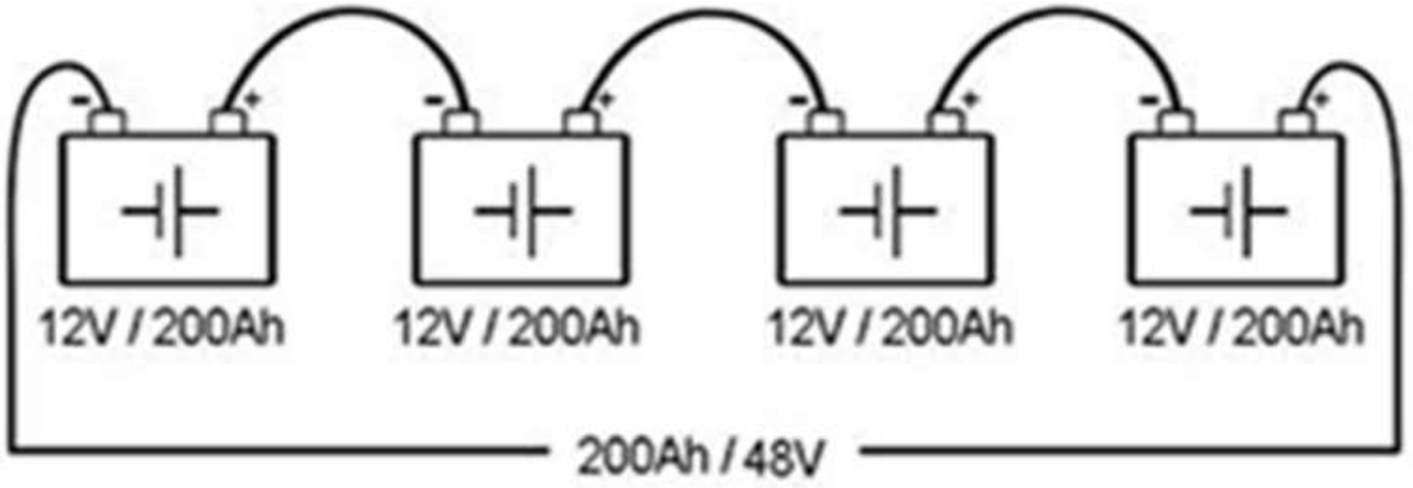
  - Series connections increase the output voltage of the battery. The negative terminal of a battery is connected to the positive terminal of the next battery.

Interconnection of batteries

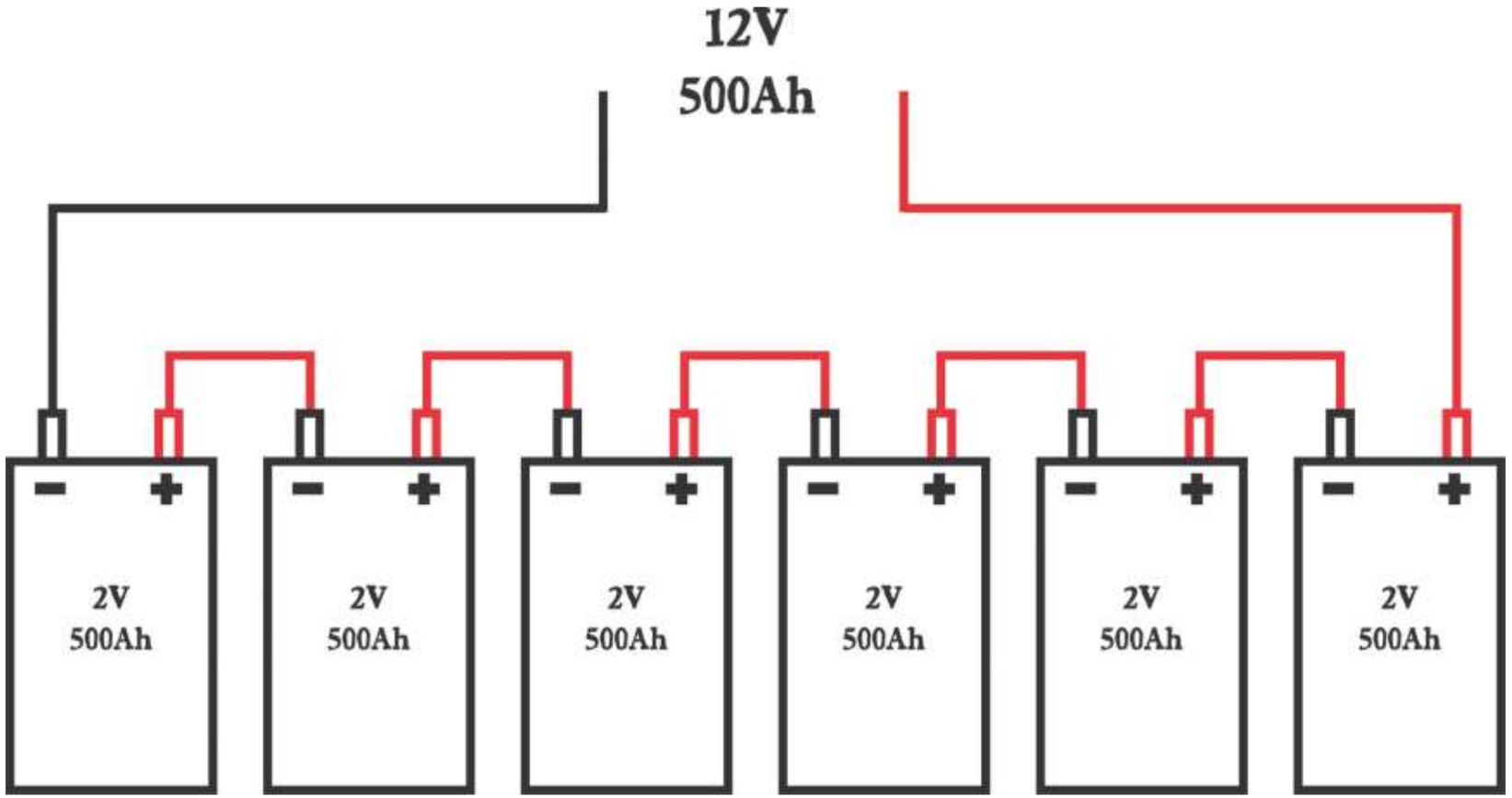
- **Parallel connections increase the output capacity of the battery bank. All negative** battery terminals are connected to negative terminals and positive terminals alike.
- **Series/parallel connections** increase both output voltage and battery bank capacity.

Series Connection

- For example, if you have four batteries that are rated at 200 Ah/12 V and they are connected in series combinations, the total output power from the battery bank will be 200 Ah/48 V.

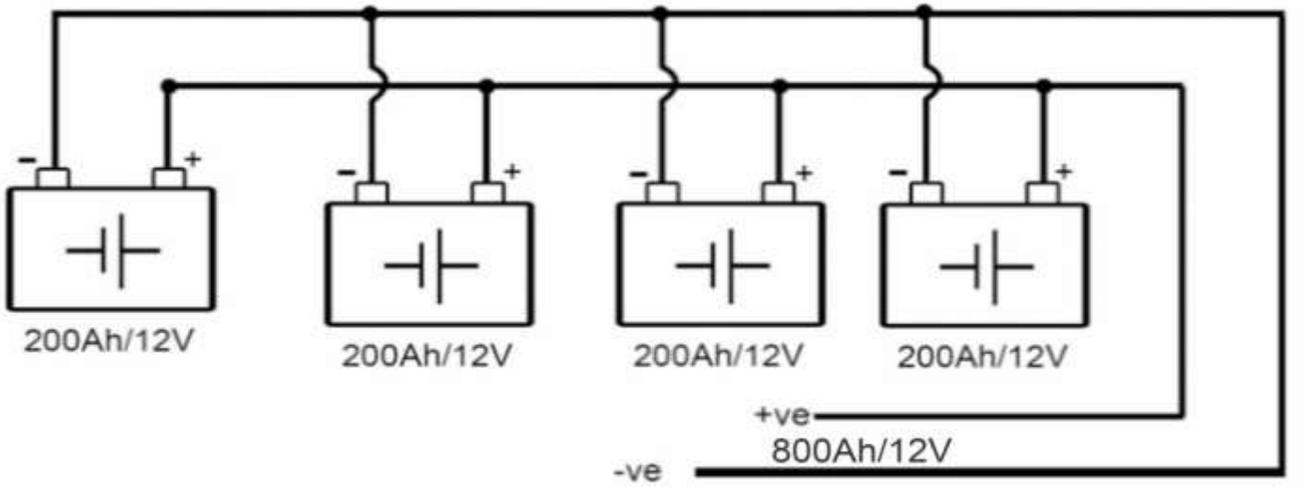


Series Connection



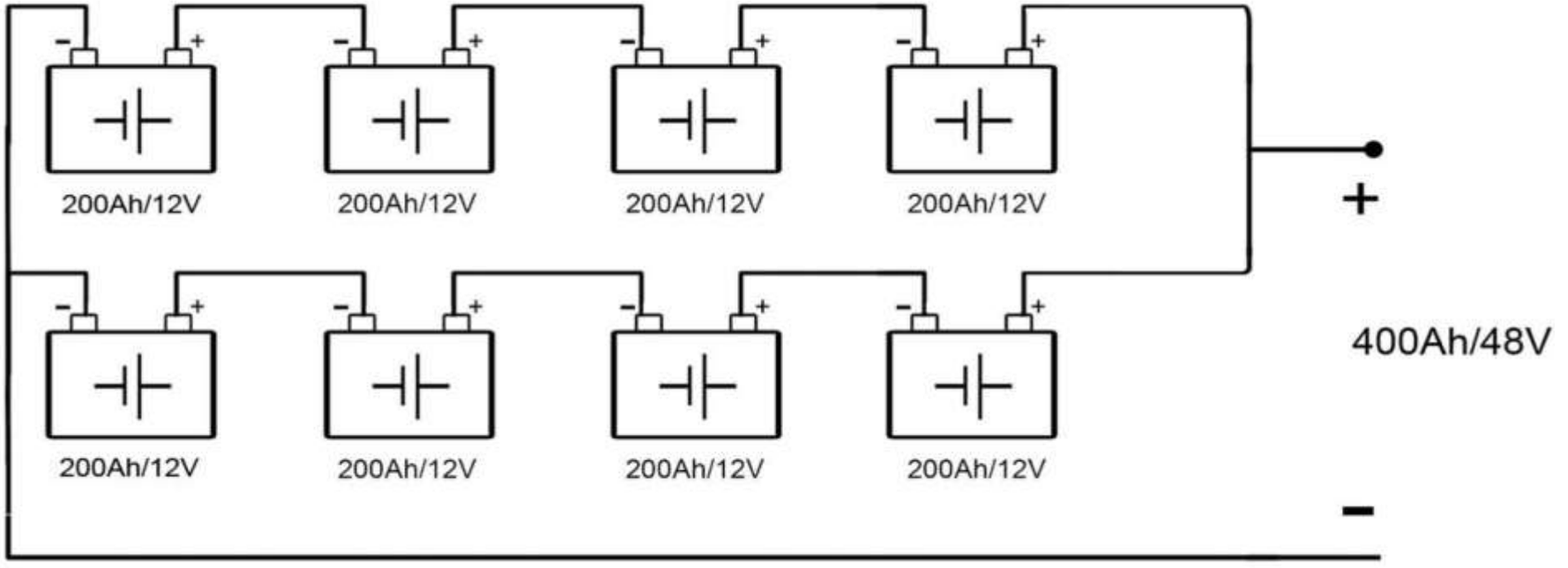
Parallel connection

- For example, if you have four batteries that are rated at 200 Ah/12 V and they are connected in parallel combinations, the total output power from the battery bank will be 800 Ah/12 V.



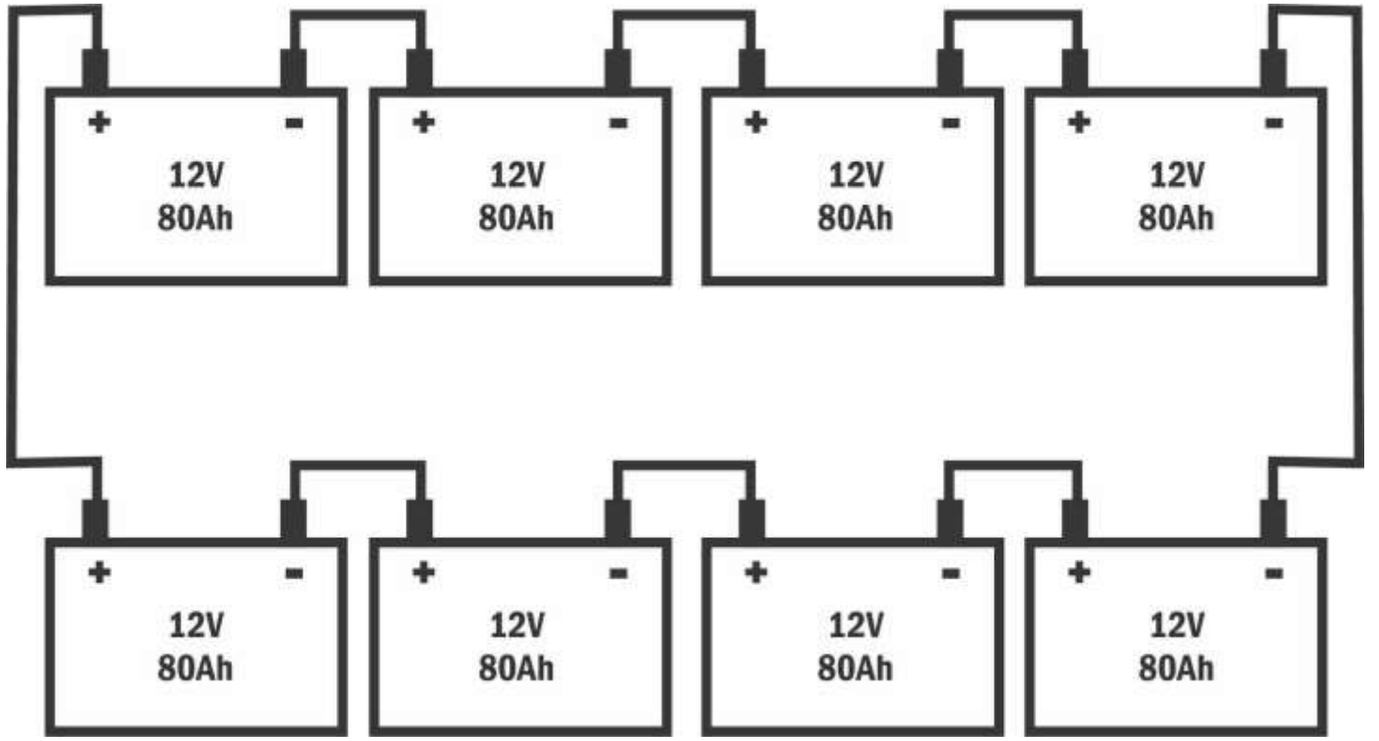
Series-parallel connection

- These connections are made when you have to create a large battery bank where the required capacity and voltage are not attainable using one string of either series or parallel connections.



Battery String

- A battery string comprises of a number of batteries connected in series



2 Strings of 4

2 x 80Ah = 160Ah

x 4 x 12 Volts = 48V

Watt hour = 7680

Battery Cable Connections

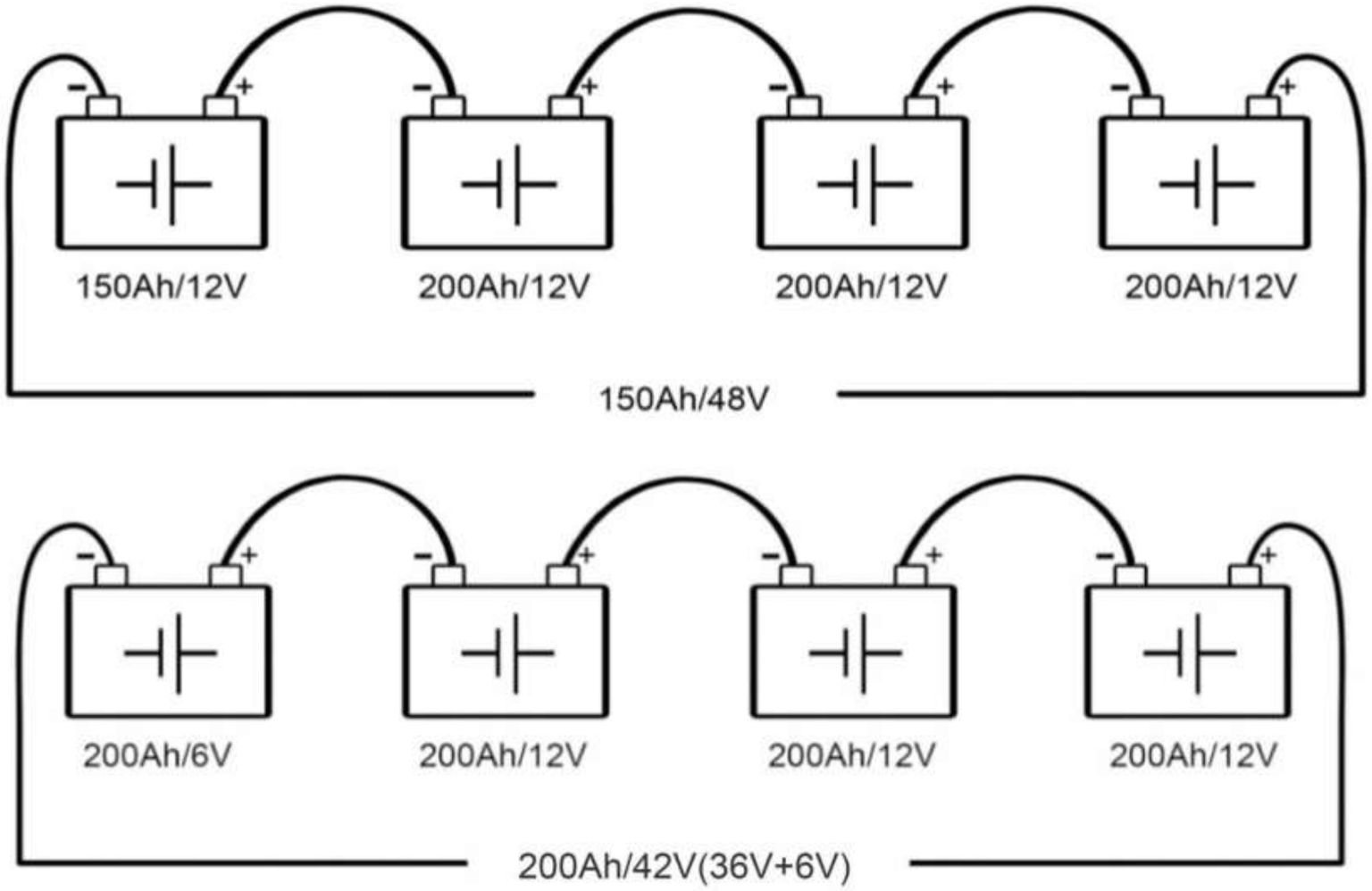
- The cables that join your batteries together play an important part in the performance of your battery bank. Choosing the correct size (diameter) and length of cable is important for overall efficiency.
- Cables that are too small or unnecessarily long will result in power loss and increased resistance.
- When connecting batteries in series, parallel or series/parallel the cables between each battery should be of equal length.
- This links the batteries together with the same amount of cable resistance, ensuring that all batteries in the system are working equally together.

Exercise

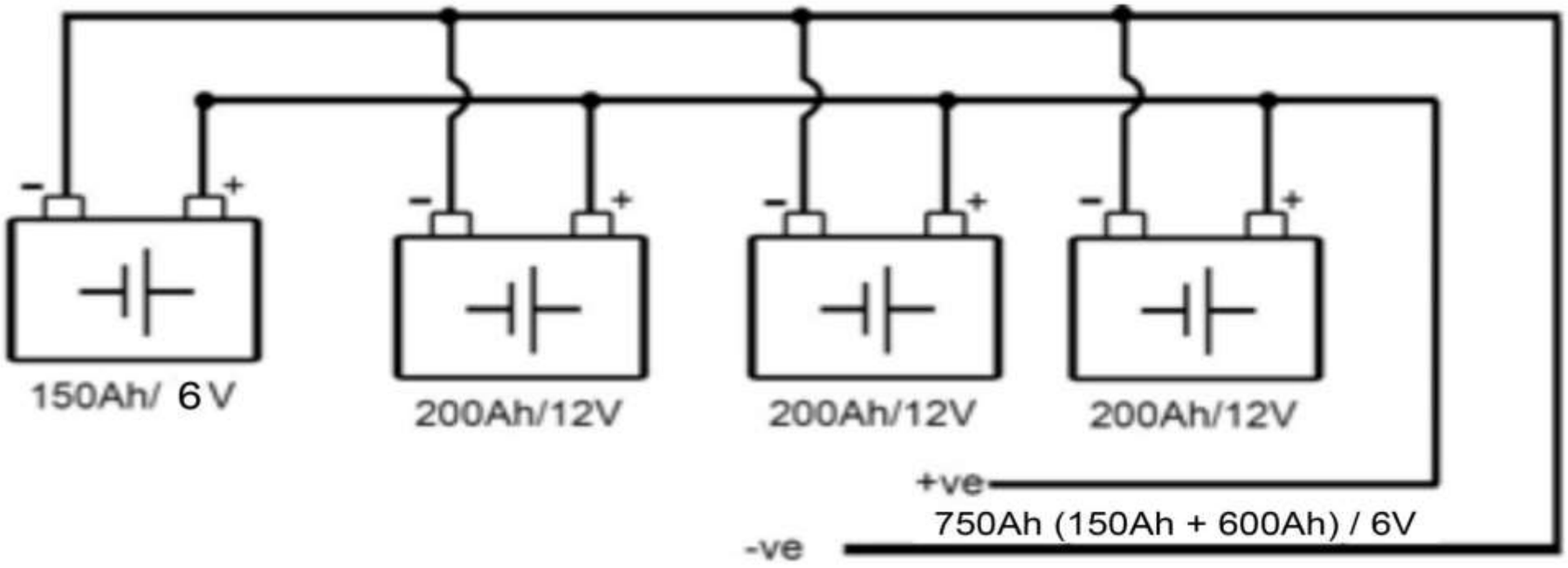
Calculate the total capacity and voltage of the battery bank with the following mismatch:

- 4 Batteries (1 – 180Ah/9V and 3 - 200AH/12V) in a parallel connection
- 4 Batteries (1 – 100Ah/6V and 3 - 200AH/12V) in a series connection

Battery mismatch: Case 1&2



Battery mismatch: Case 3



Mismatch battery in a bank

- In series connections, mismatched batteries result in:
  - Faster and deeper discharging of smaller (or older) batteries as well as faster failure.
  - Faster charging and overcharging of smaller (or older) batteries as well as faster failure.
  - Consistently incomplete charging of bigger (or newer) batteries, as the smaller battery is the signal for the charge controller to stop the charging process. Battery lifetime will be shortened as well.
  - An old battery has lost its capacity. It has become a “smaller” battery. An old 200 Ah battery connected in series with new 200 Ah batteries will affect the system as described above

Mismatch battery in a bank

- In parallel connections, mismatched batteries result in:
  - Faster and deeper discharging of smaller (or older) batteries discharge as well as faster failure.
  - Batteries with higher voltage will discharge into the ones with lower voltage; energy is wasted or the battery damaged.

Safety guidelines when handling batteries

- Always wear protective clothing, gloves and gadgets
- Keep flames, Sparks or metal objects away from the battery
- Always use insulated tools.
- Do not smoke near batteries.
- Always charge with vent caps securely in place
- Provide proper ventilation during charging to prevent gas build up.

Battery care

- Cable connections need to be cleaned and tightened as battery problems are often caused by dirty and loose connection.
- Always use a well-ventilated area for inverter installation. The inverter battery gets heated up during charging and operation. An airy place reduces the heating up of the battery.
- After installation, use battery on a regular basis. If the power cut does not occur, discharge the battery completely once every month and then recharge it.

Battery care

- Check all vent caps are tight
- Always keep the surface and sides of battery clean and dust free. Use cotton cloth to clean these surfaces.
- Keep the battery terminals corrosion free and rust free. If the terminals get corroded, pour hot water and baking soda solution on the corrosive area or use a wire brush for cleaning. This will remove the corrosion.

Battery care

- Monitor and maintain the battery state of charge to prevent sulfation.
- From safety point of view, install the inverter battery at safe places in your home which is out of the reach of children or a less used area. But at the same time make sure that it is airy and properly ventilated.
- Turn off the inverter system once the battery is low. These ensure healthy battery usage and prolonged battery life.

Battery manufacturers and brands

- East Penn, Chloride, Crown, EnerSys, Exide, Giant, GreenPower, Hawker, ManBatt,
- Newmax, Northstar, Odyssey, Optima, Panasonic, PowerKing, Tanya, Trojan, US
- Battery, Yuasa.