Solar Energy Batteries-A Critical Review

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ABSTRACT
Solar power has numerous benefits, it is a clean and renewable energy resource that can help us to reduce carbon emissions from fossil fuel use and mitigate climate change. However, solar energy production is limited to daytime hours when sunlight is abundant, and for solving the intermittency problem batteries bank has been used, where it store electricity for later use, so you can keep appliances running during a power outage, and use more of the solar energy that you produce at your home. Solar batteries are a deep cycle batteries, as the current flows from the battery in small quantities and evenly. This article represents; difference between automotive batteries and a solar batteries, a brief explanation of the different types of solar batteries and a comparison between them in terms of price, depth of discharge , service life, charge and discharge temperature, and energy density. The article also introduces an electrical representation of the battery, criteria that are taken into account when choosing the appropriate battery such as battery capacity, battery efficiency, depth of discharge of the battery, the time required for charging the batteries, and connect batteries in series and in parallel, where it is necessary to know this information to choose the appropriate battery for designing the solar systems.

Keywords: Flooded batteries, Gel batteries, AGM batteries, Lithium batteries, Electrical models of batteries, Battery energy, Series and parallel connection of batteries

INTRODUCTION

Automotive batteries also known as starting, lighting, and ignition (SLI) batteries have a very low internal resistance (50 milliohm) to produce a burst of energy. Low internal resistance is achieved by adding extra plates and the lead is applied in a sponge-like form that has the appearance of fine foam for maximum surface area (Figure 1). The plates are thin (1mm), which make the discharge is short

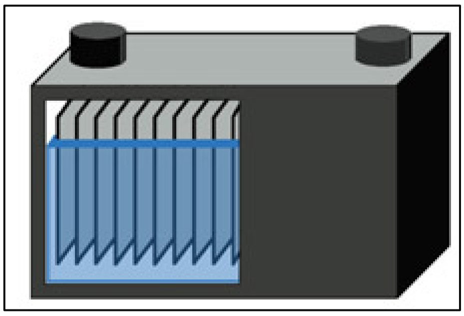

***Figure 1**: Starting battery*

The deep-cycle batteries have an internal resistance that is ten times that of the automotive batteries which is achieved by making the lead plates thick (figure 2). These batteries are characterized by a maximum capacity and a high cycle count, and this makes it ideal for solar energy systems.

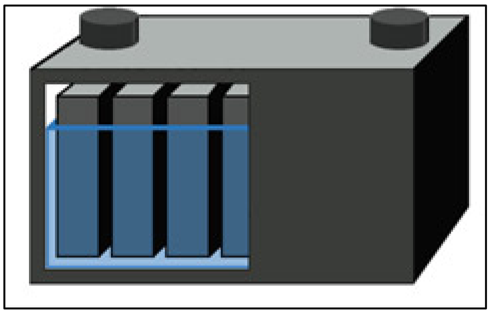

***Figure 2**: Deep-cycle battery*

Solar Batteries are a deep cycle batteries used to store the direct current generated by the solar panels, which is converted into alternating current by the inverter to operate the various loads. The battery (12v) generally consists of (6) cells, each of these cells consists of, anode, cathode, and the conductive material (the electrolyte).

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There are many types of solar batteries (figure 3), which differ among themselves in the materials from which the anode and cathode are made and the type of electrolyte.

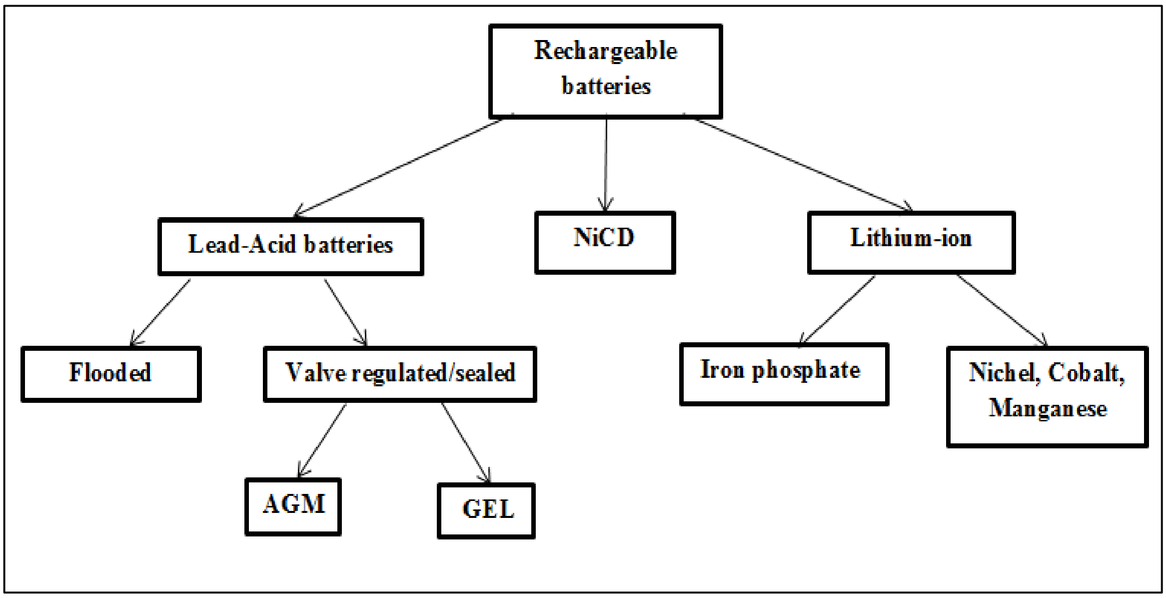

Figure 3: *The different types of solar batteries*

The most common types of solar batteries are:

1 – lead-acid batteries that include:

- Liquid lead-acid batteries (flooded)
- Gel Batteries
- AGM batteries

2- Lithium batteries

The flooded batteries

It is the oldest type of batteries, the cheapest and the most widespread. It is called "liquid" because the conductive material between the anode and cathode plate is a liquid substance, which is sulfuric acid diluted with water, concentration ratio 3:1. Flooded batteries need maintenance, which includes replacing the acid and adding distilled water once or twice a month to compensate for the water evaporating from the batteries. Figure 4 demonstrates the components of a single cell of a flooded battery, which consists of sponge lead which represents the cathode electrode and a clip of lead, and behind the clip a plate of dioxide Lead, which represents the anode electrode, and these cells are immersed in acid diluted with water

Figure 4: *The liquid lead -acid battery*

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The gel battery

A gel battery has the same design and functionality as a traditional flooded battery. The gel battery differs from the liquid battery in that the conductive material contains silica in the electrolyte, which creates a gel-like substance. The gel battery is characterized by being suitable for use in many positions due to its stability and absence of any gases emitting from it, and it is a deep cycle battery

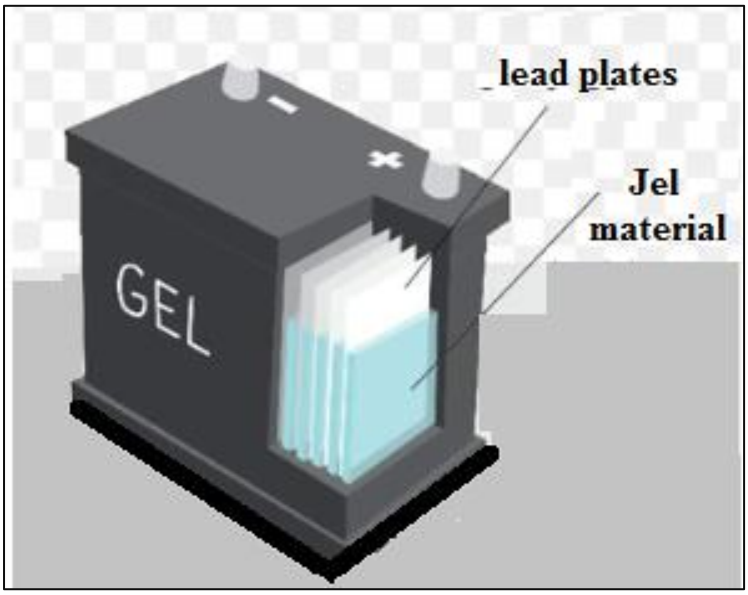

Figure 5: *The Jel battery*

The AGM battery

A fiberglass material is placed between the anode and the cathode, which absorbs the electrolyte like a sponge and prevents it from leaking or evaporating. An AGM battery is a deep cycle discharge with the provision of mixing the sulfate back into the hydrogen gas, resulting in a reduction of the hydrogen released during the discharge process.

Figure 6: *The AGM lead battery*

The lithium battery

An anodes consist of graphite-based materials due to the low cost, wide spread, and the stability to accommodate the lithium insertion, but it carbon suffer from a low capacity, so in recent year, the carbon-based anode has been improved, and new types of

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anode materials, such as silicon, alloy, and metal oxides have been developed, which has improved the lifetime, capacity and performance of lithium batteries. Cathodes consist of a complex lithium compound material, such as $LiCoO_2$ and $LiFePO_4$. Battery performance significantly differs with different cathodes. Cathode has been fabricated from lithium material blending with conductive material such as carbon due to low impedance because of high diffusion coefficient and high ionic conductivities compared with other materials compound. The electrolyte in lithium batteries includes three types liquid electrolyte, semisolid electrolyte, and solid-state electrolytes. Liquid electrolyte consists of lithium salts such as., $LiBF_4$, $LiPF_6$, $LiN(CF_3SO_2)_2$, and LiBOB, which are dissolved in organic carbonates such as, ethylene carbonate, propylene carbonate, ethyl methyl carbonate, dimethyl carbonate, and their mixtures. While, the semisolid electrolyte, and solid-state electrolyte are composed of lithium salts as the conducting salts and high-molecular-weight polymer matrices such as, polyvinylidene fluoride and poly(ethylene oxide).

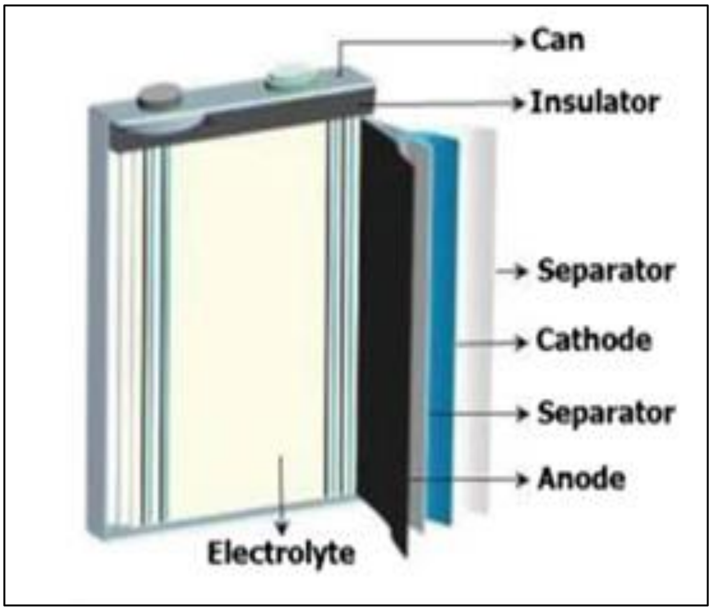


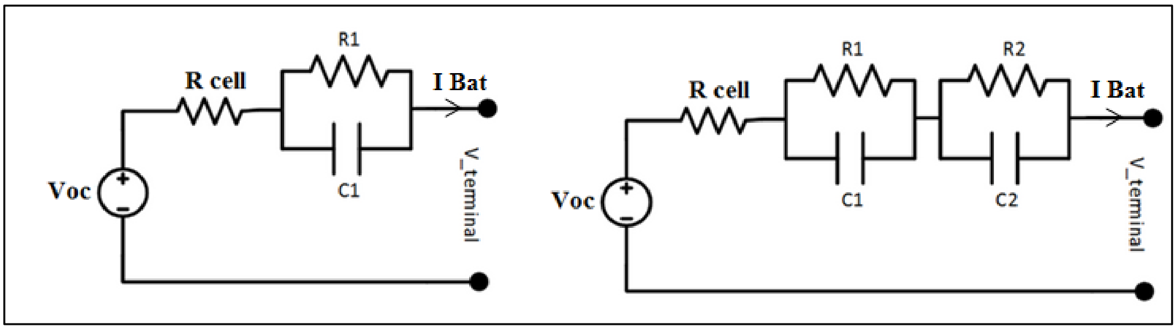
Figure 7: *Lithuim-ion battery*

Table 1: *Comparison of different types of batteries*

	Lead-acid battery	Jel battery	AGM battery	Lithium battery
Maintenance	Need	No need	No need	No need
Depth of discharge	50%	75%	50%	80%
Lifespan	3-5 year	6-8 year	6-8 year	20 year
Cost	150$	300$	250$	2000$
Charge temperature	-0°C to 50°C	-20°C to 50°C	0°C to 50°C	0°C to 45°C
Discharge temperature	-30°C to 70°C	-40°C to 60°C	-20°C to 60°C	–20°C to 60°C
Storage temperature	-20°C to 60°C	-40°C to 60°C	-20°C to 60°C	-20°C to 60°C
Energy density	30W.h/kg	40W.h/kg	50W.h/kg	50-260W.h/kg

The electrical representation of the battery

To determine the power losses and the terminal voltage of the battery an electrical representation has been achieved by models based on thevenin network. The most simple model consists of a series resistor, RC network to describe basic charge transfer phenomenon, and open circuit voltage (Voc) which dependent on the state of charge (SOC) as obvious in figure 8(a). An enhancement for the batteries simulation can be done by adding a second RC branch as demonstrated in figure 8(b). The first RC branch represents short-term transient behavior, and the second RC branch represents long-term transient behavior.



(a) *(b)*

***Figure** 8(a) Thevenin-based model, 1RC network (b)Thevenin based model, 2RC network*

Voc(soc) = $K_0 + K_1.(soc) + K_2.(soc)^2 + K_3.(soc)^3 + K_4.(e)^{K5.SOC}$

Rcell (soc) = Rcell(0) + $K5(e)^{K6.SOC}$

R1 (soc) = R1(0) + $K7(e)^{K8.SOC}$

C1 (soc) = C1(0) + $K9(e)^{K10.SOC}$

R2 (soc) = R2(0) + $K11(e)^{K12.SOC}$

C2 (soc) = C2(0) + $K13(e)^{K14.SOC}$

The coefficients K0, K_1, K_2, K_3,…….,K_{14} depend on the respective cell type and are subjects of measurements.

For higher accuracy another RC network is proposed, in order to describe finally short-term, mid-term, long-term transient behavior. However, this makes the calculation of the associated capacitors and resistors much more complex, also studies have shown that 2RC model achieves good results, therefore it is proposed in simulations of electrical power grids

The most important information about batteries

The effectivity and performance of the battery depend on the following parameters:

1. Capacity of battery
2. Efficiency of battery
3. Depth of discharge

Battery capacity

The amount of energy that the battery can storage.

If a battery of (12v) has a capacity of (500 A.h) ,the energy can be storage with this battery is:

Energy = Voltage * Current * Time
= 12v * 500A.h
= 6000w.h

Battery efficiency

It is the ratio of the output energy from the battery to the input energy that the battery needs to charge.

If the energy that the battery needs to charge is (6000 wh) and the energy that can be obtained from this battery is (4800 wh), then the efficiency of this battery is:

Battery efficiency = (output energy) / (input energy) * 100%
= (4800 w.h) / (6000 w.h) * 100%
= 80%

Depth of Discharge (DOD)

It is the amount of capacity that can be obtained from the battery capacity.

If the depth of discharge is equal to 50% for a battery whose capacity is (60Ah), then the amount of capacity that can be get it from this battery is:
= 60A.h * 0.5
= 30Ah

The time required for charging the batteries

When the solar panels used to charge the battery, the time required for charging the battery is equal to (capacity of the battery / panel current)

If the panel(9A) used in charging the battery (200A.h) then the time that required to charge the battery = $\frac{200A.h}{9A}$ = 22.22h

Series and parallel connection of batteries

The batteries are connected in parallel or in series to obtain the required current and voltage

Figure 9 shows four batteries each one of (12v , 100Ah) connected in series

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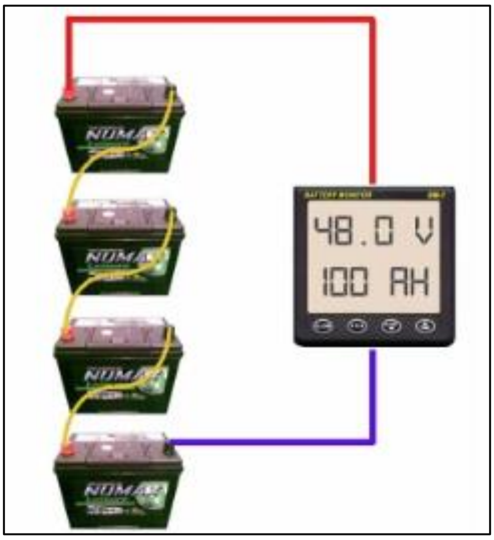

***Figure** 9. Series connection of batteries*

and figure 10 obvious these foure batteries connected in parallel

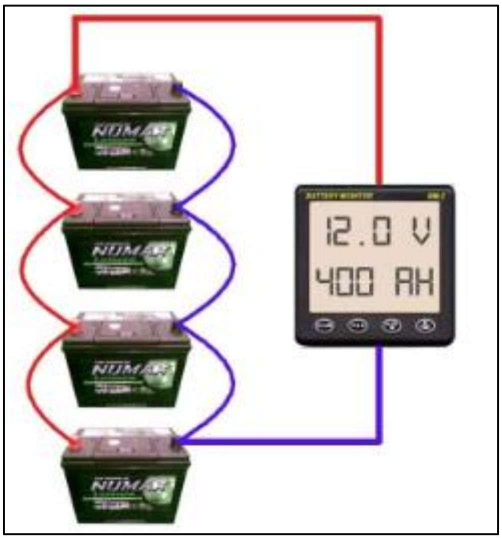

***Figure** 10. Parallel connection of batteries*

CONCLUSION

At the present time, due to the rise in temperatures over the past years, it is necessary to take into account the impact of temperatures on the performance of the battery when choosing the appropriate battery for working on design. Temperature, have a significant effect on the performance, and the safety of the solar batteries**.** As the temperature of the battery increases the chemical reactions inside the battery also quicken, and increased storage capacity of the battery. It was found that an increase in temperature from 25 ^{0}C to 45 ^{0}C led to a 20% increase in maximum storage capacity, but an available capacity decreases over time, and the lifecycle of the battery is decreased over time. Lithium battery has better volume and weight, and is relatively cheaper to maintain but the initial cost is higher, and it is more temperature sensitive. Flooded batteries and Jel batteries are the most using in Iraq because they are more cost-effective, it's price is just 1/4~1/6 of the lithium battery cost with an acceptable limits of the discharge depth (DOD) and it is suitable for high temperature work,

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