ET3034TUx - 7.5.1 - Batteries 1 - Introduction

Welcome back.

In this block I shall discuss a vital component of not only PV systems but also renewable energy systems in general.

As we discussed in the solar fuels block, there is a great need for energy storage at both small and large scales to tackle the intermittency of renewable energy sources.

In case of PV systems, the intermittency of the source is of two kinds - diurnal fluctuations, the difference of irradiance during the 24 hour period; and the seasonal fluctuations, the difference of the irradiance across the summer and winter months.

There are several technological options to fulfill the storage requirements.

How do we make an optimal choice for the storage system?

Let us go back to the Ragone plot again.

For solar applications, depending on the scale of implementation, we need a high energy density, and a reasonably high power density.

We cannot use capacitors because of their very poor energy density.

For short-term to medium-term storage, the most common kind of storage in use is of course the batteries.

They have just the right energy density and power density to meet the daily storage demand in the PV system.

Of course, the seasonal storage problem at large scales is yet to be solved convincingly.

For now, batteries still seem to be the most reliable option for PV systems in the small to medium-scale.

The ease of implementation and efficiency of the batteries is still unbeatable when compared to other technologies, like pumped hydro, compressed air energy storage, conversion to hydrogen and converting back into electricity, and others.

I will therefore focus on the battery technology in this block as a viable storage option for PV systems.

Batteries are electrochemical devices that convert chemical energy into electrical energy.

They are mainly classified as primary or secondary batteries.

Primary batteries irreversibly convert chemical energy to electrical energy.

Examples include zinc carbon batteries and alkaline batteries.

Secondary batteries or as they are more commonly called - rechargeable batteries, reversibly convert chemical energy to electrical energy.

That is, they can recharge when the chemical reaction is reversed using an over-potential.

In other words, the excess electrical energy is stored in these secondary batteries in the form of chemical energy.

Examples include lead-acid batteries and lithium-ion batteries.

It is the secondary batteries that we are interested in to explore as a possible storage option.

There are several kinds of secondary battery technologies available that could be used.

For example, lead-acid batteries.

These are the oldest and the most mature battery technology available till date.

I will go deeper into this widely accepted PV storage option later.

Another secondary battery type is nickel metal hydride and nickel cadmium batteries.

Nickel metal hydride have a good energy density, comparable to that of the Li-ion batteries.

But NiMH batteries suffer from a high rate of self discharge.

NiCd batteries have much lower energy densities.

Due to the environmental impact of cadmium, the sale of Ni-Cd batteries for consumer use is largely banned in the EU.

Further, NiCd batteries suffer from what is called as memory effect - the batteries lose their usable energy capacity if they are repeatedly charged after only a partial discharge.

These demerits make the NiCd and NiMH unlikely candidates for storage in PV systems.

Next we go to the lithium-ion and lithium-ion polymer batteries.

These are being heavily researched currently as storage alternatives in various applications.

Their high energy density has already made them a favorite in lightweight storage applications.

But for their costs and low maturity, they would have been instant favorites for storage in PV systems.

Note that you shouldn't confuse lithium batteries with Li-ion or Li-ion polymer batteries.

Lithium batteries are disposable primary batteries while Li-ion and Li-ion polymer are secondary batteries.

The last and the most upcoming category is that of the redox flow batteries.

The 2 main storage options for PV storage, i.e.

lead-acid and Li-ion batteries are similar in the sense that their electrodes undergo chemical conversion during charging and discharging.

Therefore, the electrodes tend to degenerate with time, adding to the inevitable "aging" of the battery.

Redox flow batteries are a very new technology, which seem to combine the properties of both the batteries and the fuel cell.

The different reactants only exchange ions in the form of electrolytes through a membrane in a cell.

Thus the cell reactions proceed without a physical mixing of the reactants.

The chemical energy in a redox flow battery is stored in its 2 electrolytes, which can be maintained physically separate from each other.

Redox flow batteries thus have a high life expectancy.

Let's look at the Ragone plot specific to the typical batteries only.

This is slightly different from the Ragone plot shown earlier, as this shows the comparison between the various battery technologies in terms of gravimetric energy density and the volumetric energy density.

Volumetric energy density is the amount of energy stored per volume of battery.

The typical unit of measurement is Wh/l.

Higher the volumetric energy density, smaller the battery size.

Gravimetric energy density is the amount of energy stored per mass of the battery.

The typical unit of measurement is Wh/kg.

Greater the gravimetric energy density, lighter the battery will be.

As seen, lead-acid shows the lowest volumetric and gravimetric energy densities among the batteries.

Lithium-ion batteries show ideal material properties to make it an optimal storage choice.

Redox flow batteries have shown a lot of promise in their research phase so far.

However, redox flow batteries and Li-ion technologies are still being heavily researched upon.

Consequently, these technologies are also very expensive.

Due to the unbeatable maturity and low cost of the lead-acid batteries, they are still the storage technology of choice in PV systems, despite their much lower energy density and extremely low cycle life.

Let's look a little bit more closely at the lead-acid battery.

Here you see a typical construction of a lead-acid battery.

As with most batteries, the lead-acid battery is composed of several individual cells, each of which have a nominal cell voltage of around 2 V.

Lead-acid batteries could have different types of assembly.

When built as a block assembly, the individual cells share the housing and are interconnected internally.

For instance, to get the popular lead-acid battery pack of 12 V, 6 such cells have to be connected in series.

As the battery name suggests, the electrolyte in this battery is made from dilute sulphuric acid (H2SO4).

Two plates of opposite polarity are inserted into the electrolyte solution, which act as the electrodes.

The electrodes contain grid shaped lead carrier and the porous active material.

It is this porous, active material that acts as a sponge-like structure, providing sufficient surface area to help the electrochemical reaction.

The active mass in the negative electrode is lead, and in the positive electrode is lead oxide.

When electricity is drawn, electrons flow from the negative to the positive electrode through the external circuit, causing a chemical reaction between the plates and the electrolyte.

This forward reaction also depletes the electrolyte, affecting its state of charge or SOC.

When the battery is recharged, the flow of electrons is reversed, as the external circuit doesn't have a load, but a source that has a higher voltage than the battery to enable the reverse reaction.

In the PV systems, this source is nothing but the PV module or array providing clean solar power.

Remember that the use of storage is more common in the stand-alone PV systems, because there is no other source of power to support the PV array.

The loads are at the mercy of the availability of the sun.

In such a case energy storage options like the battery can be very useful.

As an example, a typical solar irradiance profile is shown during the day.

You can also see the load demand, which is significant in the parts of the day where there is no sun.

In a stand-alone system without storage, even though the sun has more than enough power during the day, the system fails to utilize this excess energy to power the loads when the solar power isn't enough.

With the introduction of the battery storage in the PV system, the excess energy from the sun during the day can be stored in the battery.

The battery can then be discharged during the periods of low solar irradiance, and thus the load demand can be met.

To summarize, we have seen the different kinds of battery technologies, and discussed why lead-acid is the battery of choice for most current PV systems.

I will talk in detail about the various battery parameters in the next block.

We will also see how managing the different battery parameters is a whole new optimization challenge on its own.

See you in the next block!