Model of a Li-ion battery with Simulink

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ABSTRACT

The central idea is to couple a battery with a PV system in order to optimise the energy production of the panels. In particular, the surplus of energy produced by the system can be stored in the battery when it is not needed and then granted to the user when needed, for example at night when the PV system is not able to produce energy.

In this case the battery will be a Li-ion one, it has been chosen mainly because of its high specific energy and long cycle life with respect to other kind of batteries.

The simulation is performed during a whole day, the input data are the energy produced by the PV system and the energy required by the house, the battery's nominal capacity and nominal voltage.

In order to study the system, a model of both the charging and discharging phase of the battery is set up in Simulink and the simulation is run for 86400 seconds, the number of seconds in a day.

The aim of the simulation is to calculate the state of charge, the voltage and the current of the battery during the day to see if it can provide the energy to the house when needed, so if it is undersized or oversized with respect to the energy request.

1. INTRODUCTION

Nowadays there are four main types of rechargeable batteries:

- Lead-acid
- Nickel-Cadmium
- Nickel-Metal Hydride
- Lithium-ion

Lead-acid battery is the oldest developed among the mentioned ones. In the discharge phase both the cathode and the anode, respectively a solid wafer of lead dioxide (PbO_2) and metallic lead (Pb2), react with the electrolyte, in this case sulphuric acid (H_2SO_4), from this reaction a salt (lead sulphate $PbSO_4$) and liquid water are obtained.

Nickel-Cadmium battery is typically composed of nickel hydroxide ($Ni(OH)_2$) as positive electrode and cadmium hydroxide ($Cd(OH)_2$) as negative electrode, the electrodes are dipped in potassium hydroxide (KOH). This kind of battery contains a toxic metal (cadmium) which may cause health problems to workers especially during battery disposal, for this reason this material combination is now restricted in many countries [1].

In the Nickel-Metal Hydride battery the cathode is made of nickel oxide hydroxide (NiO(OH)) and the anode is a metal hydride (XH). This kind of battery is termed an alkaline storage battery due to the use of potassium hydroxide (KOH) as the electrolyte [2].

Lithium-ion batteries, like the other batteries, incorporate the redox reactions between the electrolyte and electrodes, accompanied by the diffusion of ions in the electrolyte. The difference between this battery and the other cells is that in typical galvanic batteries the redox reactions proceed simultaneously with the solidification and liquefaction of the material of which the electrode is composed of, but are not accompanied by the mass diffusion in the electrodes, while the heterogeneous redox reactions in Li-ion batteries are always accompanied by solid-state mass diffusion even if the electrode surfaces do not retreat or advance (when the change of the electrodes volume is not taken into account) [3].

The battery is composed of a cathode that can be made of a lithium metal oxide like lithium cobalt oxide (LCO) or lithium manganese oxide (LMO), an anode for which the dominant material is graphite, an electrolyte which is a mixture of lithium salt and organic solvents and a separator that prevents direct contact between anode and cathode while letting lithium ions pass through it.

At the beginning of the battery cycle the lithium atoms are are stuck in the cathode. During the charging phase, thanks to the power produced by the source (in this case the PV system), a voltage is applied and lithium ions and electrons take different paths: the first ones move through the separator to the anode while the second ones reach the negative electrode through the external circuit. As both ions and electrons are at the anode, they recombine and the battery is fully charged, so that the user can employ the stored power discharging the battery.

As previously highlighted, one of the significant aspects of a Li-ion battery is its energy density. This feature depends on the used materials, in particular since anode materials usually offer a higher Li-ion storage capacity, the cathode material is the limiting factor in the performance of these batteries. For this reason to enhance the energy storage performance a thin and porous carbon film can be applied on nano-structured cathode materials [3].

Lithium-ion batteries have the potential to become a key component in the transition towards sustainable energy, in fact most of renewable energy sources are discontinuous (they depend on factors like sunlight, weather, etc…) and sometimes cannot provide energy when needed or produce too much energy when there is no one to use it, for this reason an energy storage coupled with these sources is needed. Therefore Li-ion batteries are also important because they could support the integration of photovoltaic and wind energy in the power mix by providing storage capacity and so contributing to an electricity mix with a smaller carbon footprint [5].

2. METHODS

To model this kind of battery the electric circuit-based model is used, this is because of the straightforward way in which the dynamic model parameters can be extracted. In fact to obtain these parameters only three points on the manufacturer's discharge curve are required: the fully charged voltage, the end of the exponential zone and the end of the nominal zone and the maximum capacity [4].

The assumptions of the model are:

- The internal resistance is constant during the cycles and does not vary with the amplitude of the current.

- The model's parameters are deduced from the discharge characteristics and assumed to be the same for charging.
- The capacity of the battery does not change with the amplitude of the current.
- The temperature does not affect the model's behaviour.
- The self-discharge of the battery is not represented.
- The battery has no memory effect.

The battery voltage during the discharge phase is given by:

$$V_{batt} = E_0 - K\frac{Q}{Q - it} \cdot (it + i^*) - R \cdot i + Aexp(-B \cdot it) \quad (1)$$

While in the charge phase we have:

$$V_{batt} = E_0 - K\frac{Q}{it - 0.1 \cdot Q} \cdot i^* - R \cdot i + Aexp(-B \cdot it) - K\frac{Q}{Q - it} \cdot it \quad (2)$$

Where

E_0 is the battery constant voltage (V)

K is the polarisation constant (V/Ah)

Q is the battery capacity (Ah)

it = ∫ i dt is the actual battery charge (Ah)

A is the exponential zone amplitude (V)

B is the exponential zone time constant inverse $(Ah)^{-1}$

R is the internal resistance (Ω)

i is the battery current (A)

i* is the filtered current (A)

In this model there is a filtered current flowing through the polarisation resistance, this is to represent the voltage slow dynamic behaviour for a current step response. Another peculiarity of this model is the polarisation resistance that changes between the charge and discharge phase and models the rapid increase of voltage when the battery is fully charged [4].

The Simulink model is built as shown in figure 1:

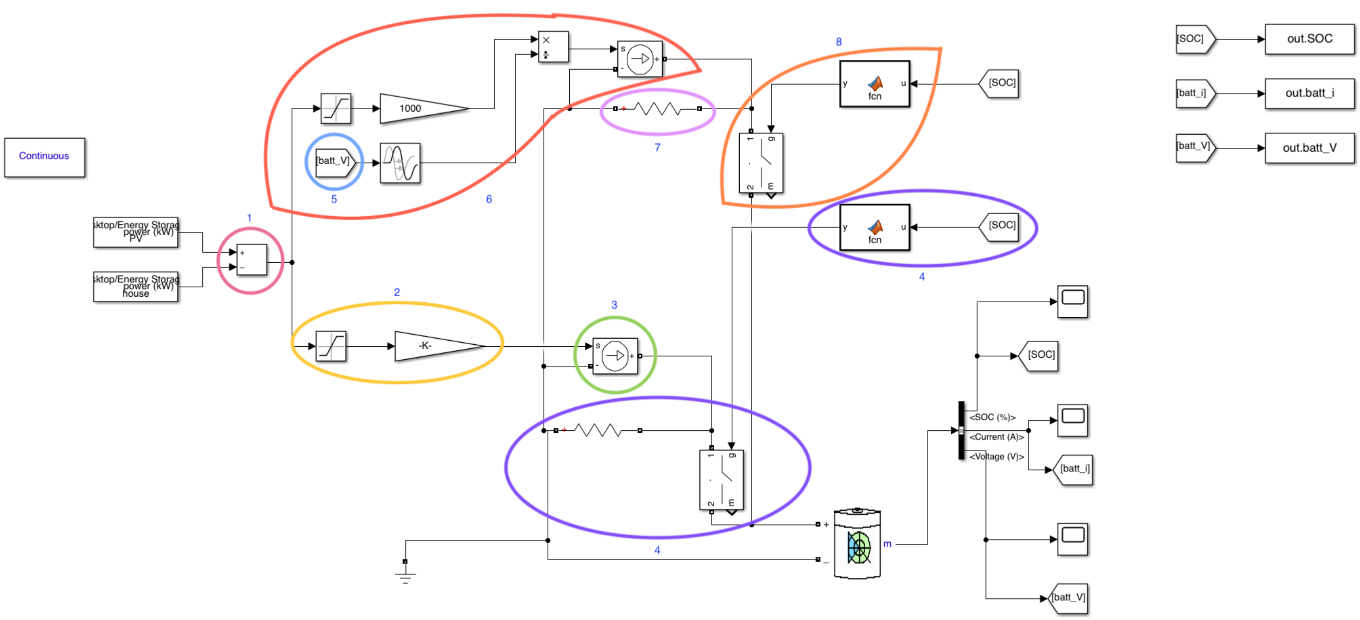

Figure 1 - Simulink model

The points 1-2-3-4 are part of the charging phase while the points 5-6-7-8 are part of the discharging phase:

1. The sum block in point 1 is the algebraic sum between the PV production and the user demand. If it is positive the supply from PV is greater than the house demand and so

we can charge the battery with the energy in excess, vice versa if it is negative we need to discharge the battery to power the house.

2. To charge the battery we need a DC/DC converter which is a circuit that converts a source of direct current from one voltage to another, the power generated by the PV system is converted it into a current with a nominal voltage which is the nominal voltage of the battery. In Simulink this circuit is represented by a gain block, in particular it takes the power in kilowatt, multiplies it for one thousand in order to obtain watt, multiplies it again for 0.85 which is an approximation for the efficiency of the converter (in real life it dissipates power, cannot be a perfect device) and then it divides the power by the nominal voltage of the battery. Now the power initially in kilowatt is a current in ampere.

3. The charge current block takes the value of the current in the positive port and delivers it to the battery, this current after charging the battery returns in the negative port.

4. The blocks with number four represent the state of charge control of the battery: when the SOC is higher than 99% the circuit is opened (by means of an ideal switch) so that the current cannot flow in the battery anymore. Since the current is produced anyway but it cannot charge the battery, the circuit has to be closed in another way, in order to do this a dummy load is used.

5. The voltage in point five is the one computed at the previous step of the simulation.

6. To discharge the battery we do not need the DC/DC converter because the battery itself imposes the voltage of discharge, so in this case the gain just multiplies the power in

order to obtain watts from kilowatts. This power is then divided by the voltage described in point five in order to obtain the discharge current.

7. The dummy load is also present in the discharge phase, we need it to close the circuit when the SOC is low.

8. The state of charge control of the discharge phase opens the ideal switch when SOC is lower than 10 % because the battery has run out of power.

3. RESULTS

With the input data in table 1 the simulation is run:

Battery nominal capacity	730	Ah
Charging nominal voltage	14.4	V
Power produced by PV	$1.3*PV_0$	kW
Power requested by the house	$2.1*House_0$	kW

Table 1 - Input data according to the team subdivision

According to the team subdivision, the trend of the PV power and the one requested by the house during the day is the one shown in figure 2:

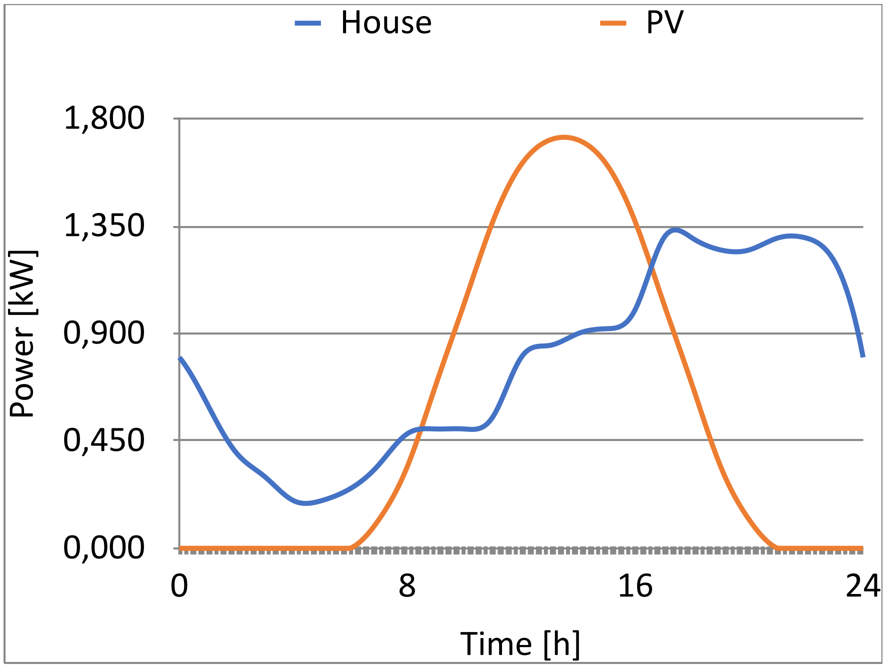

Figure 2 - Power produced by PV VS power requested by the user

The results of the simulation are the current, the voltage and the state of charge of the battery during the day, respectively shown in figures three, four and five:

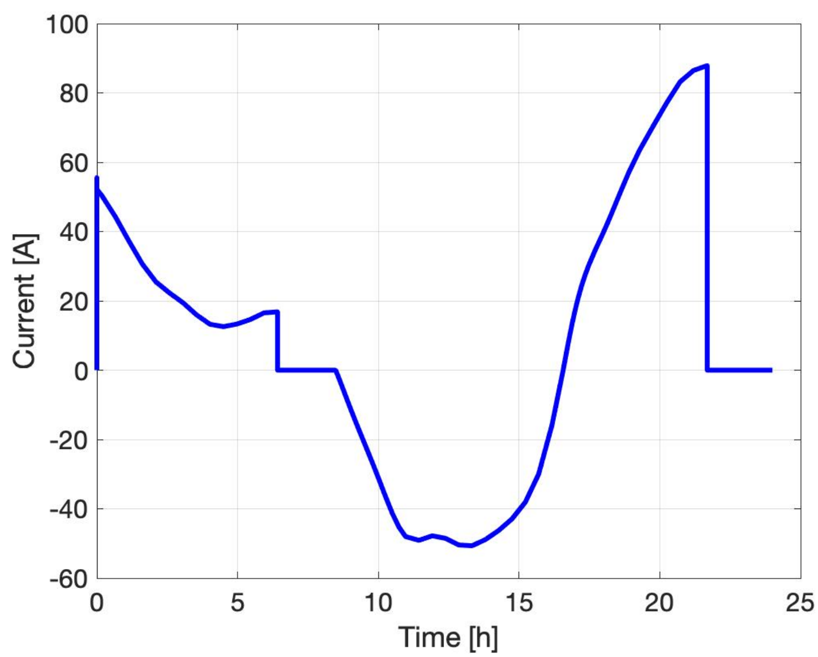

Figure 3 - Current during the day

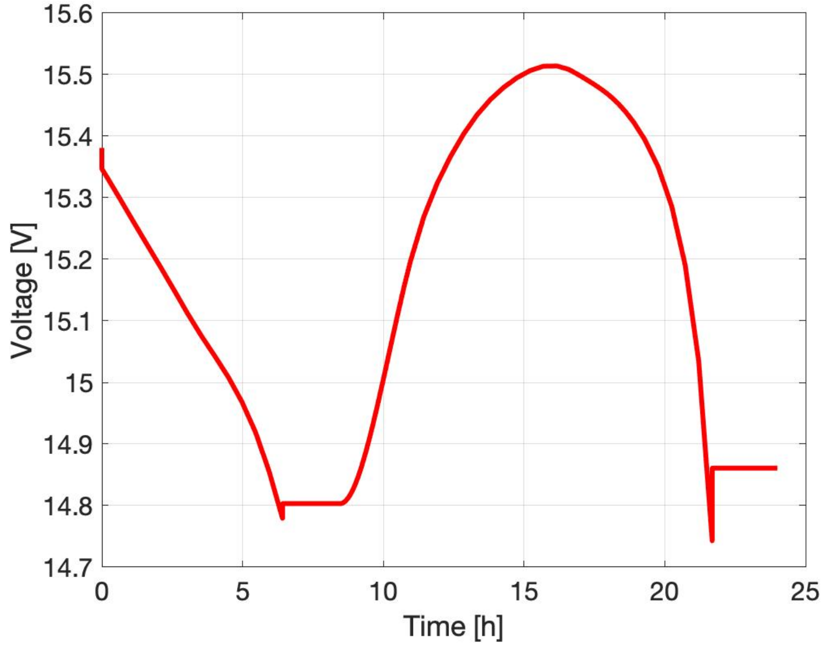

Figure 4 - Voltage during the day

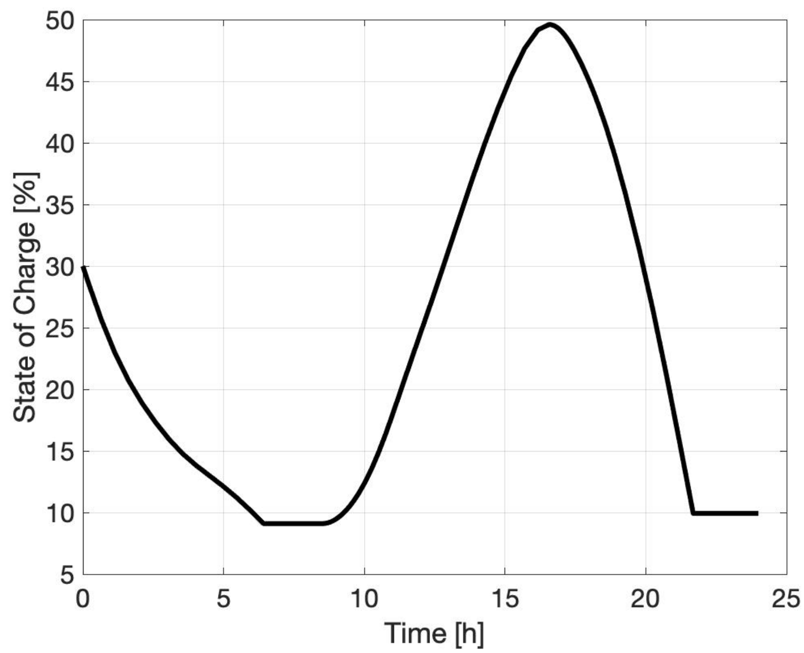

Figure 5 - State of charge during the day

As we can see, at night when the production from the PV system is zero, the house has anyway a power request and this power is provided by the battery.

Its state of charge goes from 30% (the initial condition) to 10%, at this point it cannot power the house anymore. From about 7 a.m. the PV system starts producing power and by 9 a.m. it can power the house and also charge the battery with the energy in excess, so the state of charge starts rising and the current in the battery is negative because we are in the charging phase. At about 4 p.m. the power requested by the house outmatches again the PV production so it is time to discharge the battery, the state of charge is now decreasing and the current is again positive. Unfortunately, from 10 p.m. to 12 p.m. the state of charge of the battery is again too low to power the house.

4. CONCLUSIONS

Coupling a Li-ion battery with a PV system to store the energy in excess has proven to be an efficient way to make the intermittent renewables energy sources more competitive in the energy market. The high energy density and long cycle life of this kind of battery, along with the possibility of improvement through various techniques (like the application of a thin carbon film on the cathode), make this device promising for future applications [3].

The battery can be modelled by the electric circuit-based model and simple simulation of its behaviour can be implemented in Simulink. From this simulation the values of the battery voltage, current and state of charge can be computed during the day and comparing these results with the power requested by the house some considerations can be made.

In this case the battery seems to be a little undersized with respect to the energy request, in fact from 6 a.m. to 8 a.m. and from 10 p.m. to 12 p.m. it is discharged. In particular, in these time slots, the panels are not producing energy and with the battery discharged it is not possible to match the energy request of the house. However the battery helps covering the energy demand in the afternoon, when the PV system does not produce enough energy and avoids the waste of the energy in excess produced around noon, because of these reasons it is a valuable technology for future and present applications.

REFERENCES

[1] Pruthvija, Lakshmi, "Review on Battery Technology and its Challenges" *International Journal of Scientific & Engineering Research Volume 11, Issue 9, September 2020:* 1706-1711

[2] Kopera, "Inside the NiMH Battery" *Cobasys 25 June 2004:* 6-13

[3] Liu, Neale, Cao, "Understanding electrochemical potentials of cathode materials in rechargeable batteries" *Materials Today Volume 19, Number 2 March 2016:* 110-111

[4] Tremblay, Dessaint, "Experimental Validation of a Battery Dynamic Model for EV Applications" *Stavanger, Norway, May 13 - 16, 2009: 290-292*

[5] Zubi, Dufo-López, Carvalho, Pasaoglu, "The lithium-ion battery: State of the art and future perspectives" *Renewable and Sustainable Energy Reviews 89 (2018):* 292