Energy Management for IoT

ENERGY STORAGE GENERATION LABORATORY

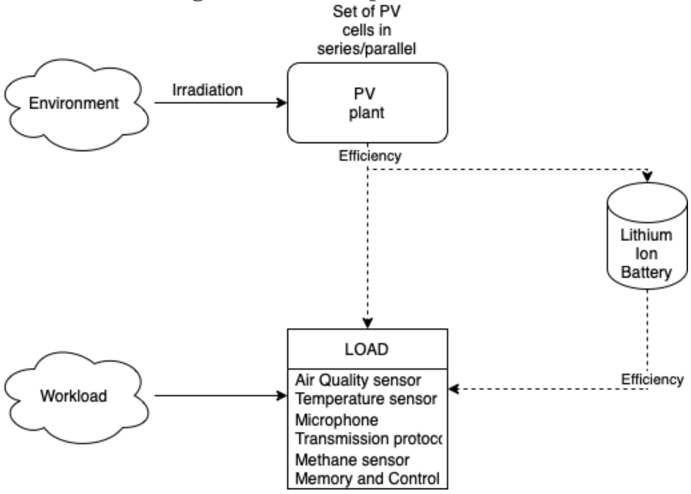
Alessandro Landra (s284939)
Dalmasso Luca (s281316)
Course: Embedded Systems (Computer Engineering branch)
Date: 21/01/2022

Goal of the lab

In this last experiment the goal was to simulate an IoT system in MATLAB/Simulink to proper analyze it's behaviour in terms of power consumption, efficiency and lifetime (battery duration).

Since every detail of the system is already described in the Simulink model, as well as in the slides, in this report it's enough to model the system like the following:

Figure1: IoT simplified view



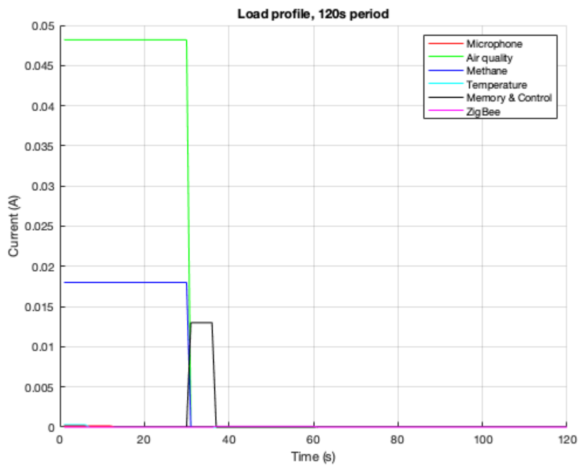
Given a fixed irradiance profile and a lithium ion battery is possible to obtain different lifetimes by acting on the workload scheduling and the PV plant structure.
A change in the workload scheduling or in the PV plant will determine:

- How often is the battery used to Produce power.
- How much efficient is the battery.
- How much power is produced by the PV cells.
- How much efficient is the PV plant.
- Overall cost of the PV plant (more PV cells will increase the cost)

FIRST SIMULATION

The first simulation was run with 1 PV cell and the following workload schedule:

Figure2: initial workload schedule



With this configuration the battery, and the PV plant are able to sustain the system for approximately 13 days, and these are the data collected:

Figure3: Battery power generation and PV cells power generation in the first 3 days

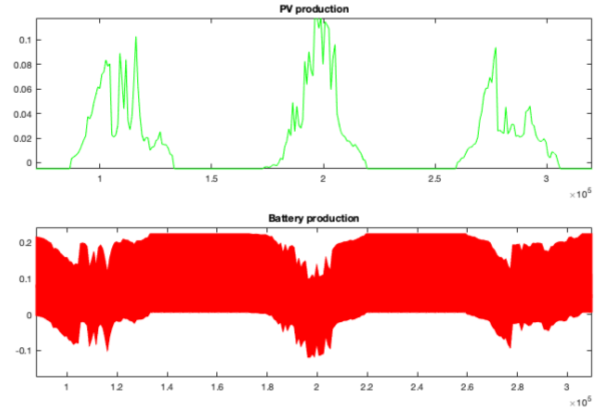
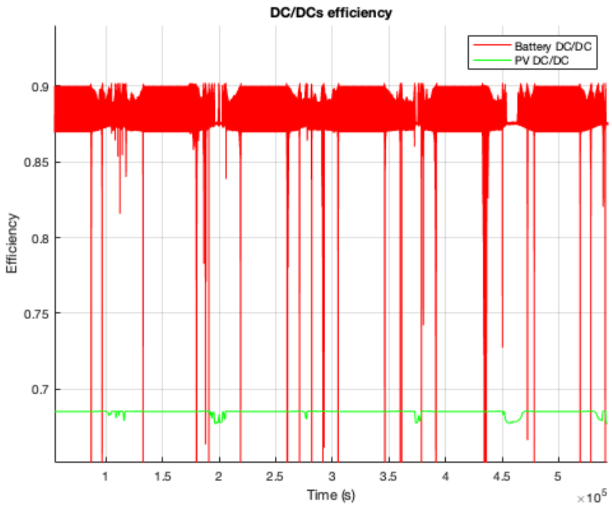


Figure4: DC/DCs convertions efficiency

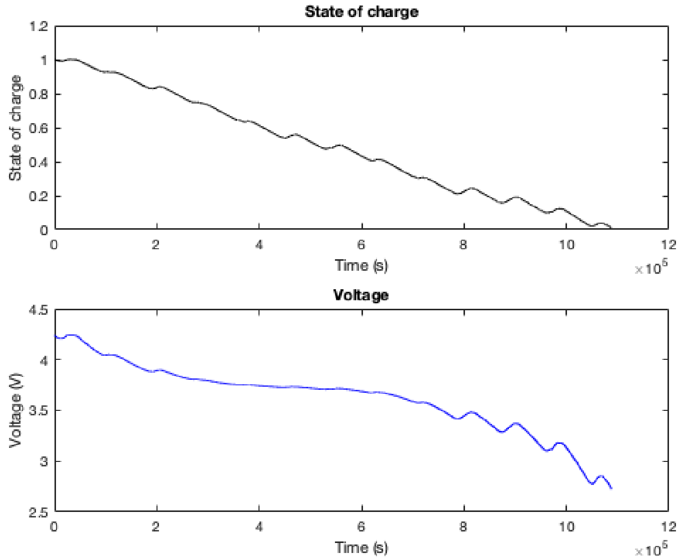


In some periods the PV plant is able to charge the battery and, in the meantime, also sustain the systems (this happens when the battery power goes in negative, this means that is charging herself). Most of the time the PV cell alone is not able to provide enough power to the system, in this periods the battery needs to help.
Concerning the convertion efficiencies is possible to say that the battery on average works in high efficiency, while the PV plant is not.
This is due to the fact that the PV's DC/DC converter works great with input voltages between 1-2.5 volts (from datasheet), but this kind of ranges cannot be generated by a PV cell that works in MPP.

It is expected that, with this configuration, the battery eventually going to be discharged, because the power used to charge her is less than the power consumed from her.

In the below Figure5 is possible to observe the discharge profile of the battery, notice how fast the battery voltage quickly drops as the battery approaches the minimum capacity.This should be the expected behaviour, because its very typical for a lithium-ion battery.

Figure5: Battery state of charge variations

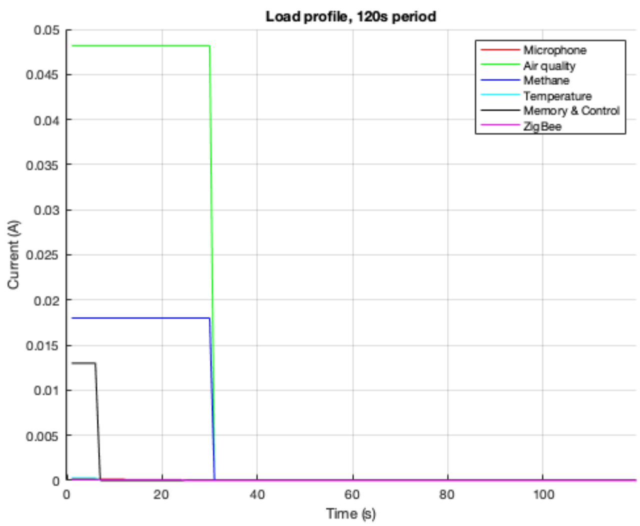


Load current profile evaluations

According to the battery model, the load current profile determines the actual capacity and lifetime of the battery.
In particular when a load profile asks more current (peak current or average current) the battery is going to discharge faster.

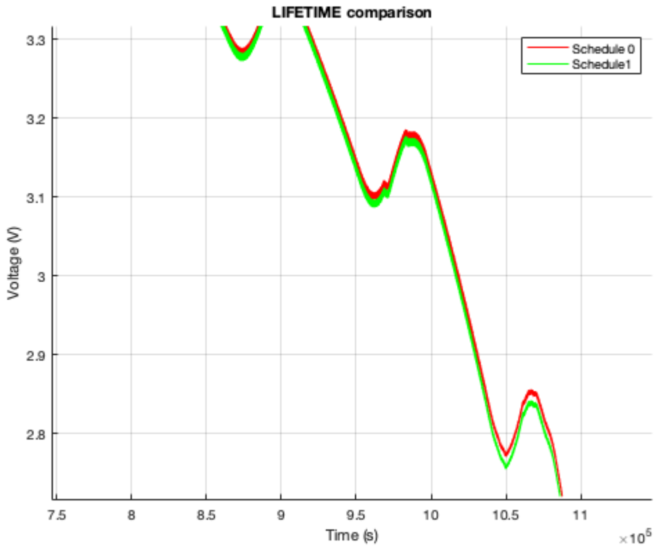
In order to demonstrate this, and also to demonstrate that the model is working correctly, we started a new simulation with the following load profile:

Figure6: Load profile more aggressive, all loads are active at the same time, peak current is higher.



The result in Figure7 is basically confirming that this new load profile is decreasing the lifetime of the system with respect to the first profile.

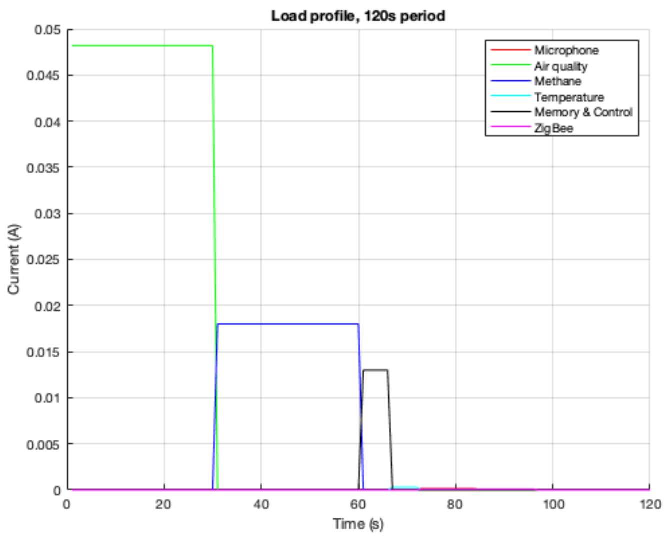
Figure7: lifetime with the more aggressive load profile (schedule 1)



Scheduling optimization: rate dependent capacity

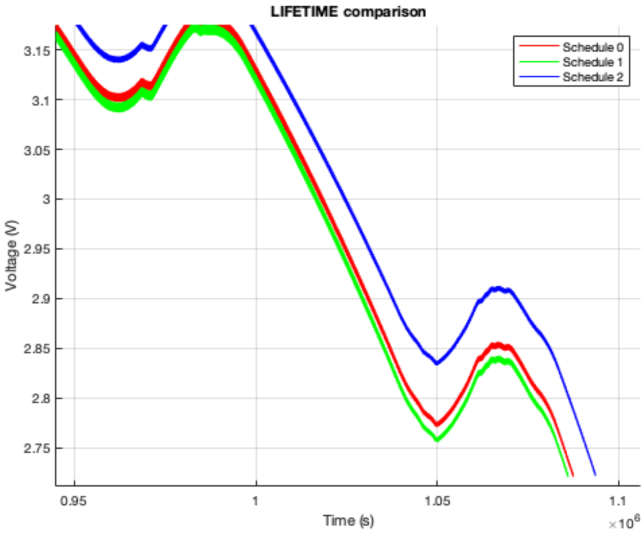
An active strategy to optimize the battery lifetime is to shape the current profile in such a way that the battery properties are used appropriately, in particular the rate-dependent capacity.
As the theory suggests, highly current-demanding operations should be executed first and low demanding ones later (Figure8).

Figure8: schedule2, operations executed in series, non increasing load profile



Lifetime increased a little bit (less than 3hours with respect to worst case schedule, Figure9).

Figure9: comparison of the 3 cases



Lifetime improvement, PV plant refinements

In this final section some solutions to increase the lifetime of the battery will be discussed.

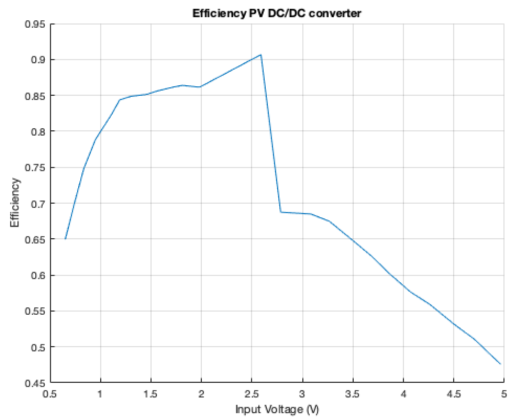
Starting from the previous analysis, we should first of all increase the power produced by the PV plant in order to avoid using too much the battery.
The experiment impose 1 limitation:

- The cost of an additional PV cell is 5.50 $.
- The cost of an additional Battery is 4.99 $
- The maximum additional cost is 11.00 $.

We decided to avoid adding additional batteries because we considered the system as closed, in which the solar plant can be connected as if it were a power supply.
So the possibilities are constrained to 1 or 2 additional PV cells that can be connected in series or parallel.

Another constraint should be linked to the DC/DC converter efficiency (Figure10).
If more than 1 PV cell is placed in series, than the overall DC/DC's input voltage is going to be very high and the resulting efficiency extremely low.

Figure10: PV DC/DC's efficiency, each PV cell is expected to work around 3V.



2 PV cells in series

These are the results with 2 PV cells in series, as expected the efficiency of the DC/DC in the PV plant has dropped from an average of 68% to an average of 30.54% (Figure11).
As a consequence of this, also the lifetime is reduced (21 hours approximately) with respect to the best schedule(Figure12).
The overall cost is 5.50$ more.

Figure11: Efficiency of PV DC/DC convertion.

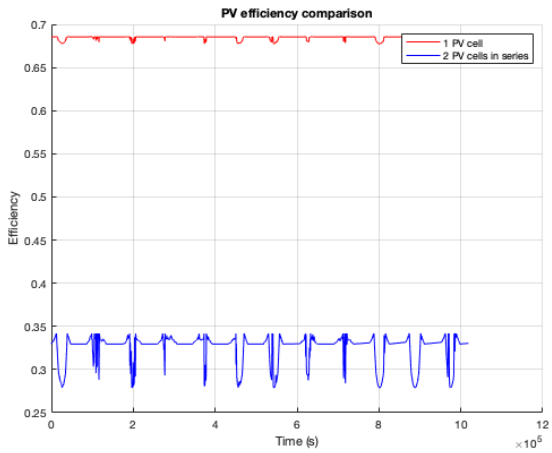
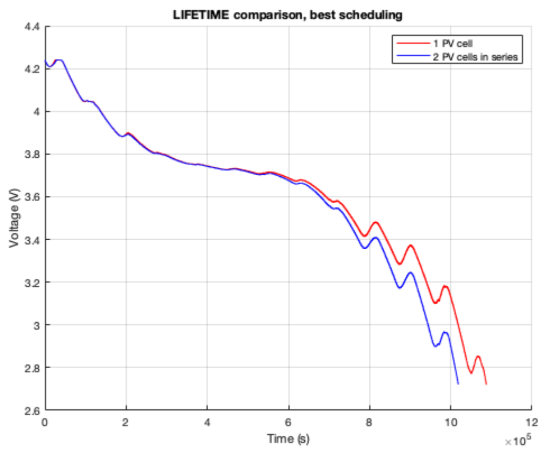


Figure12: Lifetime comparison with new plant vs old plant



2 PV cells in parallel and 3 PV cells

With this solution there's no more any issue correlated to the PV DC/DC converter, because the parallel configuration doubles the current not the voltage, as a consequence this approach of placing PV cells in parallel should be the optimal.

The solution with 3 PV cells is anyway the optimal, the system is able to fully work with the specified irradiance conditions for all the time (90 days roughly).

These are thus the final results: (Figure13)

Figure13: 1PV cell, 2 PV cells in parallel, 3 PV cells in parallel
1 PV cell: lifetime is 13 days approximately
2 PV cells in parallel: lifetime is 32 days approximately
3 PV cells in parallel: lifetime fully covers the 90 days with the given irradiance.

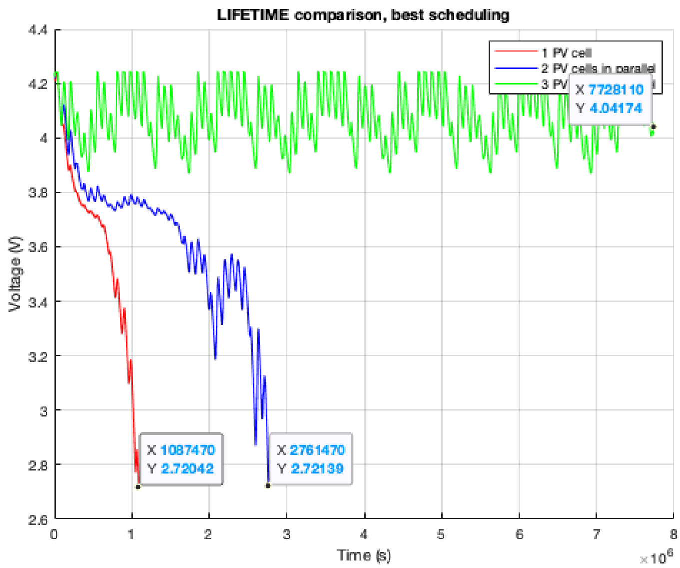


Figure14: Simulink changes to the PV module to perform simulations with any possible series/parallel PV plant configuration.