

Politecnico di Torino

# Energy management for IoT application Report laboratory session 3

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## Introduction

The goal of the laboratory is to create and study a model for a battery system. The creation of the model is performed using Simulink environment. In particular the battery has been simulated improving its electrical model, fig. 1. In order to stress the battery a pack of 4 sensors has been created, each one present a specific workload supporting two states: SLEEP and ACTIVE. Furthermore, a memory module and a transmission module are implemented. The whole power demand is handled by a DC bus, which interfaces the loads with power supply.

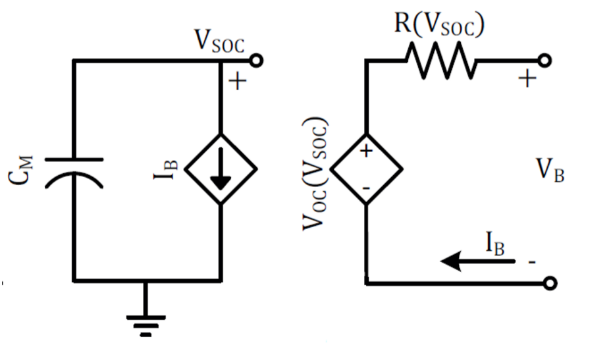


Figure 1 - Battery model

In order to improve the battery system, a Photovoltaic cell has been connected and interfaced with the system. The DC bus, senses the power demand and adapts the supply between the PV and battery. Furthermore, when the PV power exceeds the current power demands the remaining energy is harvested on the battery. Is important to highlight that both PV cell and battery, present a DC-DC converter as interface to the bus. The efficiency of the converters will be stored digitizing the datasheet curves. Photovoltaic cell is assuming to work always at its maximum power point.

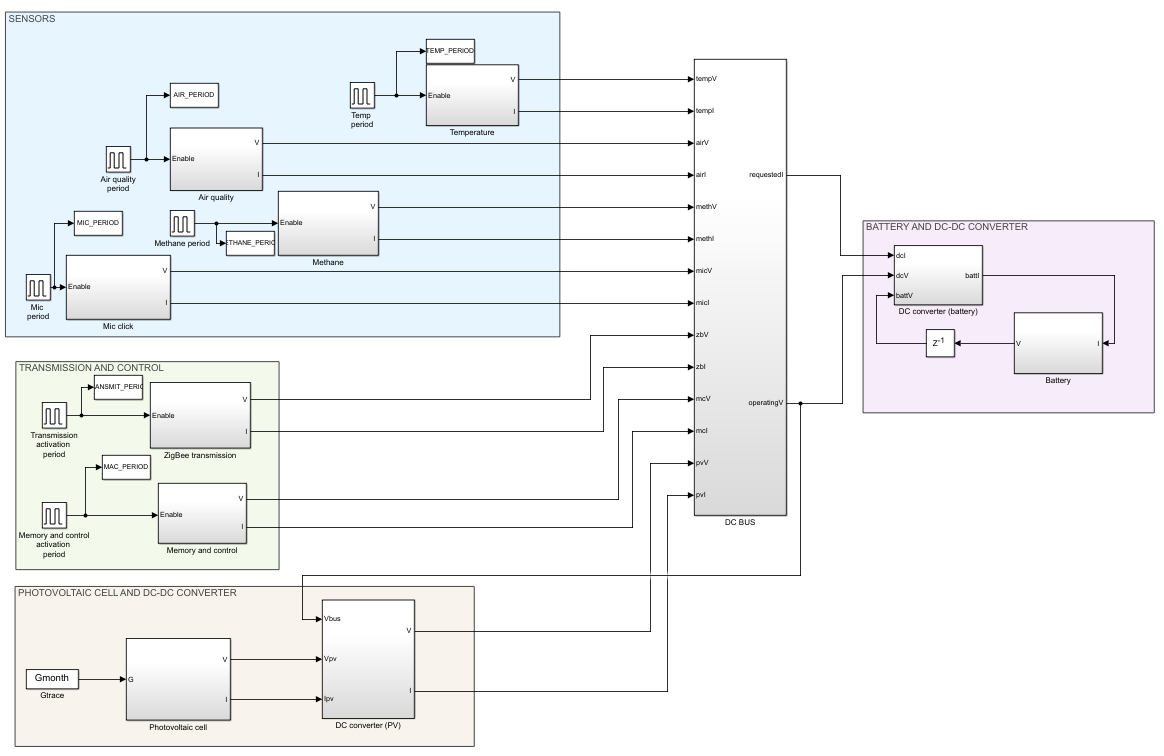


Figure 2 - System model

## Simulation trace

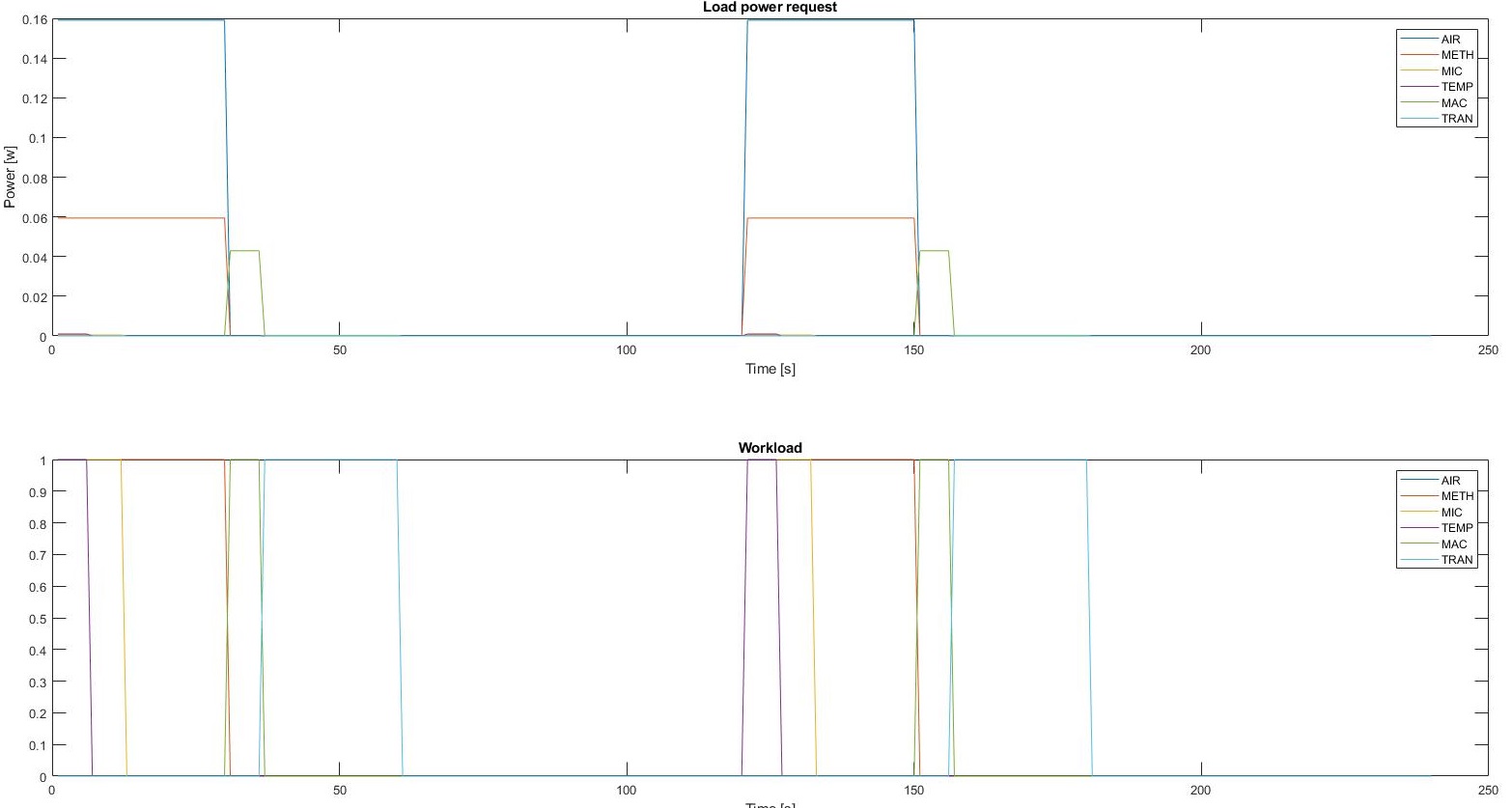
Once the model has been created and filled, the simulation can start. The first simulation has been launched considering a parallel scheduling of the loads, in a period of 120 seconds. The shape of the workloads is reported in figure below, the plot is reported in two periods. As possible to notice, in some points of time the workloads are overlapped increasing the current demand. All the loads are supplied by a constant voltage of 3,3V. The upper plot represents the power requested by each sensor. In the lower plot is reported the scheduling of the sensors over time.

Figure 3 - Workload and power demand

In this section, a description of the simulation will be carried. Is important to highlight that simulation ends when one of two situations are satisfied:

* The simulation time elapses (around 3 months)
* The battery is considered discharged (voltage under 2,5 V or SOC under 0.01)

The first simulation last for 91,37 hours, before reaching the drop-out voltage. The figure below reports the curve of the state of charge and battery voltage changing over simulation time, reported in second.

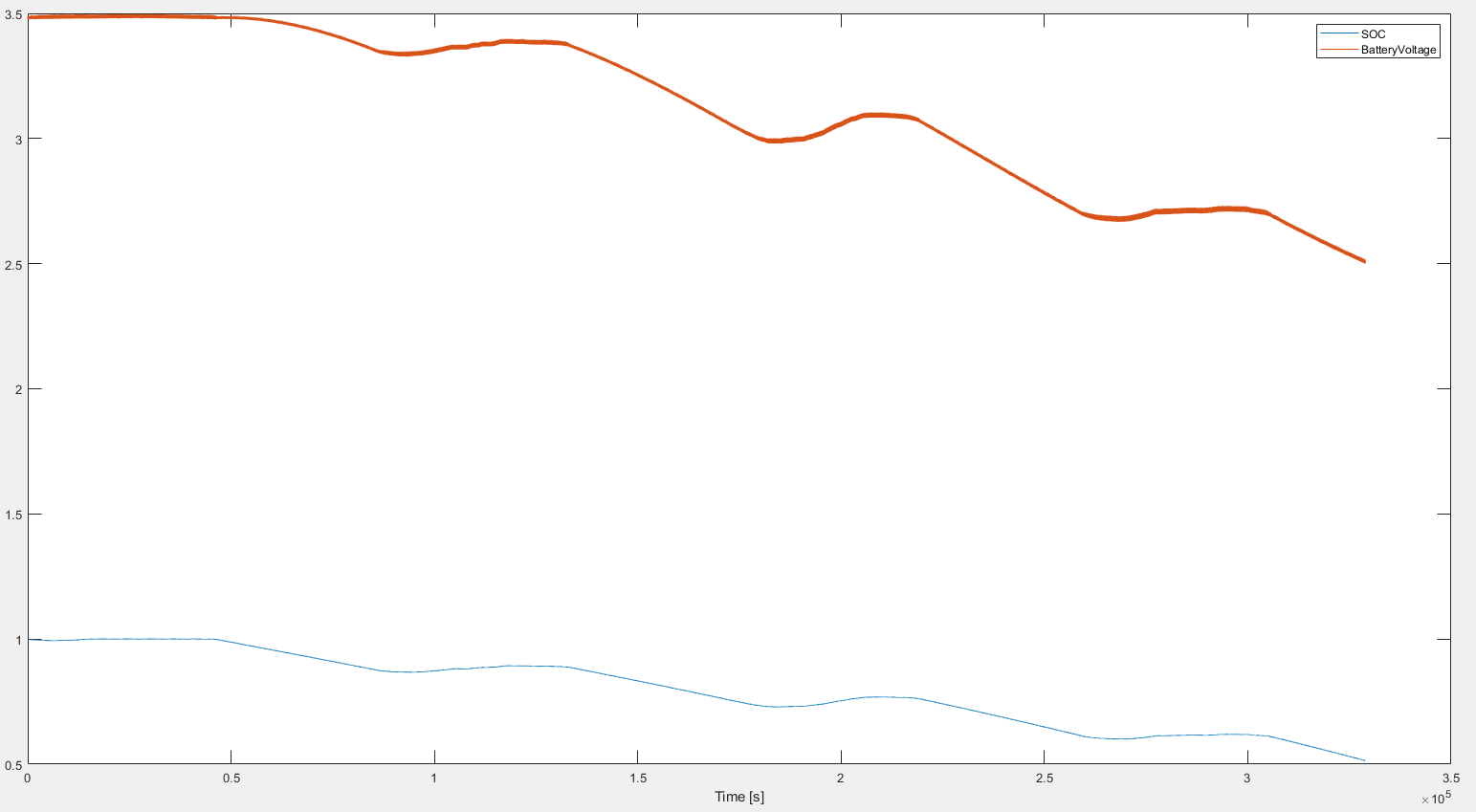


Figure 4 - Battery state of charge and voltage

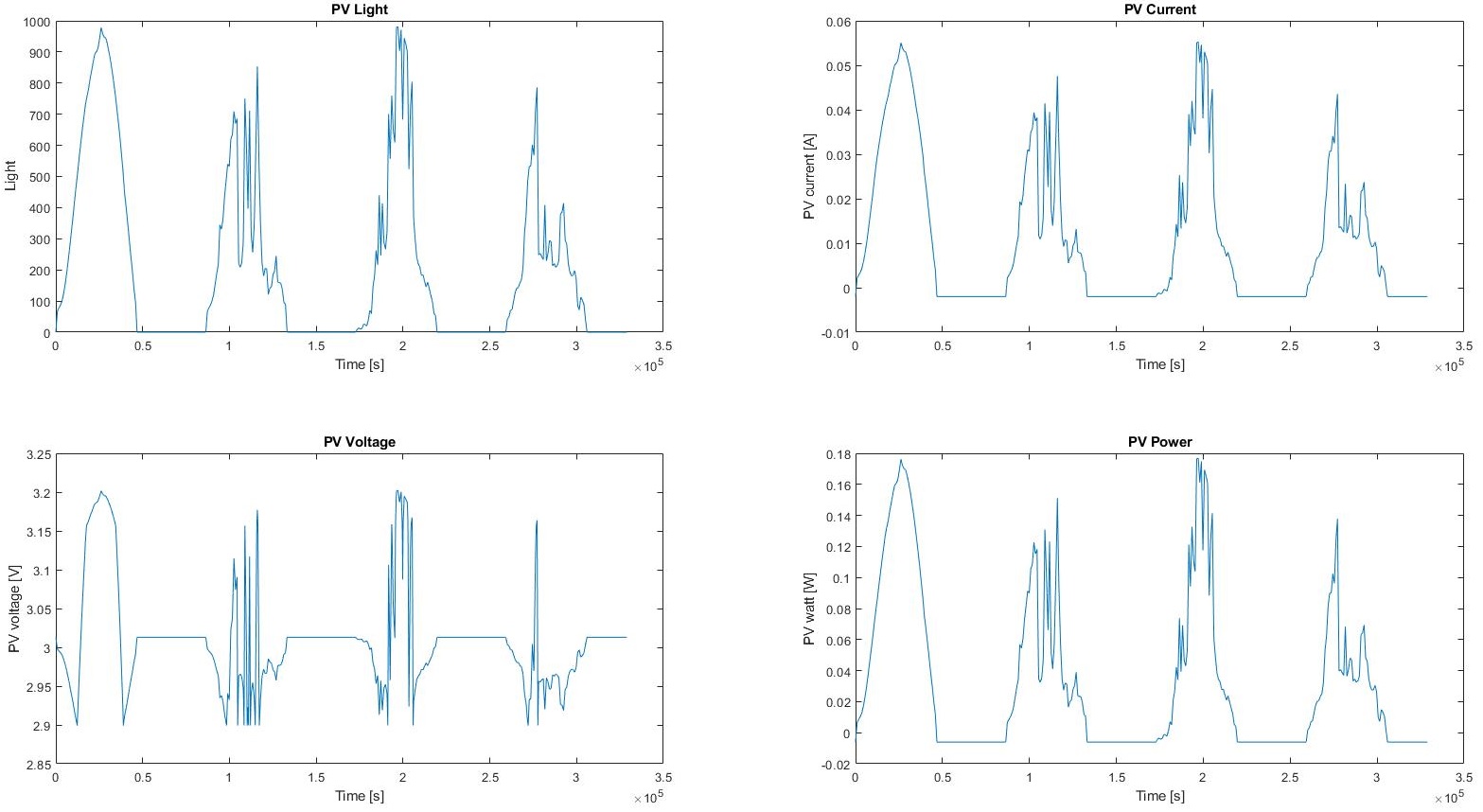
As possible to see the battery discharge is not linear, but presents some waves while discharging. This factor is given by the presence of the photovoltaic cell, that depending from the light factor can generate power, relaxing the battery effort. The details of the PV are reported in figure 5, which resumes the shape of the light over the simulation time. As possible to see, the light shape changes only in the sunnier hours, in the 4-day simulation (91 hours). The current and voltages values are generated considering the maximum power point related to four values of incident light (250, 500, 750, 1000), thus the values are obtained by interpolation.

Figure 5 - PV cell

The PV cell is the adapted through a DC-DC converter that present a certain efficiency. Which is expressed from the datasheet as function of voltage. The figure below reports the datasheet shape (left one) and the simulation shape (right one). Is possible to see that in the PV voltage falls in an efficiency range between 67% and 68%. This means that more that 30% of the power generated from the cell is consumed by the converter.

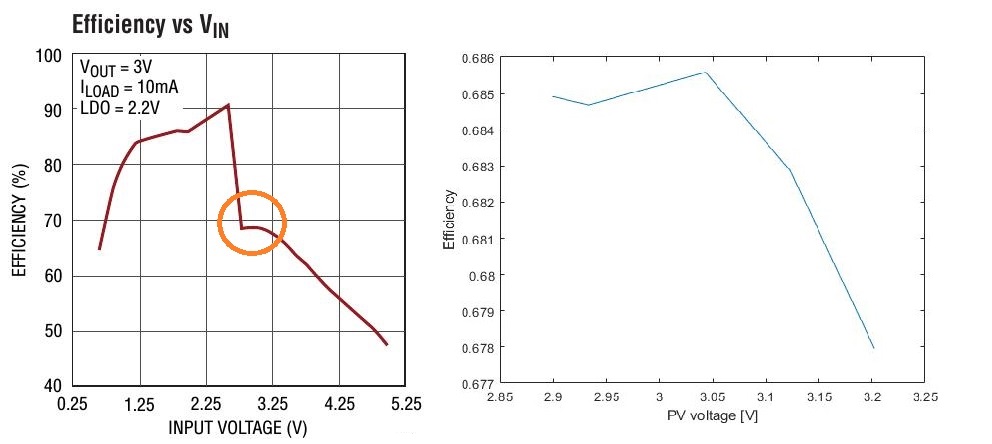


Figure 6 – PV DC-DC efficiency

The second DC-DC converter is related to the battery, interfacing it with the bus. This time the efficiency is related to the current request. The figure below summarizes the efficiency in a period of the workload.

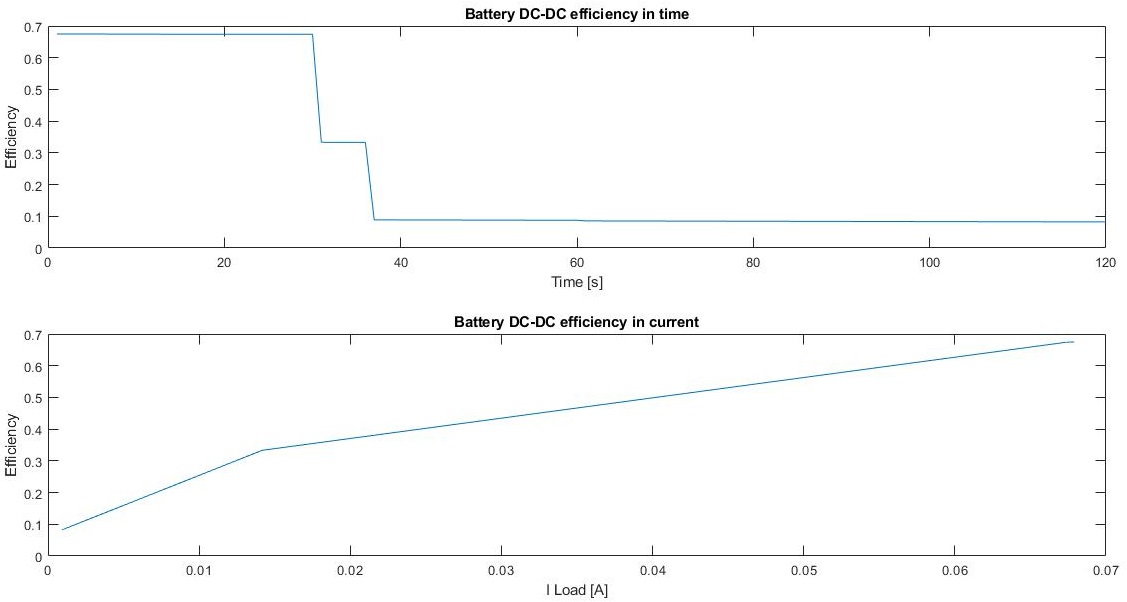


Figure 7 - Battery DC-DC in a period

As possible to see, this battery efficiency strongly depends by the workload. Last thing is interesting to underline, is how many times the PV has been used for charging the battery. Figure below reports the time periods where PV is actively working (as Boolean variable). Comparing the time axis with figure 5 is possible to see that this period corresponds to maximum light situations.

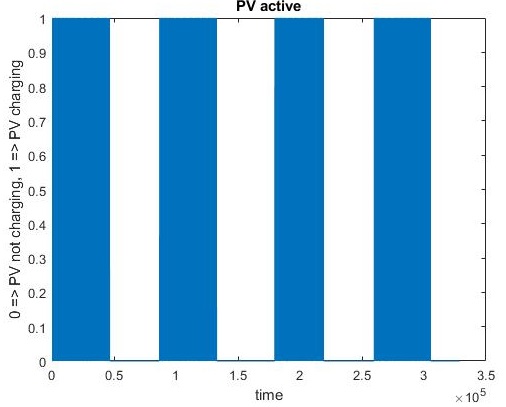


Figure 8 - PV active periods

## Scheduling

The first simulation has been performed under the assumption of all loads working at same time. In this section, a discussion concerning the workload will be carried. In particular, the workload presents some constraints to respect, firstly the activation time of each load must not be modified. The second constraint is that the last two loads, activated in time, must be the memory and the transmission. So, the degrees of freedom are: the period and the scheduling of the sensors. Knowing this, some simulations have been performed acting on these parameters. The first approach was to order the loads in terms of cost. The idea was that initially in the period the battery is in its best state, so could provide higher currents. The result was a decrease of battery time, that falls to 68.4 hours. This reduction is probably given by the fact that the new shape of the workload consumes the period completely, thus, no rest times are available for relaxing the battery. Doubling the period and maintaining the sorted schedule the time of the battery increases to 456.4 hours. The figure 9 and 10 illustrates the workloads and the battery behavior for the two situations. Is interesting to notice that in second case the battery is discharged by the load till a certain period, then the PV provides enough power to supply the battery and recharge its state. Is also possible to notice how the relax time influences the state of charge. In picture 9 the voltage decreases in an unstable manner (sharp shape), while in figure 10 the decreasing of the voltage is quite stable.

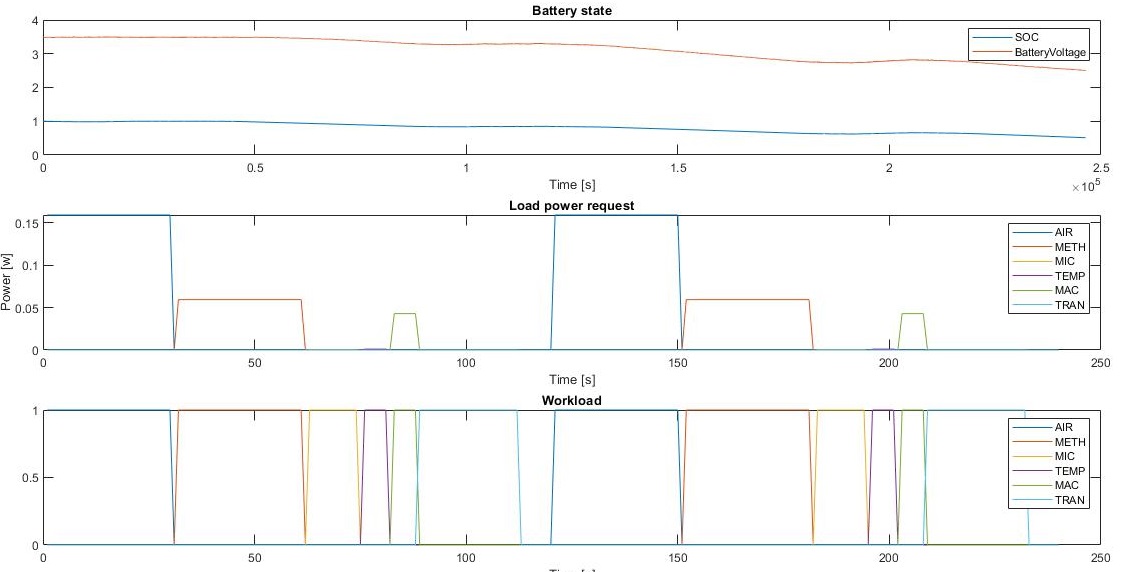


Figure 9 - Sorted loads, period 120 s

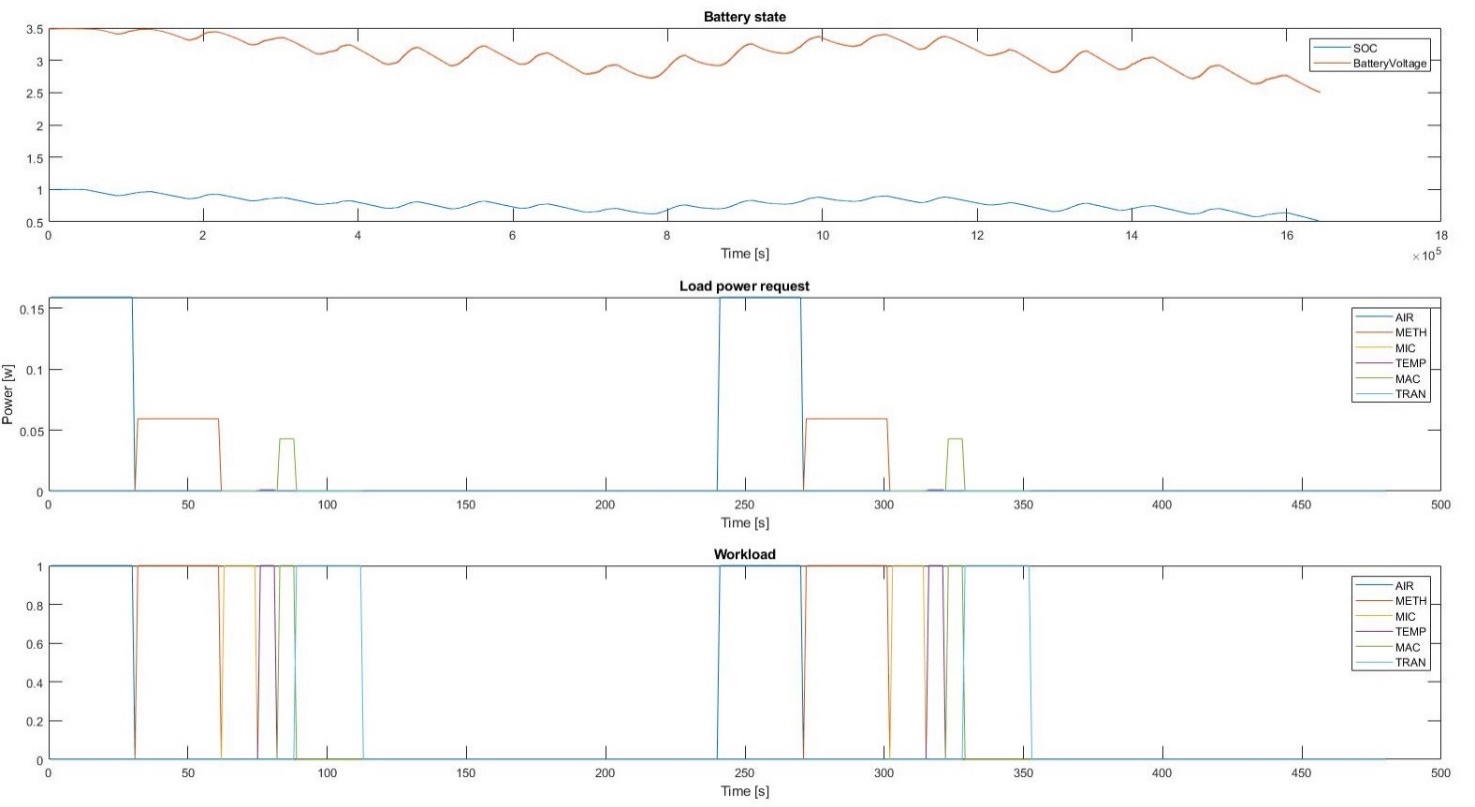


Figure 10 - Sorted loads, period 240 s

Last test performed was to insert some rest period between the tasks. The result is reported in figure 11. This time no changes has been observed with the previous test. This probably means that the battery in this model is relaxed considering only the cumulative rest time, no matter how is distributed over the period.

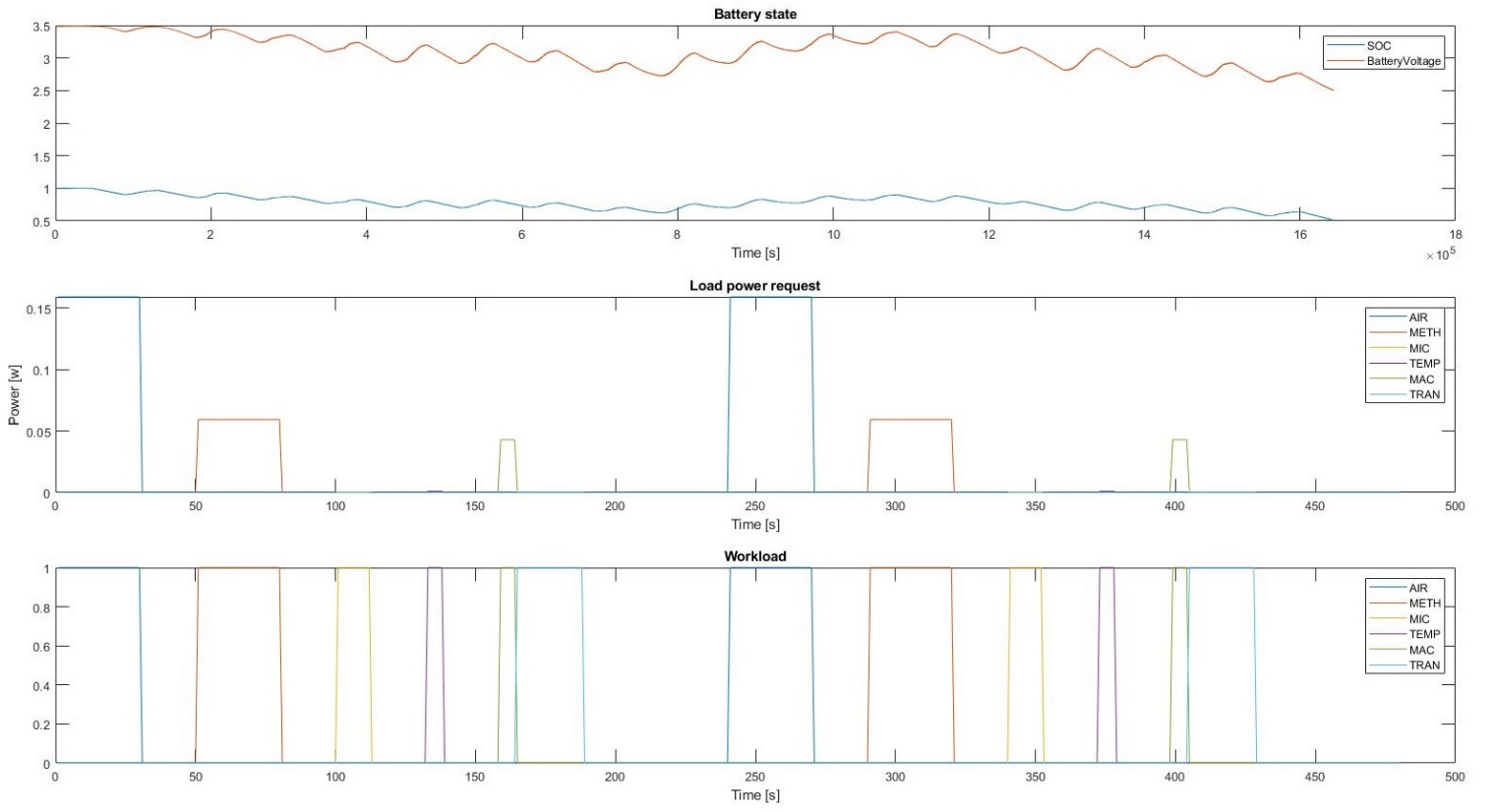


Figure 11 - Sorted task, period 240 s, 20 s rest

Last consideration to do is related to the battery converter. As shown in figure 7 the efficiency of the converter changes depending from the load current. Thus, decreasing the average current the average efficiency decreases, but as seen, the overall time increases. This is probably given by the fact that the battery rest is more impacting than the efficiency. Considering the contribution of the photovoltaic cell.

## Active components analysis

In this section an analysis on the active components, battery and PV cell, will be discussed. In particular the idea is to study how the system depends from the presence of these components. First approach is to increase the active power provided by the photovoltaic cell. This can be achieved increasing the number of cells an connecting them in a good manner (series / parallel). Is important to highlight that while acting on the scheduling the cost of the system remains approximately the same, acting on active part of circuit impact the cost. In order to have a good classification also the cost will be considered in this section. In particular the reference cost will be:

* Battery, 5€
* PV module, 5.50€

First approach for improving the system was to add a PV module in parallel, so that the overall current is doubled while the voltage remains unchanged. The scheduling of the loads has kept as the initial one (parallel), so no optimization from that side has been applied. Figure 12 summarizes the circuit applied and the battery behavior in time. As possible no notice the spikes applied on the voltage where PV is charging the battery are higher. Using this solution, the battery lasts for 114.5 hours, having a price overhead of a PV cell. The charge rate, i.e. numbers of times PV is charging the buttery over simulation time, is at 40.3 % using this approach.

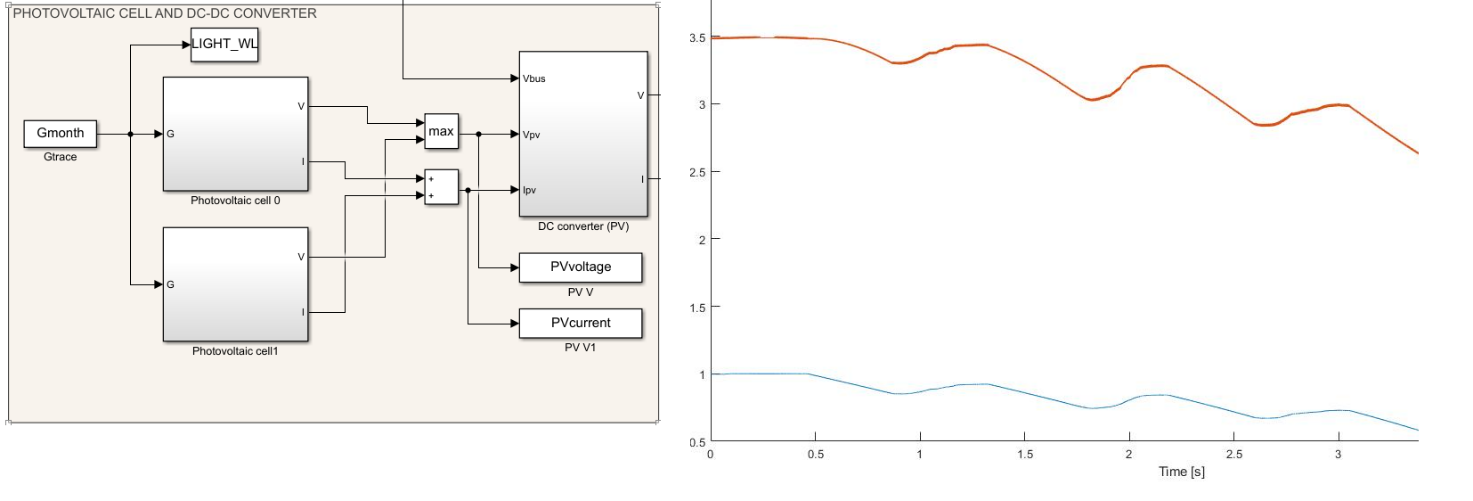


Figure 12 - Parallel PV connection

In this situation, the efficiency of the converter is unchanged with respect figure 6. This is given by the fact that the converter efficiency depends only by the voltage. If instead of parallel the PV cells are configured in series, the voltage is doubled and the current is unchanged. Applying this second transformation the circuit lasts for 91.7 hours that is approximately the original time considering only one cell. This decrease in performance is given by the converter that as shown in figure 6 (left one) has a dependency from the voltage. Indeed, as shown in figure below, the efficiency falls in a low range. The converter takes around 60% of the generated power.

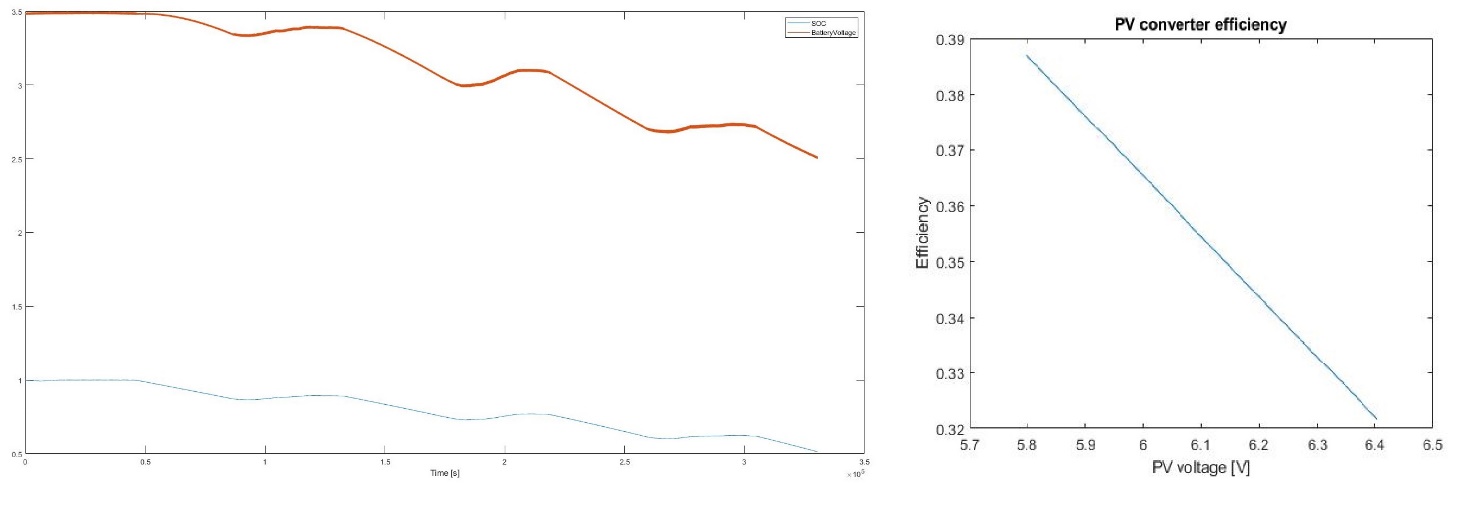


Figure 13 - Serial PV connection

Last analysis was performed using the parallel configuration with the optimized scheduling, figure 11. In this case the system is completely self-charging and the battery life presents the whole simulation time (around 3 months). The results is shown in figure 14.

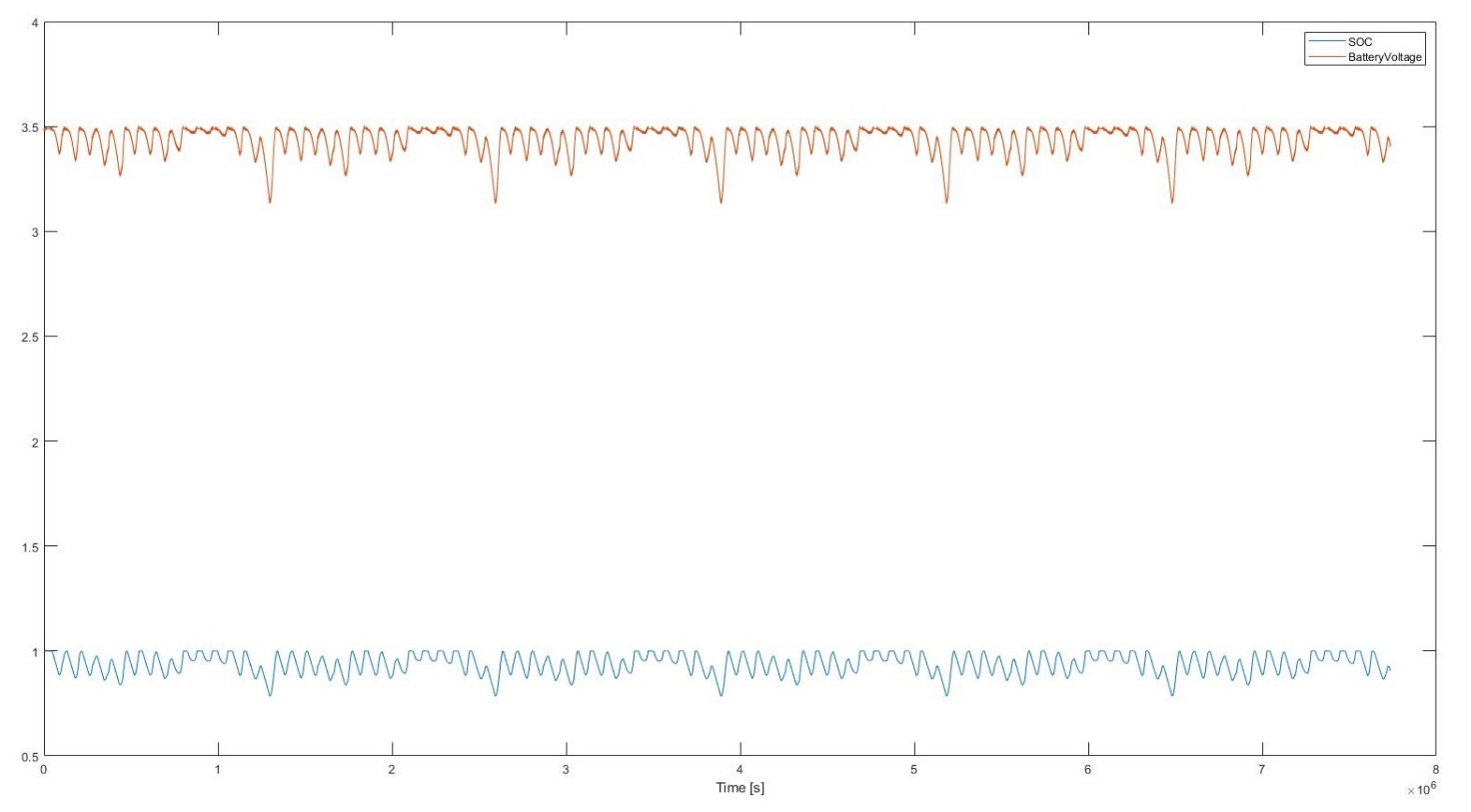


Figure 14 - Self-charging system

Furthermore, is possible to act directly on battery rather than the PV cells. As the previous simulations also the batteries can be connected either in series or in parallel. In this part the circuit presents only one photovoltaic cell and the schedule is kept as parallel, so no optimization from these sides is applied. Figure 15 report the status of the two batteries considering the parallel configuration. In this case the system lasts for 189.7 hours, that is approximately the double of the time with respect the single capacity.

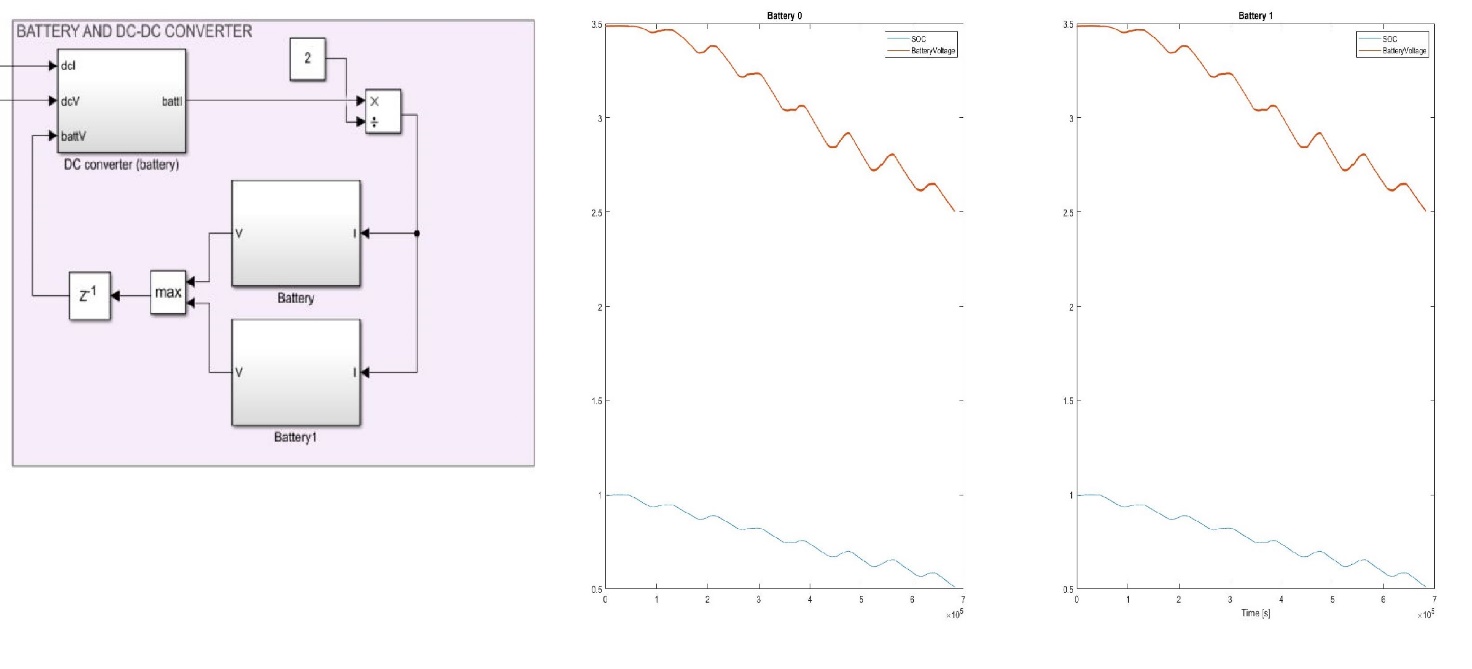


Figure 15 - Battery parallel configuration

The same result is obtained using a serial configuration of the battery. While in the parallel situation there is a division of the load current for the serial one there is much more voltage for the converter.

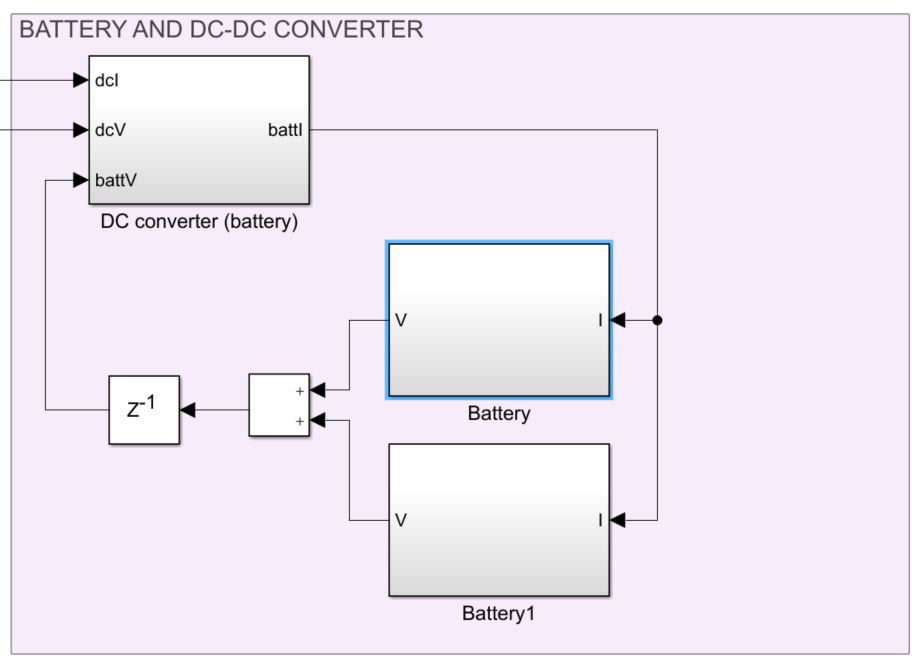


Figure 16 - Battery serial configuration

In both cases the cost overhead is one battery. Of course, increasing the number of battery the system will last more.

Knowing these results is possible to study a configuration that allow the circuit to be self-charging. Has been observed that using the serial scheduling an additional PV cell is enough. Assuming the impossibility to change the scheduling some experiments has been carried. Table below resumes the results of the tests acting only on the active modules.

Table 1 – Multi power results

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Parallel Batteries | | | |
| Parallel PV cell | 1 | 2 | 3 | 4 |
| 1 | 91.3 hours | 189.7 hours | 347.77 hours | 433,0 hours |
| 2 | 114.5 hours | 429.5 hours | 717.3 hours | 906.1 hours |
| 3 | 479.24 hours | Self-charging | Self-charging | Self-charging |
| 4 | Self-charging | Self-charging | Self-charging | Self-charging |

In this table are considered only the parallel configuration given the fact that serial PV cells impact the converter, while for the battery there aren’t differences. Is important to highlight that acting on these parameters have an impact on the state of charge shape over the time. Indeed the batteries have not the time to rest to the voltage shape is quite unstable.

## Considerations on simulation

Some additional consideration on the simulator should be done. In particular there are some assumptions that in a real system are not so reachable. Considering the photovoltaic cell there was the assumption to always work in maximum power point, the simulator could be improved adding a MPP tracker emulating a real one, not always at MPP point. Another issue could be the non-ideality of the battery model regarding the short and long term transitions, that are not modeled.