POLITECNICO DI TORINO

Master's Degree in Computer Engineering

Energy Management for IoT

Lab 3 Report

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1. Model characterization

The third and final laboratory section aimed at simulating an IoT device in MATLAB/Simulink, with the subsequent analysis of its behavior in terms of power perspective and possible optimizations to increase the system lifetime.

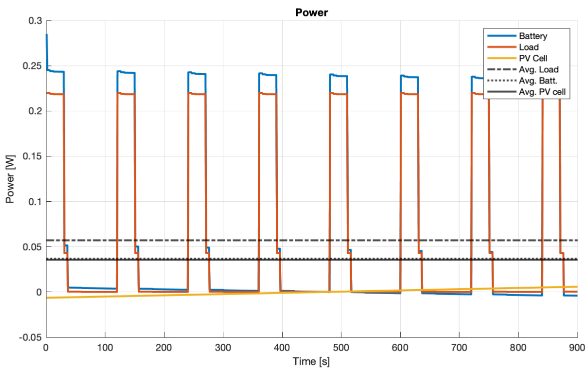
The model construction will not be discussed in this report, as requested, with an overall description of the system provided in table 1.1. The following results concerning the simulation performed prior to any modification of the system, i.e., with all loads being activated in parallel every 2 minutes.

Load	Active Period [s]	Active Current [mA]	Sleep Current [mA]
Air Quality Sensor	30	48.2	0.002
Methane Sensor	30	18	0.002
Memory + Control	6	13	0.002
Temperature Sensor	6	3	0.002
Microphone Sensor	12	0.15	0.002
ZigBee Transmission	24	0.10	0.001

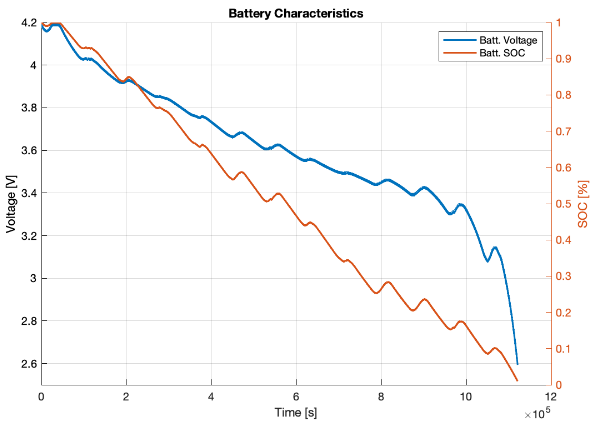
Table 1.1: Summary of the loads that must be driven by the system, in descending order of power consumption.

This simulation ran for 1120566 seconds in this configuration, approximately 13 days. It is known from previous experiments that simultaneously activating a set of loads can draw a large amount of energy, translating into high power consumption.

Notice the discrepancy between the average power dissipated by the loads and their peak when active in Fig. 1.1 a). Also, observe in Fig. 1.1 b) how the battery voltage quickly drops as this approaches its minimum capacity. This behavior was expected given the battery's discharge characteristic, meaning that the model is working in accordance with the specifications.



(a)



(b)

Figure 1.1: a) depicts the peak power consumption during operation, as well as a comparison with the average consumption seen throughout the whole simulation. **b)** shows the juxtaposition of the battery state-of-charge (SOC) and the delivered voltage.

Energy generation is another important aspect, as the battery can be recharged by a photovoltaic cell within the system. Fig. 1.2 depicts the power that can be delivered by this harvester and the consequent loss due to the DC/DC Converter. In fact, this can be seen also in Fig. 1.1 a) when comparing the power required by the loads with the amount of power delivered by the battery, the latter being slightly higher on account of another converter. Different configurations for activating the loads will be discussed in the following section.

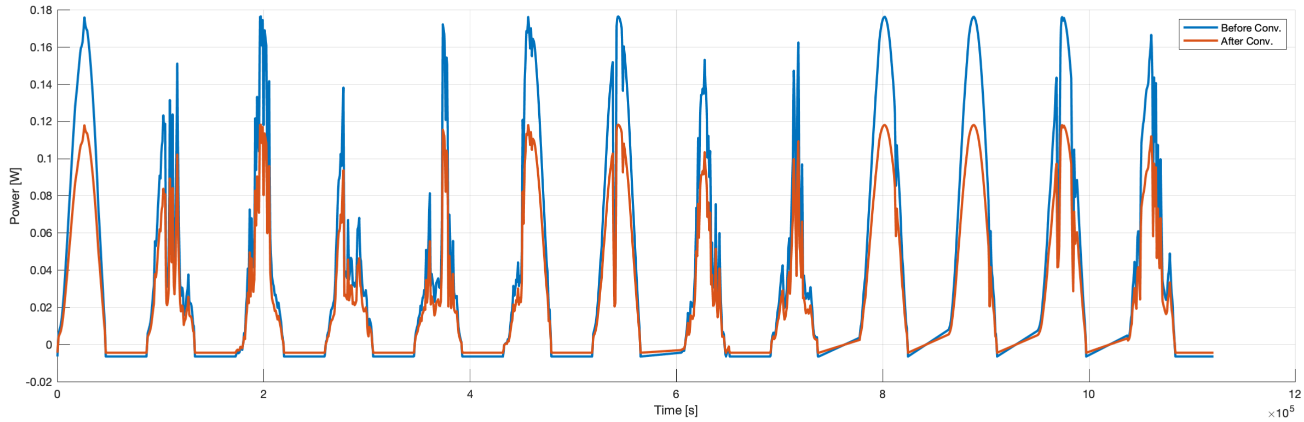


Figure 1.2: Power delivered by the harvester before and after conversion.

2. Scheduling evaluation

It is known from previous experiments that spreading the total workload throughout longer active periods can increase the system's energy efficiency. Therefore, the serial activation of the loads, as well as a mixed configuration, will be evaluated in this section. The sensors were turned-on in descending order of power consumption in the serial profile, as described by table 1.1. In the mixed profile, the methane and temperature sensor run in parallel, followed by both air quality sensor and microphone also running in parallel.

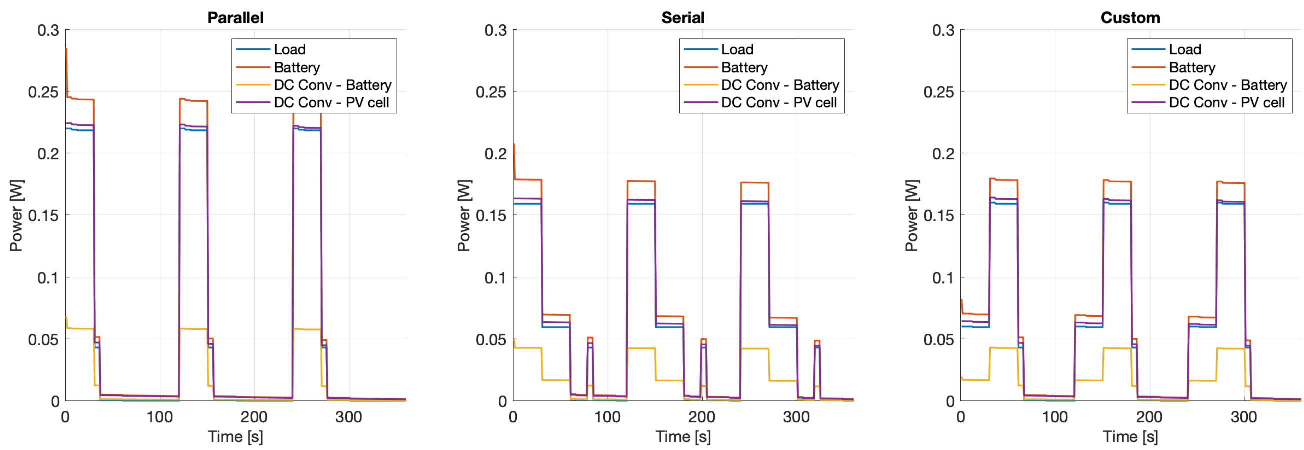


Figure 2.1: Power consumption of each configuration.

In Fig. 2.1 the power profile of each activation style is depicted. Notice that the peak power when active for both configurations is approximately 27% lower than the parallel one. The impact of the workload distribution becomes even more evident when comparing the current driven by both serial and parallel configurations, shown in Fig. 2.3 and Fig. 2.2 respectively. The mixed profile was omitted here as the results were similar to those presented by the loads activated in series.

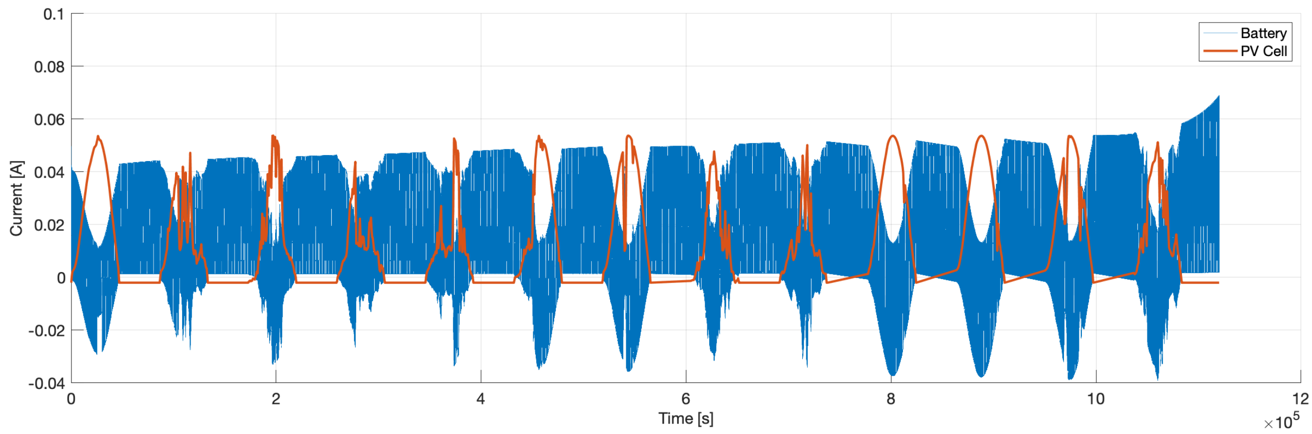


Figure 2.2: Current produced by photovoltaic cell and driven by the battery in the serial activation style.

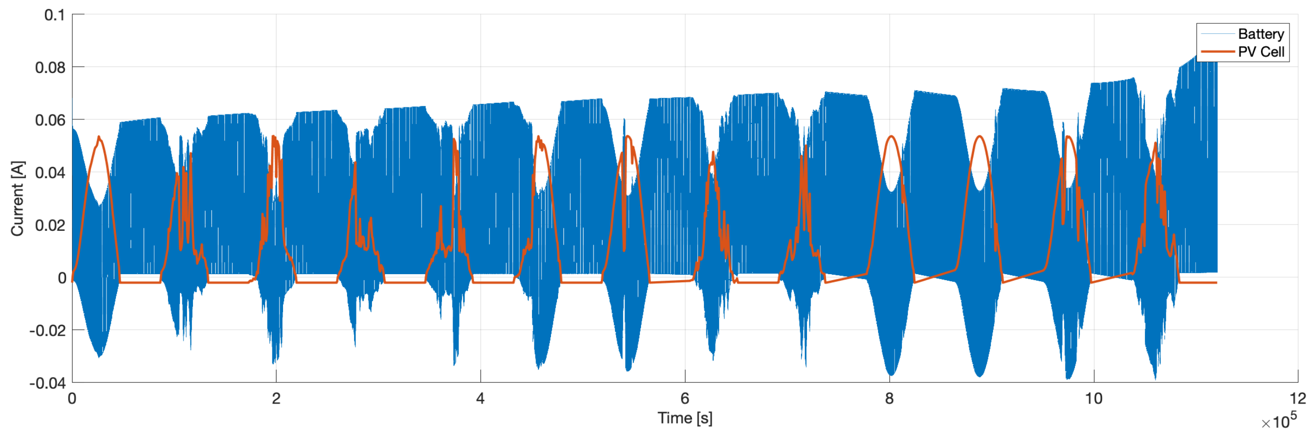


Figure 2.3: Current produced by photovoltaic cell and driven by the battery in the parallel activation style.

The transition from one task to another is rather smoother in the serial configuration, i.e., the battery is used in a better way by this configuration. Such behavior translates into the slightly better average efficiency rate seen in table 2.1. However, the simulation ran for fewer minutes in those cases, contradicting the previous assumption. In fact, when in sleep mode the voltage required by the loads drops to levels that increase the efficiency of the DC/DC Converter. The distribution of the workloads prevents it to reach this efficient state, thus, the power consumption actually increases, and the battery discharges earlier.

Load Activation	Avg. Batt. Eff. [%]	Avg. PV Eff. [%]	Duration [days]
Parallel	90.02	68.16	12.9695
Series	90.42	68.16	12.9637
Mixed	90.41	68.16	12.9639

Table 2.1: Efficiency and battery lifetime for each configuration.

3. Model refinement

In this section, possible solutions to increase the system lifetime will be discussed. Since energy storage and generation are critical to maintaining the system autonomous the following propositions consider the addition of supplemental batteries or photovoltaic cells, assuming that a battery costs \$4.99, a photovoltaic module costs \$5.50, with a total additional budget of \$11.00.

The modifications done to the Simulink model itself will not be covered by this report, as they were achieved by simply doubling the voltage/current delivered by the component under analysis, depending on the configuration, i.e., when connected in series the voltage adds up and the current/capacity remains the same, with the opposite effect in parallel.

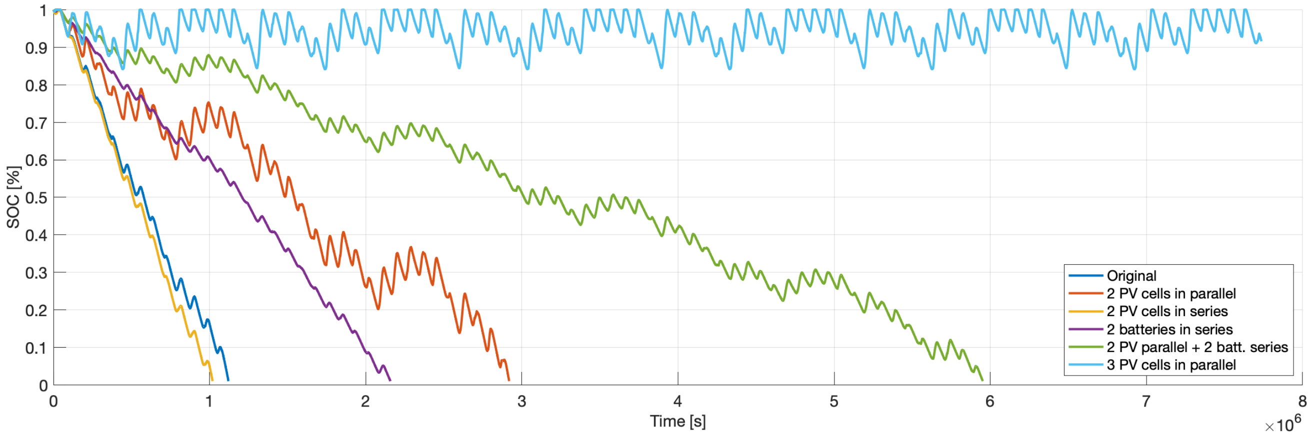


Figure 3.1: Battery SOC observed in several modifications.

In Fig. 3.1 the battery SOC for each proposed solution is shown. In particular, the addition of a second photovoltaic cell in parallel significantly improved the battery lifetime, with the series connection of the cells having a worst performance than the original model. Again, this effect is mainly due to the DC/DC Converter efficiency, as the voltage doubles in the latter case. The system becomes entirely autonomous with the addition of a third cell in parallel.

Modifications	Batt. Eff. [%]	PV Eff. [%]	Duration [days]
2 PV parallel	90.80	68.17	33.7714
2 PV series	90.36	30.54	11.7894
2 batt. series	90.43	68.17	24.9727
2 PV parallel + 2 batt. series	90.80	68.17	68.8868
3 PV parallel	90.97	68.17	89.5417

Table 3.1: Efficiency and battery lifetime for each proposed solution.

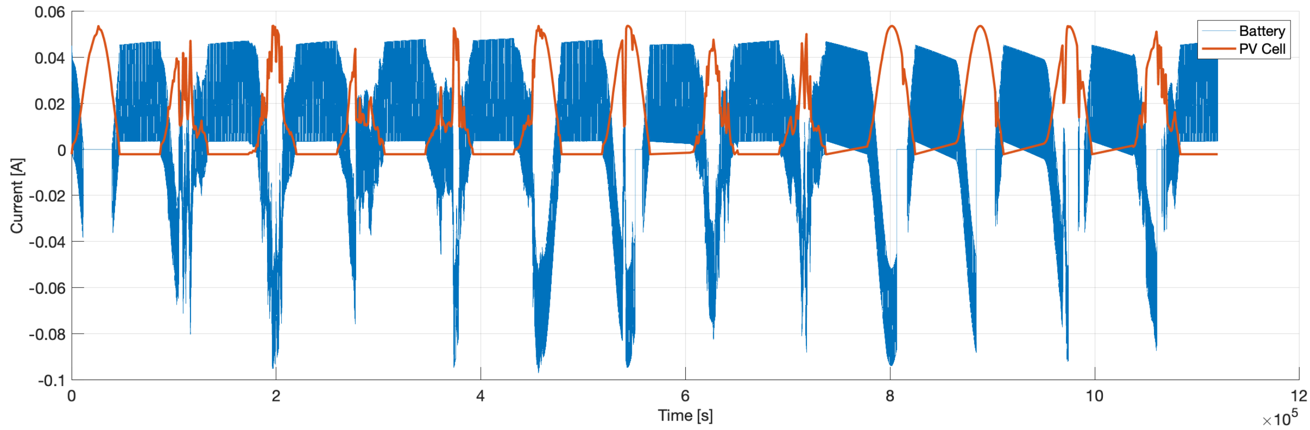


Figure 3.2: Currents observed with 3 photovoltaic cells in parallel.

The efficiency observed in each modification is given by table 3.1. The way in which the batteries were connected did not provide any significant improvement to the system, thus, by convention, only batteries connected in series were considered. In fact, the addition of a secondary battery has not contributed to the system lifetime as much as the photovoltaic module, which was expected given the previous experiments.

Finally, the current produced by the most energy-efficient scenario with 3 photovoltaic cells connected in parallel with a single battery is reported in Fig. 3.2. Notice that the battery current is kept at zero in some instants, in particular during sunny days, i.e., the additional modules not only allow the battery to quickly recharge as they can serve as primary power supply.

4. Conclusion

Overall, workload scheduling can improve battery utilization. This is an important aspect when considering that this system relies on a photovoltaic module for energy generation, i.e., on cloudy days with lower rates of irradiance the system could be designed to maximize battery recharging. However, regarding the system optimization in terms of energy efficiency, this feature has proven to have little impact on the battery lifetime. Although some characteristics such as the peak power consumption may vary throughout different configurations, the average consumption is the same for all. In fact, the discharging rate increased in some cases due to inefficiencies in the conversion.

Supplementary modules for energy generation have proven to be the best optimization strategy. None of the proposed solutions extrapolated the initial budget of $11.00. Considering the worst-case scenario where the system activates all the sensors every 2 minutes, the system became autonomous after adding 2 extra photovoltaic cells connected in parallel with the original one, implying an additional cost of exactly $11.00.

Lastly, simulations with a longer activation period of 10 minutes were also performed. In this case, the system ran autonomously without any modification of the model. Perhaps the best solution for prolonging the battery life is to simply prolong the periodicity on which the system takes the measurements, considering that they cannot vary drastically within such a short period and assuming that the system requirements can be relaxed.

Bibliography

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