Energy Harvesting Wireless Sensor Network Edge Device Simulation tool

Cian O'Shea - Ross O'Halloran - Mike Hayes - Peter Haigh

Contact Email:

michael.hayes@tyndall.ie

peter.haigh@tyndall.ie

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Cian O’Shea

Cian O’Shea received a bachelor’s degree of Electrical and Electronic Engineering from University College Cork in Ireland in 2017. On completion of that degree he began working on a master’s degree in Tyndall with his work focusing on developing an energy harvesting wireless sensor network edge device simulation tool.

Motivation

- By 2025 – 75 billion Internet of Things devices.
- This will lead to a number of environmental and commercial issues.
- These issues can be reduced by increasing the lifetime a Wireless Sensor Network (WSN) by utilizing energy harvesting methods.

Focus of the simulation tool:

- It can be used by component designers to trade off system performance against component performance in an end node.
- It can also be used by a system integrator as a validation tool during the development process of the WSN system.

Acknowledgement:

This work was part of a larger project titled ReCO2ST, (Residential Retrofit assessment platform and demonstrations for near zero energy and CO_2 emissions with optimum cost, health, comfort and environmental quality). This project has received funding from the European Union's "Horizon 2020" research and innovation program under the grant agreement No. 768576. https://reco2st.eu/

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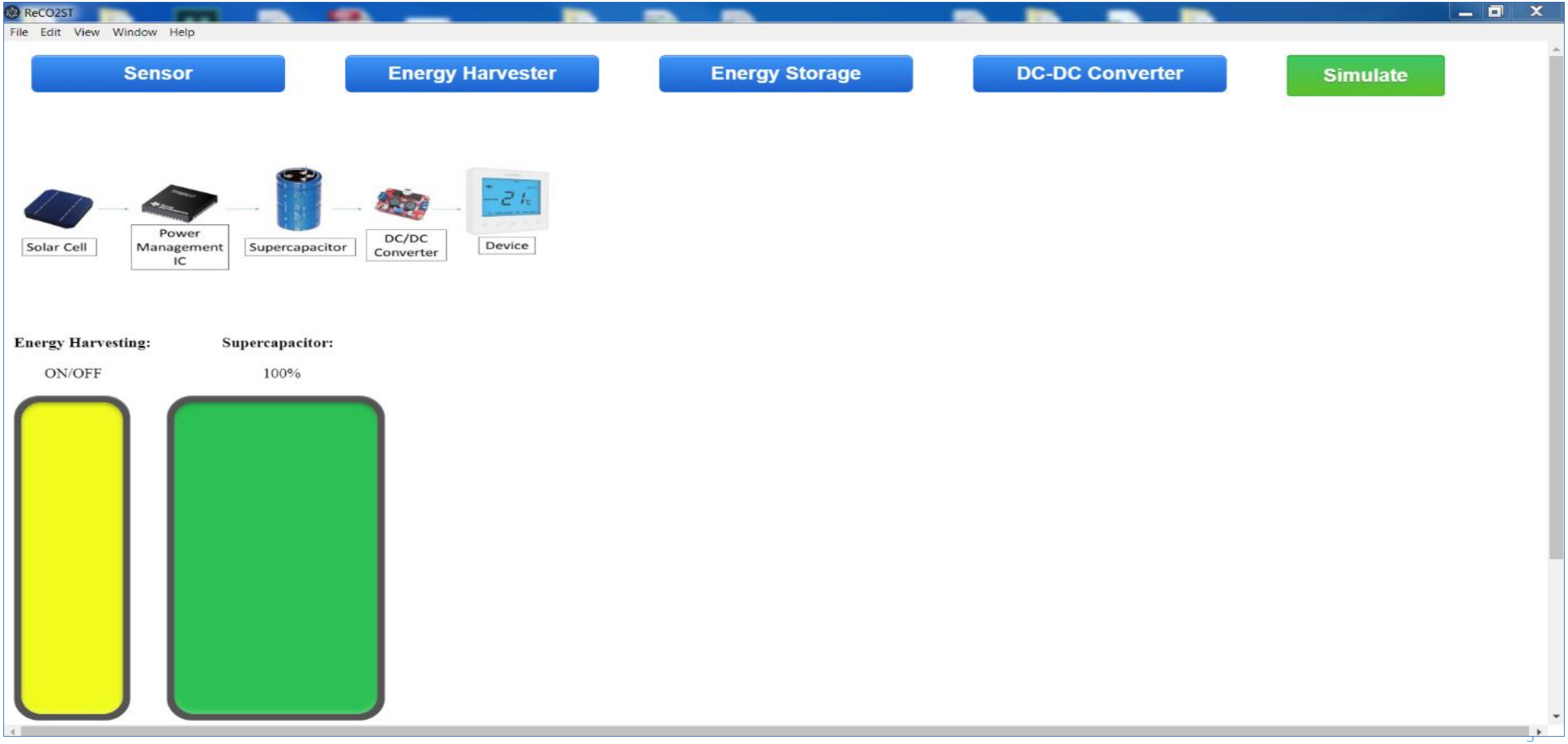
Energy Harvested WSN

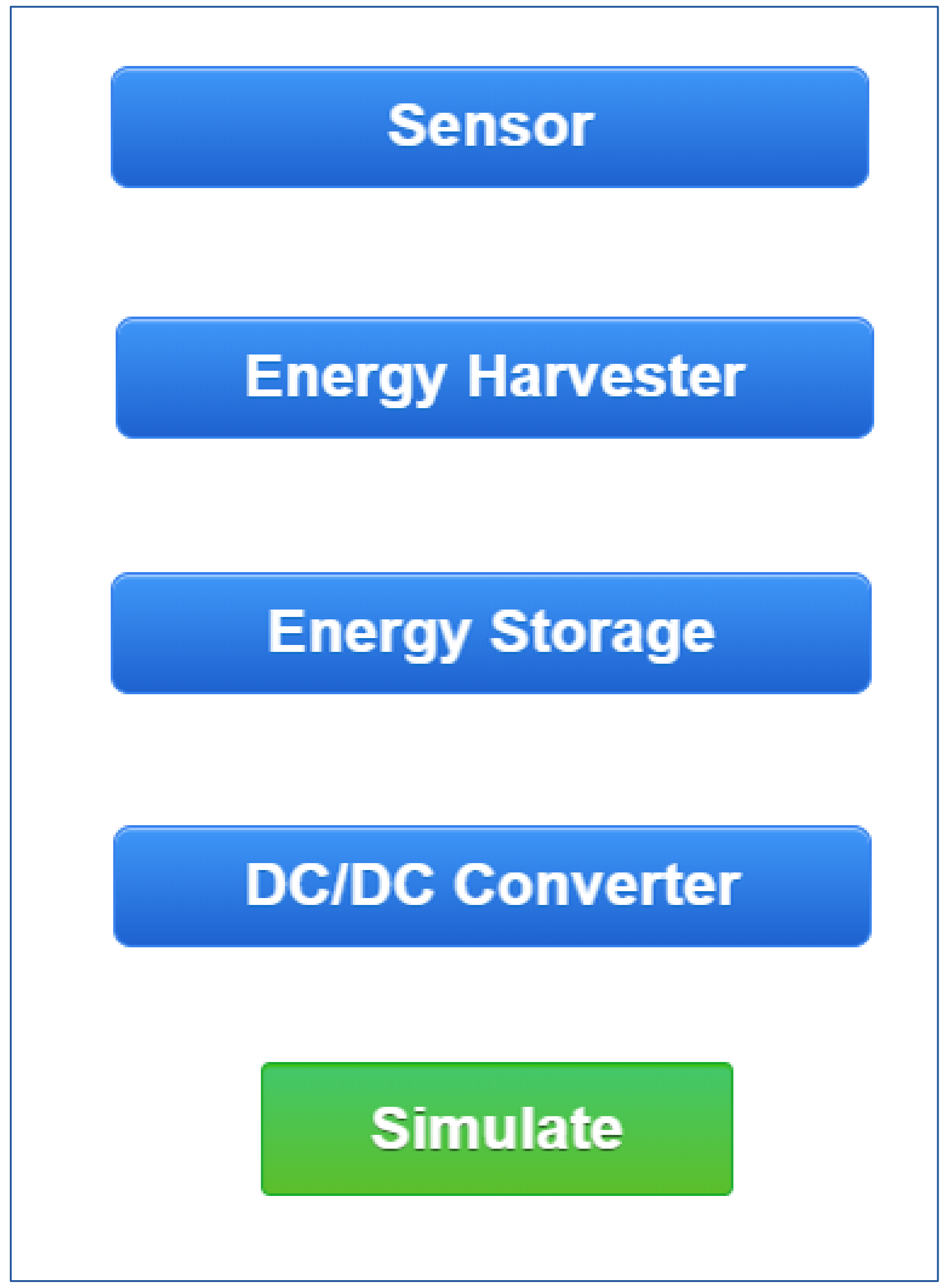
A typical node in a WSN that utilizes energy harvesting (EH-WSN):

- Energy Harvester: Harvesting ambient energies
- MPPT: Maximizing output power of the transducer
- Energy Storage: Storing excess energy when ambient energy no longer available
- DC-DC Converter: Maintaining a stable output voltage on the sensor node
- Sensor Node: Collects data

GUI

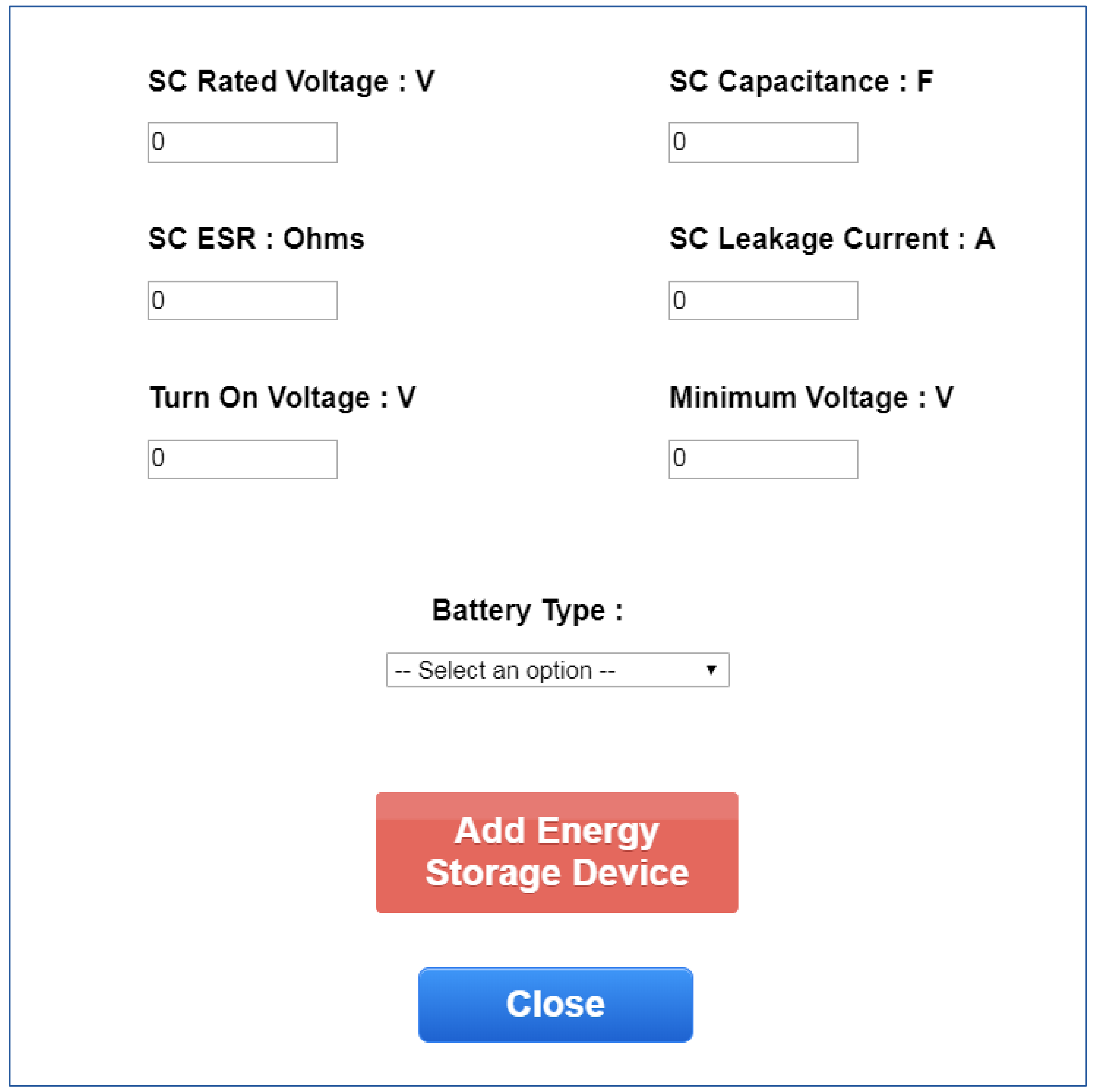

ReCO2ST
File Edit View Window Help
Sensor
Energy Harvester
Energy Storage
DC-DC Converter
Simulate
Solar Cell
Power Management IC
Supercapacitor
DC/DC Converter
Device
Energy Harvesting:
ON/OFF
Supercapacitor:
100%

GUI

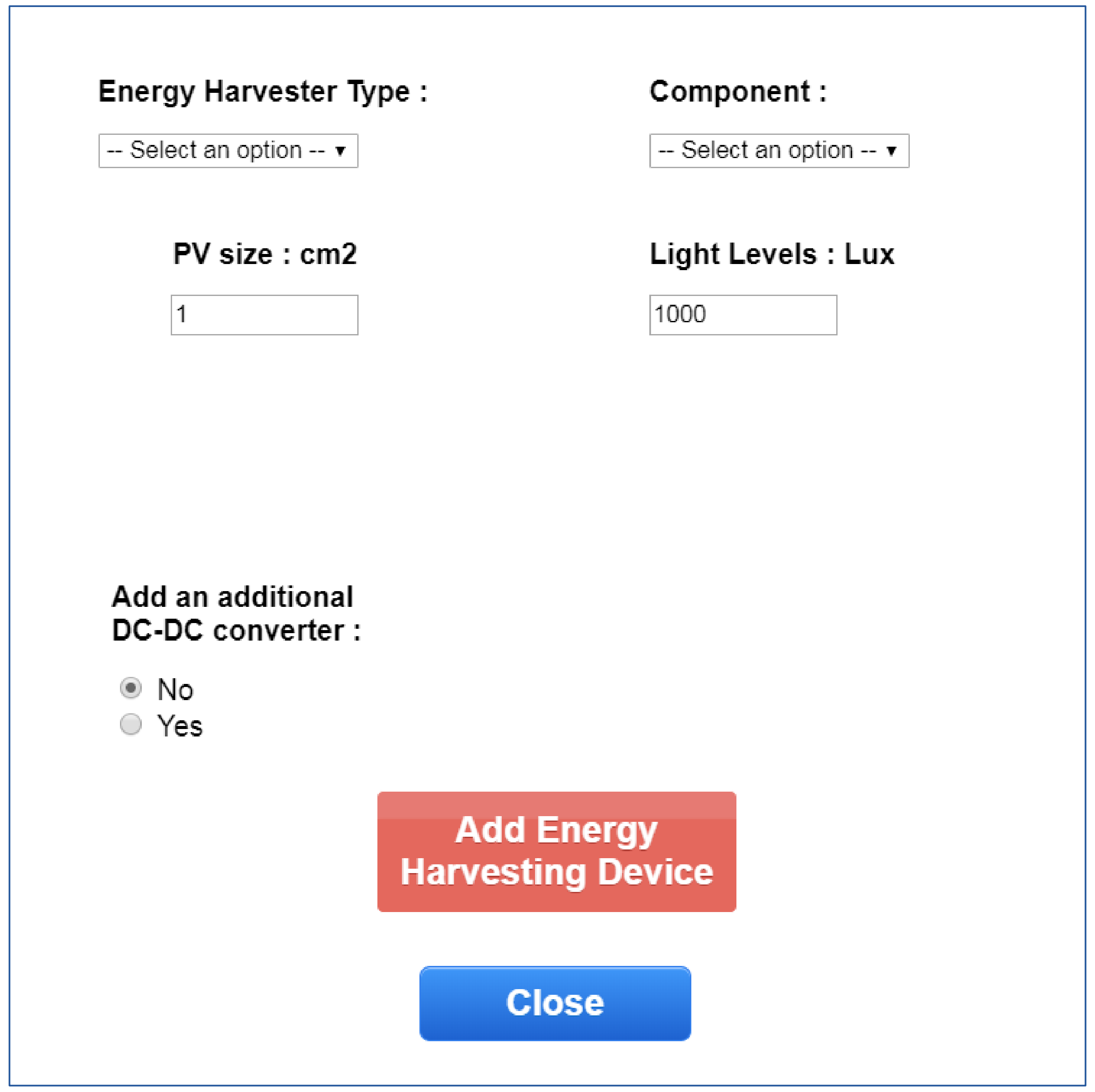


Users can vary each parameter of the simulation

Input operating voltage and average current consumption of the device



Modify the characteristics of supercapacitor

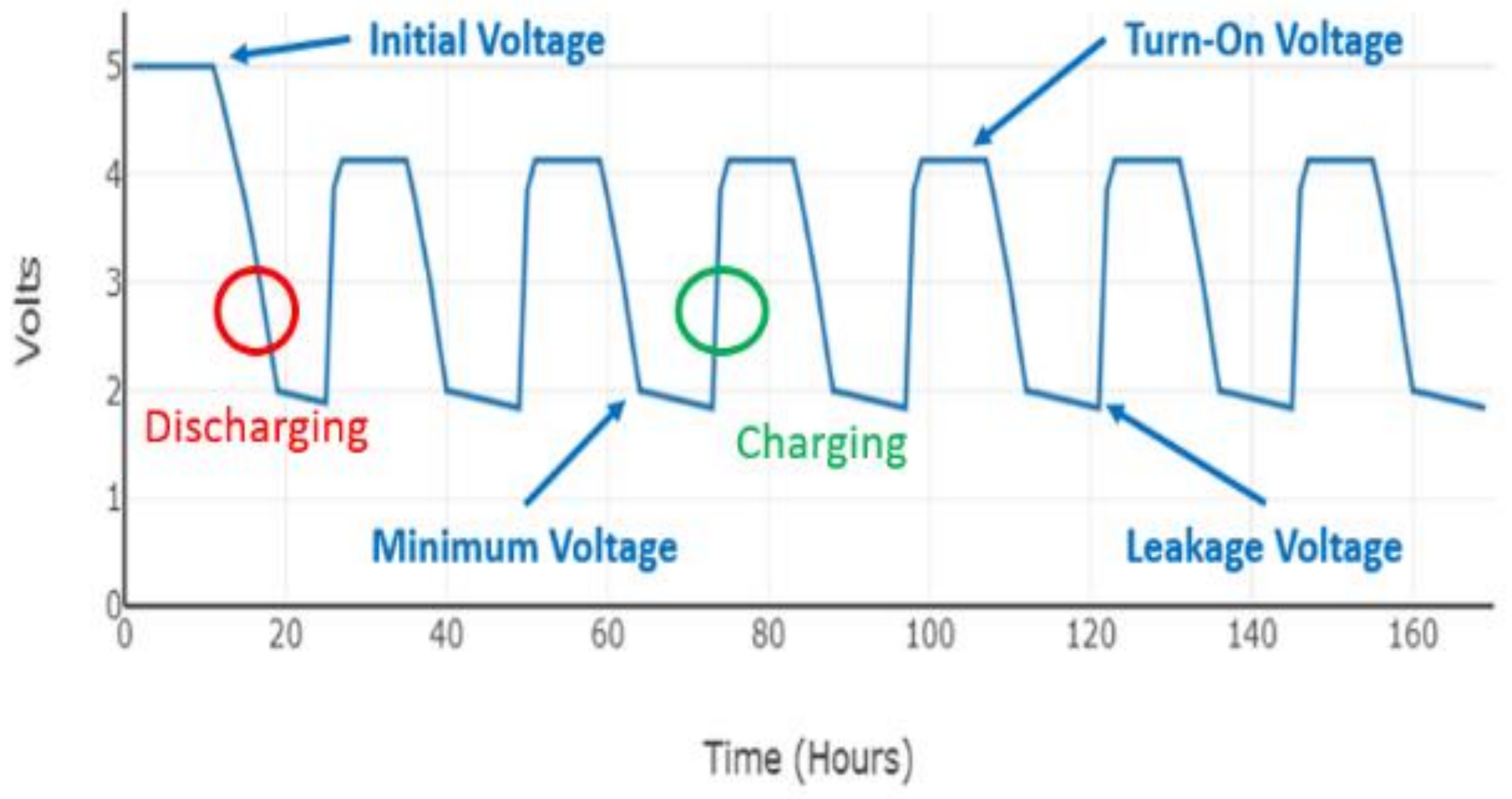


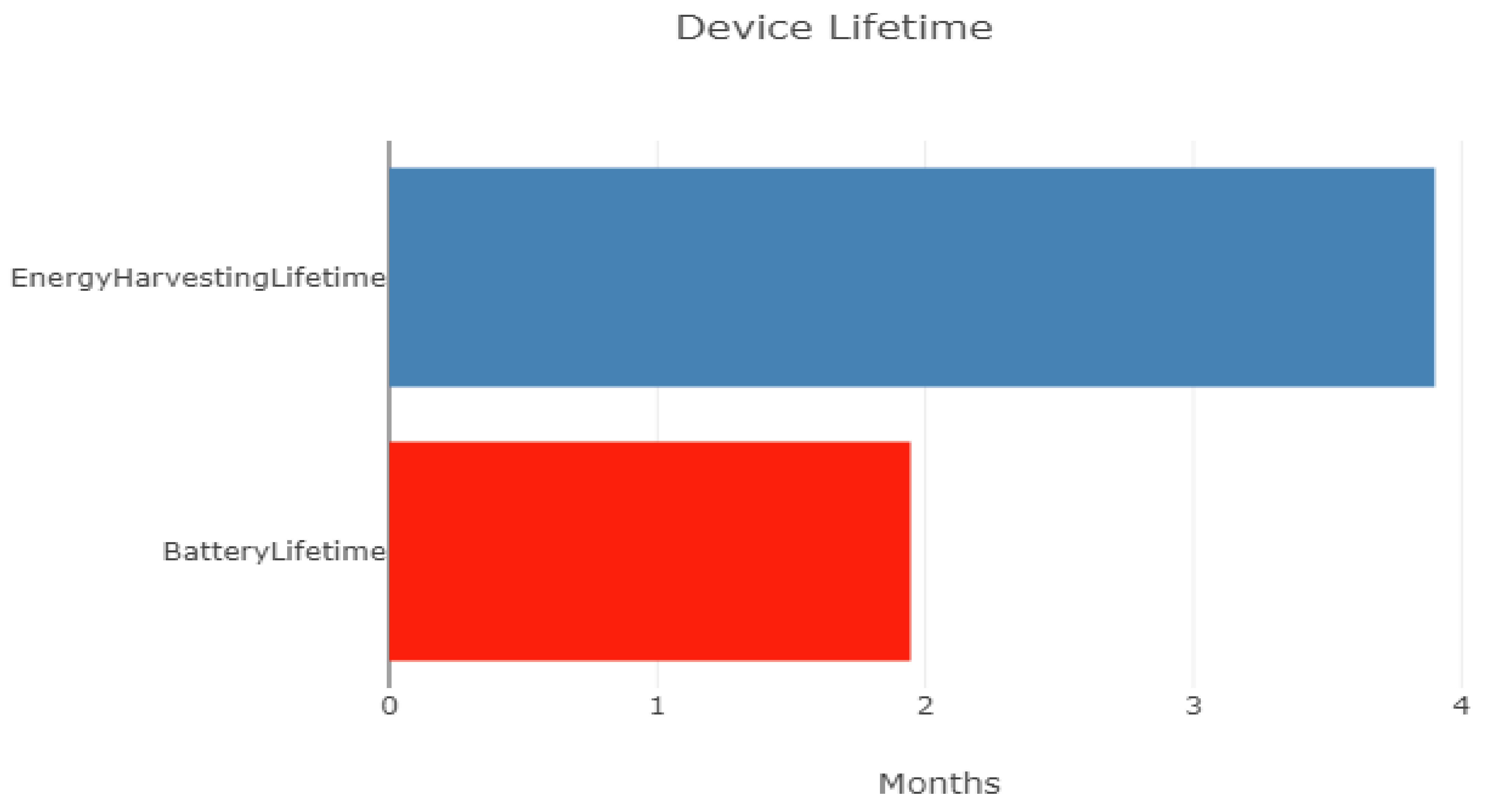
Modify the type of EH device and its characteristics

Select which DC-DC converter is most appropriate or add a user specific component

Simulation Output

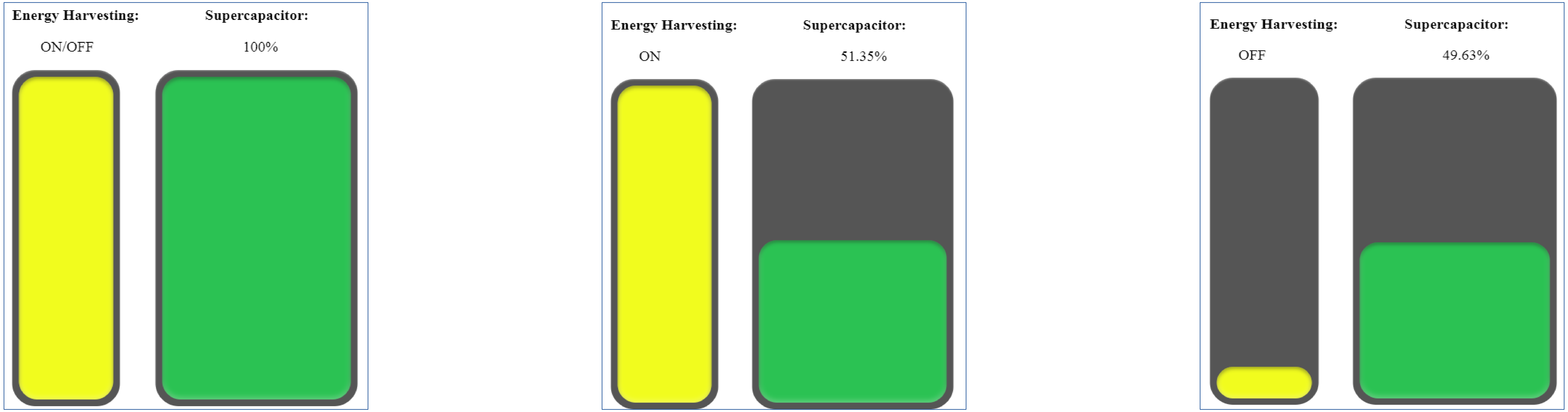
- The simulation shows the user when the supercapacitor reaches its minimum or maximum voltages.
- This allows the user to determine which components need to be modified to keep improving the power solution.
- The bar graph compares a Single-Use Battery with an Energy Harvesting Single-Use Battery combination.





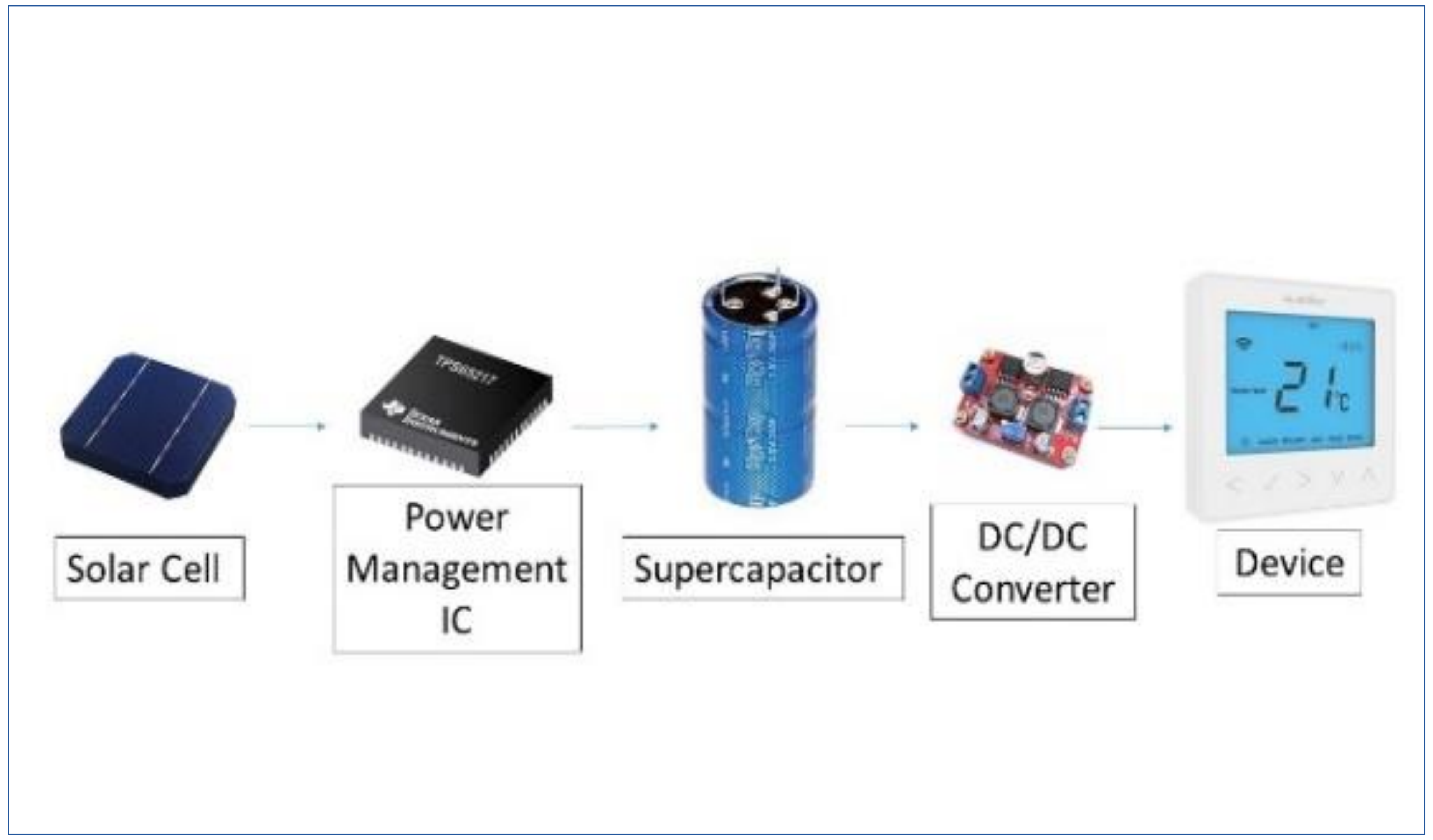
Simulation Output

- These images represent the simulation conditions in the system over time.
- The yellow bar indicates the availability of ambient energies.
- The green bar presents the available energy in the supercapacitor over time.



Simulation Output

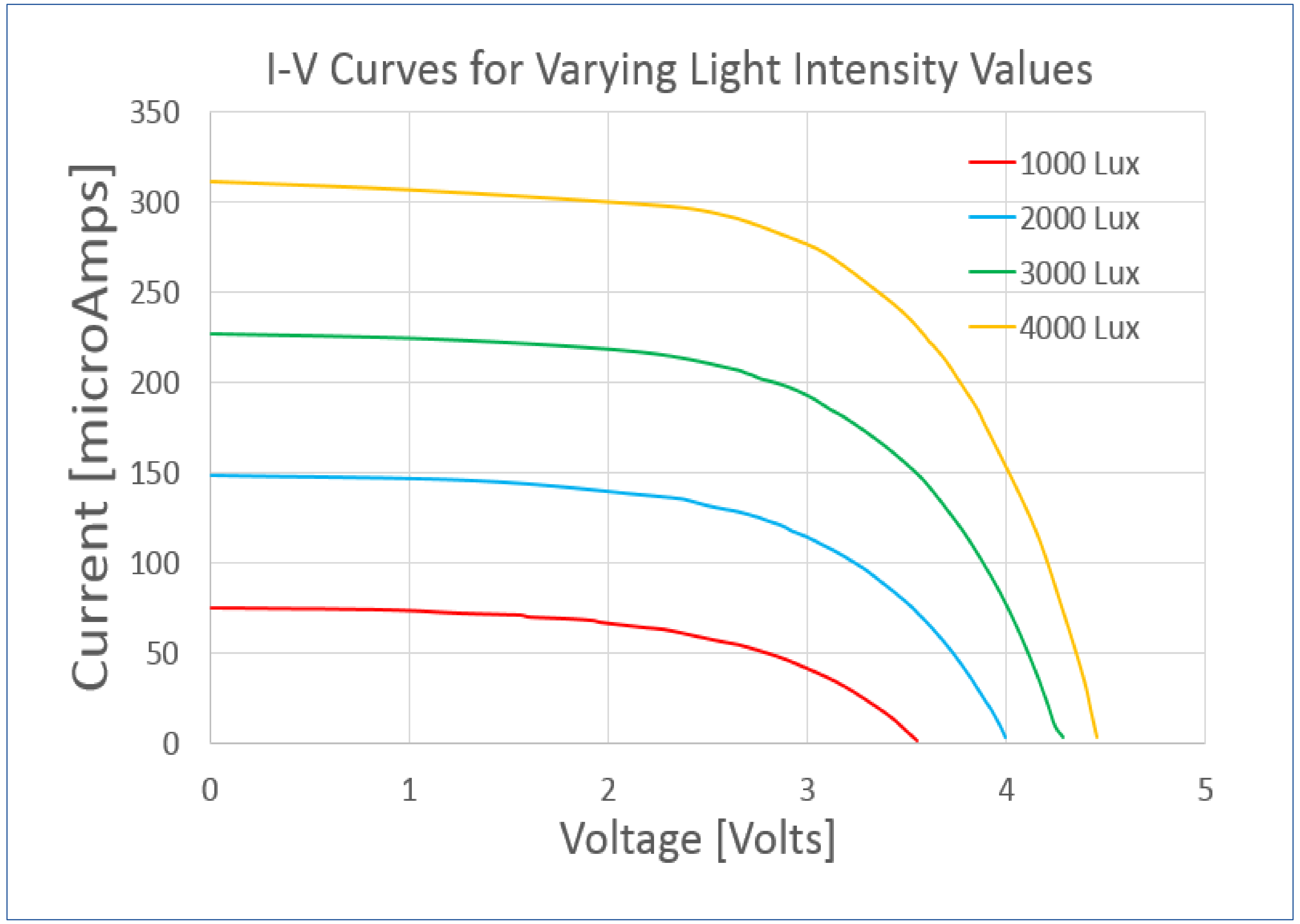
- While the simulation is running, the user is also notified when the device is receiving energy from the battery and when it is utilizing EH methods

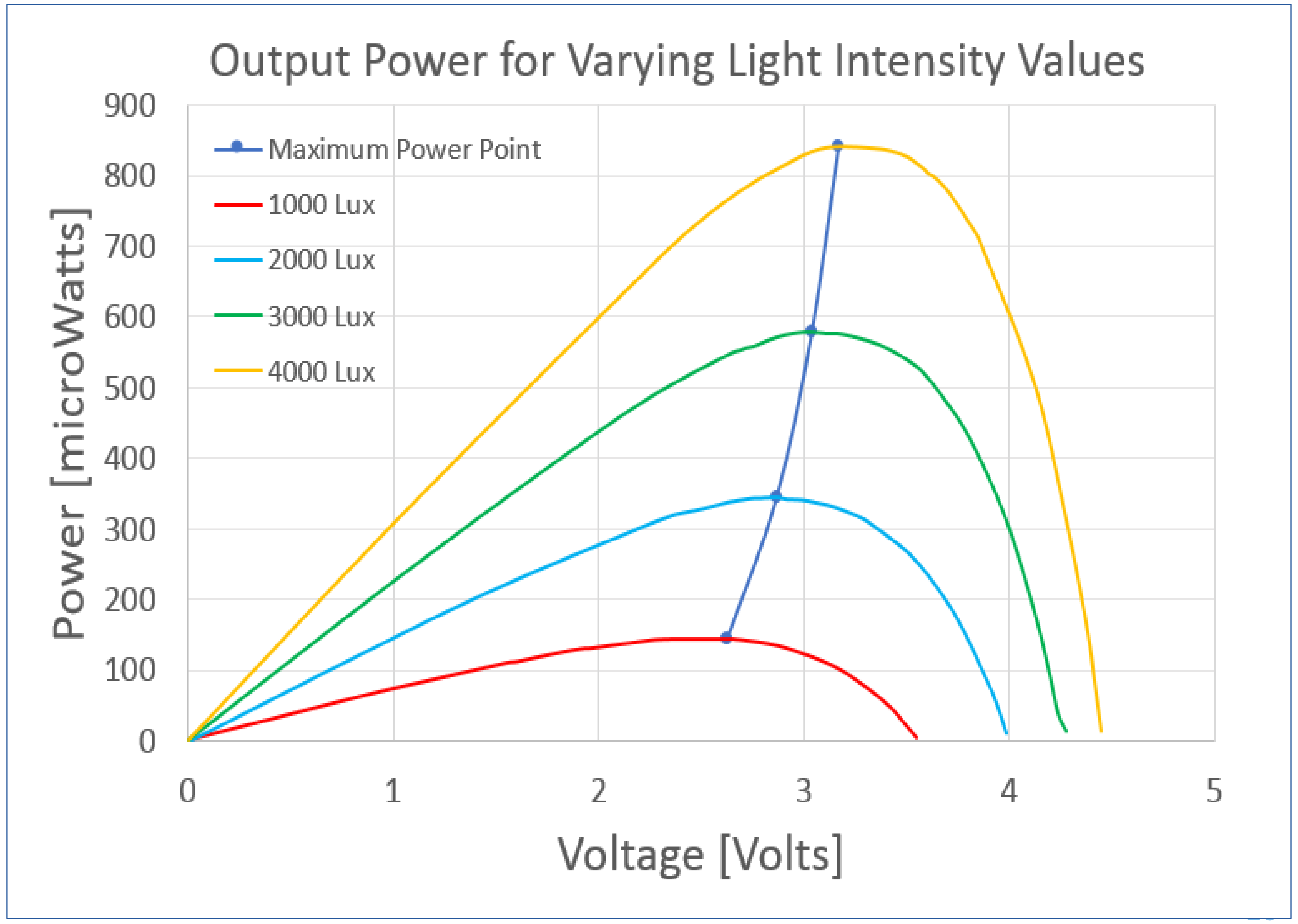


Energy Harvester

The simulation tool has pre-characterised photovoltaic cells and thermoelectric generator components using an “I-V” & “P-V” curve.

Once characterised, the simulation can take in data from any component the user wants.





Maximum Power Point Tracker

Fractional Open-Circuit Voltage (FOCV).

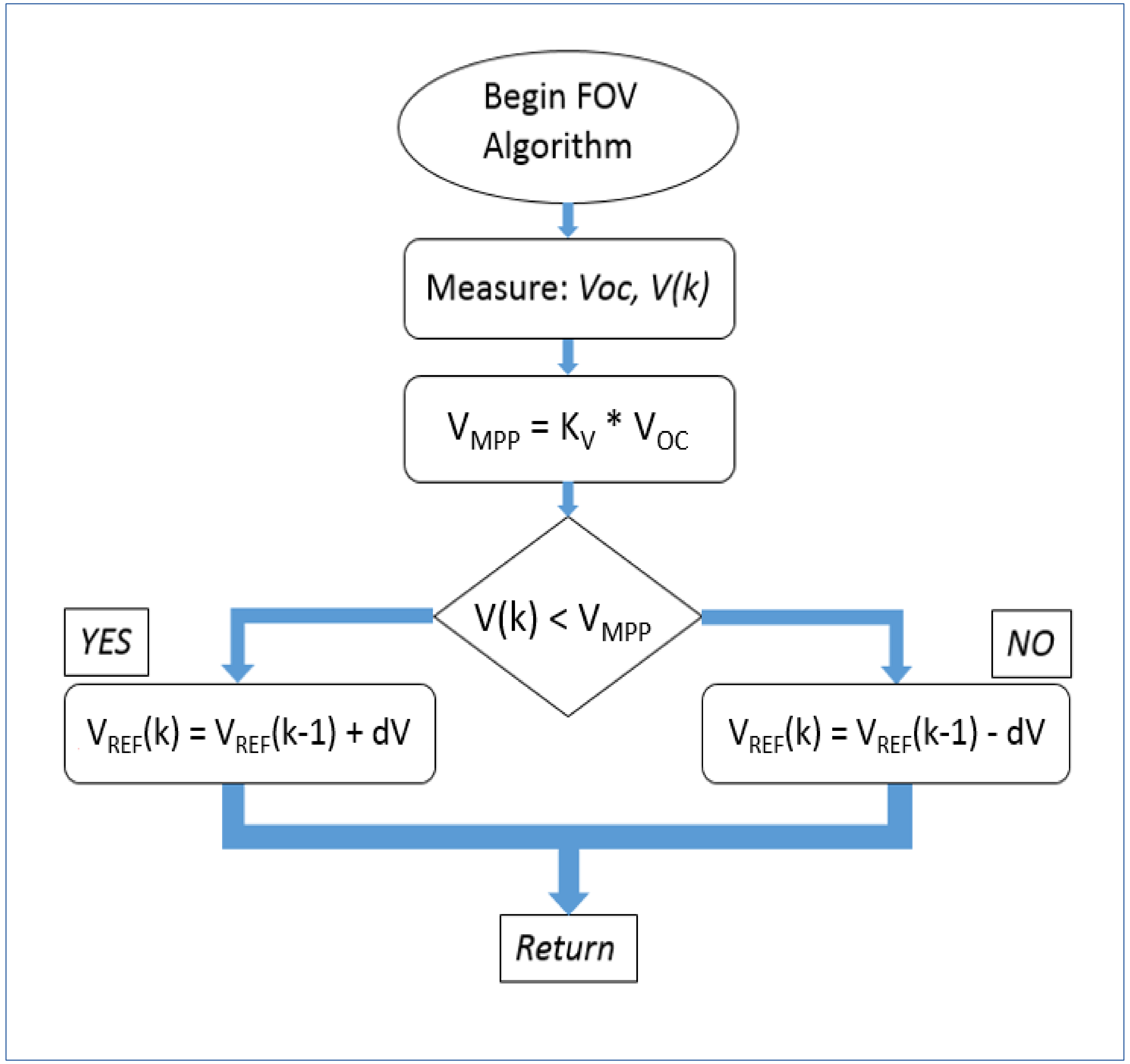
The voltage of the PV cell at the MPP is approximately linearly proportional to the open-circuit voltage and short circuit current

$$V_{MPP} \approx K_1 * V_{OC}$$
$$I_{MPP} \approx K_2 * I_{SC}$$

Where :

- K_1 = 0.7-0.9
- K_2 = 0.78-0.92

Depending on the overall characteristics of the solar cell.



Energy Storage

- For optimum energy efficiency, an energy storage device is required to store any excess energy generated by the energy harvester transducers.
- This stored energy can then be used to power the sensor node when ambient energies are no longer available in order to prolong the lifetime of the battery.
- In this simulation tool, a supercapacitor is modelled in unison with a single-use battery.

DC-DC Converter

- When using ambient energy the designer should ensure that as much power as possible is delivered to the load.

- A supercapacitor’s voltage is constantly varying requiring a DC-DC converter to stabilize the output voltage to the sensor node’s specifications.

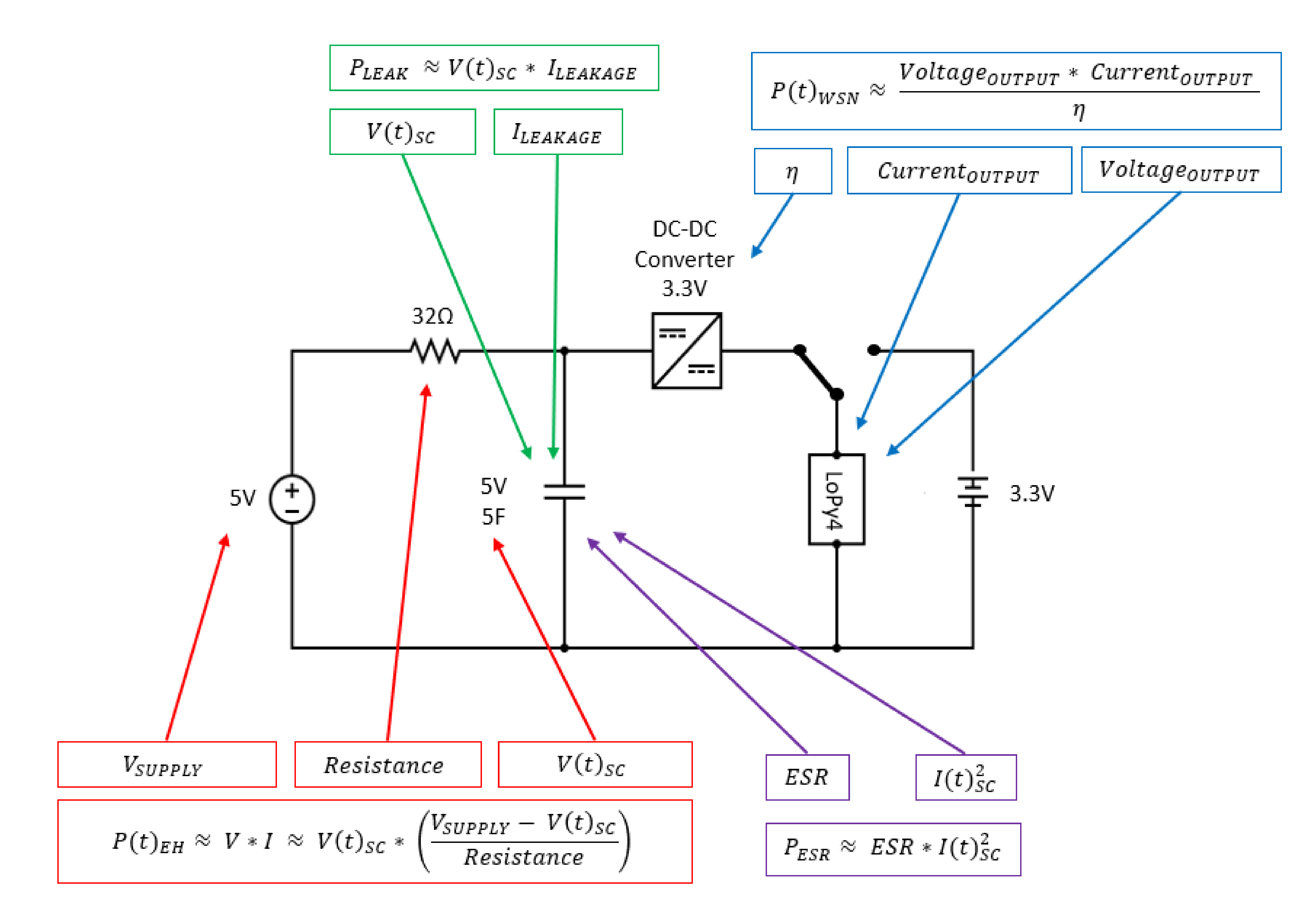
- DC-DC Converter governing efficiency equation:

$$\eta \approx \frac{Voltage_{OUT} * Current_{OUT}}{Voltage_{IN} * Current_{IN}}$$

$$Supercapacitor\ Power \approx \frac{Node\ Power}{\eta}$$

Results

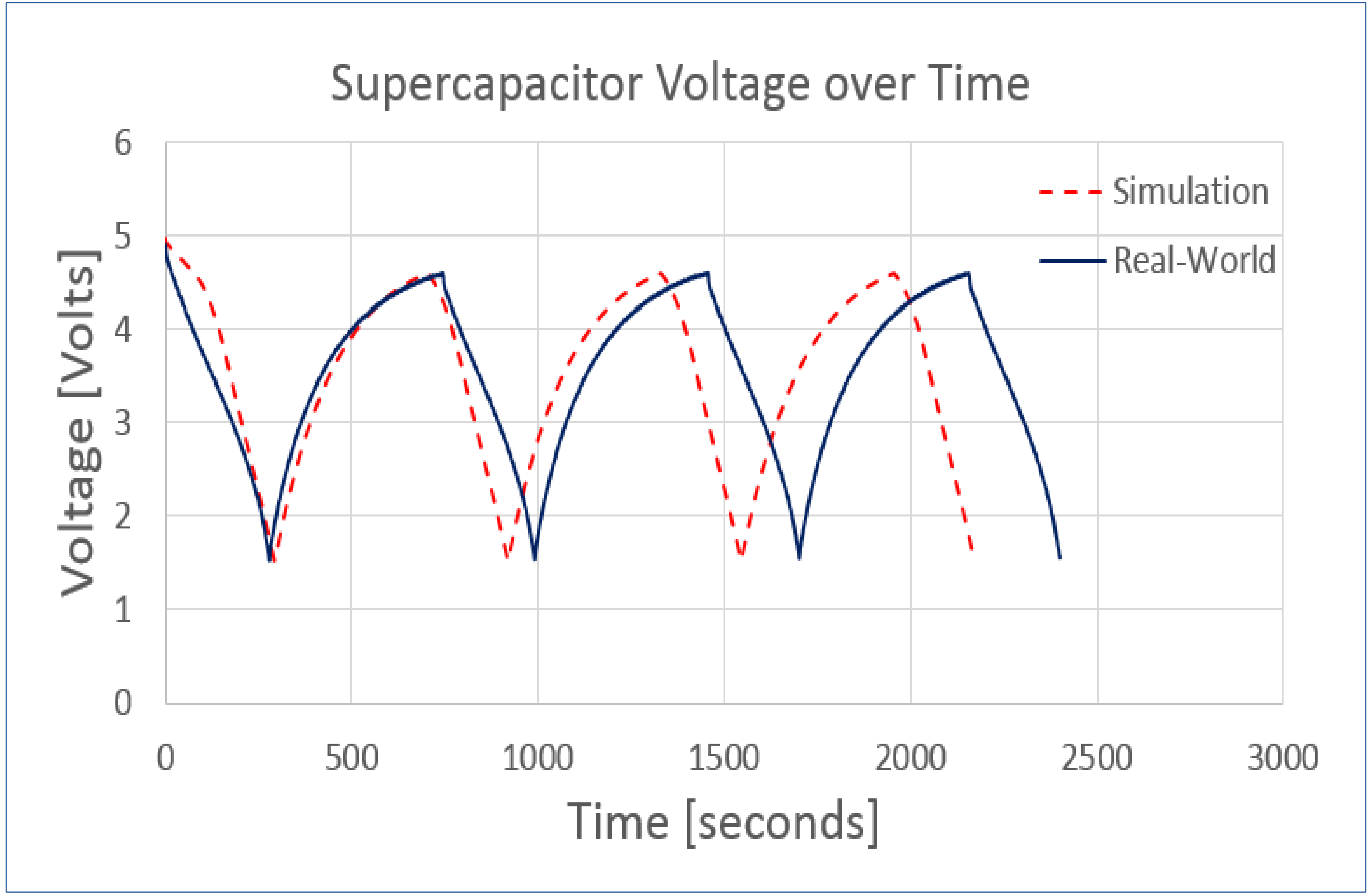
- In the circuit presented, the load is a LoPy4 MicroPython development board, operating at 90mA
- The goal of this test was to measure the voltage of the supercapacitor as it charged and discharged



Results

$$E(t)_{SC} \approx E(initial)_{SC} + \int_0^t (P_{EH} - P_{WSN} - P_{LEAK} - P_{ESR})\, dt$$

- $E(t)_{SC}$: Energy available in the supercapacitor
- $E(initial)_{SC}$: Initial energy
- P_{EH}: Power generated by the energy harvester
- P_{WSN}: Power required by the sensor node
- P_{LEAK}: Leakage in the supercapacitor
- P_{ESR}: ESR Leakage in the supercapacitor



Conclusions

- Based on the results, the simulation tool can predict a real-world scenario with a high degree of accuracy.
- Noticeable margin of error. Possible reasons:
  - Bluno V2 board used to measure voltage had a ±0.15V margin of error.
  - Capacitance of the supercapacitor was taken directly from the datasheet as the rated capacitance.
  - Simplifying assumptions were used for charging.
- With the implementation of a standardised way of characterising components, this simulation tool provides a much faster method for finding the optimum power setup for a particular application.
- Components can be added and multiple simulations performed to find the optimum power solution for any device.

Future Work

- More in depth analysis of the real-life charging and discharging currents should be undertaken via metrology and closer interaction with the supercapacitor vendor to understand device behaviour, particularly in the 4-4.5V charging region.

- In particular the previously mentioned approximation error assumptions need to be validated and their magnitude assessed.

- The models of the components in this simulation tool will be available with the software, with the goal of expanding the library of components as the simulation tool gets used.

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e.g. characterise power consumption of a wireless sensor node for different activation modes, sensor types, transceiver, sensing intervals

e.g. what combination of transducer, storage device and PMIC would self power an IoT device for a given ambient energy source (vibration/indoor light/temperature gradient)

e.g. would a new type of storage device extend battery life for my application

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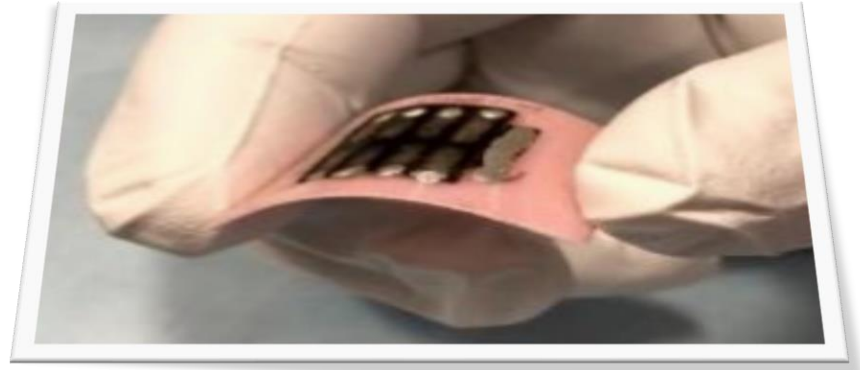

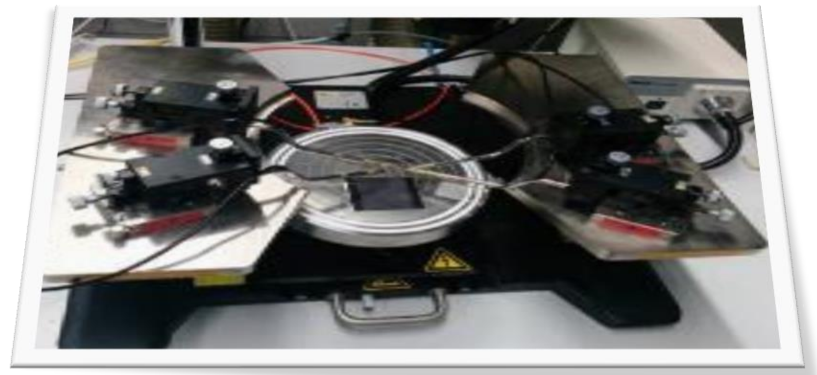

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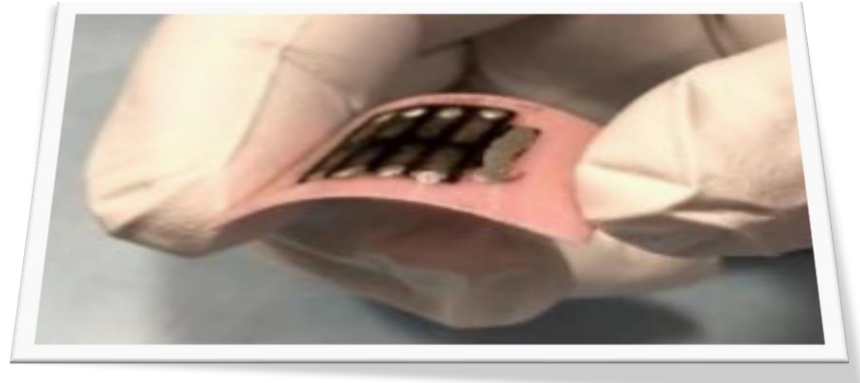

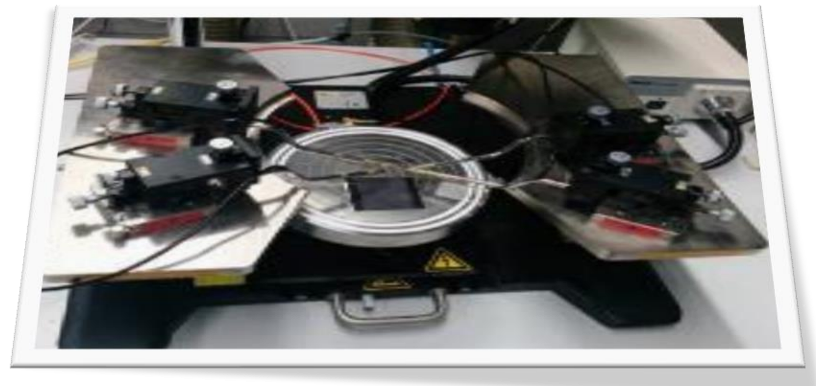

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Tyndall National Institute,
Lee Maltings,
Dyke Parade,
Cork,
Ireland.
T12 R5CP

t: +353 21 490 4177
e: info@tyndall.ie
tyndall.ie

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University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

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