application. To dimension the storage element, we assume it must yield $E_{\text{EIS}} = 3.64$ J when discharging from 3.6 to 2 V. We reach the value of $C_{\text{CAP}} = \frac{2E_{\text{EIS}}}{3.6^2-2^2} = 0.81$ F. Due to commercial availability constraints, we round this value up to 1 F. We thus select Eaton's PHVL 3F, 3.9 V supercapacitors (Table I, C_5) and place them in series to obtain a 1 F storage capacitance. Besides granting us a safety margin, the additional capacitance also allows us to safely account for storage leakage (4 μA), which consumes an extra 8.08 mJ and 1.25 μJ during EIS and TX, respectively.

Finally, considering both the selected capacitor, its leakage, and the estimated task energy consumptions for EIS and TX, we compute the two task triggering thresholds to be $V_{\text{EIS}} = 3.4$ V and $V_{\text{TX}} = 2.1$ V.

V. Conclusion

PMFCs are a promising technology in the field of energy harvesting, and EIS measurements have largely been used to characterize and improve MFCs. Unfortunately, costly EIS workstations limit impedance spectra monitoring upon deployment. This work has pioneered an innovative ultralow power EIS-monitoring technology powered by a PMFC. This breakthrough opens up exciting new possibilities for the use of PMFCs as biosensors. In a practical and novel self-powered sensing approach, the same reactor serves as both an energy source and an EIS biosensor. EIS measurements are triggered when energy levels are sufficient and then communicated to a base station through LoRa, demonstrating the potential for real-world application. We also propose to periodically detach the EHS from the cell to let it recover, in an intermittent harvesting approach apt to maximize PMFCs' power production window. We then assessed the ultralow power capabilities of the MAX30134, which successfully matched reference potentiostat results, and evaluated the consumption of a full-frequency range EIS sweep at $E_{\text{EIS}} = 3.64$ J, proving that ultralow-power EIS is compatible with PMFC power production. Our research has demonstrated the significant variations of the impedance spectra across time (three days) and different activity levels (active and inactive) of PMFCs. This finding underscores the potential relevance of EIS in assessing plant health.

Future work will explore this cost-effective infrastructure for collecting dense crop data upon deployment and developing a comprehensive link between plant health and EIS measurements.

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