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SEDIMENT MICROBIAL FUEL CELLS AS POWER SOURCES FOR SMALL ELECTRICAL CONSUMERS

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Abstract. Sediment Microbial Fuel Cells (SMFCs) are considered as reliable devices for conversion of the chemical energy of organic matter, containing in aquatic sediments, into electrical energy. In this study, nine freshwater SMFCs were connected in series or in parallel and used for charging ultracapacitors in different switch modes. Several methods for boosting voltage were explored in order to gain usable values for supplying low-power electronic devices or sensors. The collected data were compared and the optimal regime was selected for further development of power management system, based on the use of SMFCs as autonomous power sources.

Keywords: sediment microbial fuel cell, energy conversion, bioelectrochemical power sources, power management system

Introduction

It has been known for over a century that bacteria could generate electricity (Potter, 1911). However, only in the recent two decades Microbial Fuel Cells (MFCs) that can generate power sufficient for commercial use have been developed (Rabaey & Verstraete, 2005; Rabaey et al., 2005). Extensive recent studies have led to a better understanding of the electron transfer mechanisms between living cells and electrode surfaces (Liu et al., 2007). Today, the applications of MFC technology range from offshore sediment-based electricity generation toward small-scale batteries and larger-scale bio-converters.

Sediment microbial fuel cells (SMFCs) are adaptation of reactor-type MFCs, where anode and cathode are contained in one or two closed compartments. The anode is embedded into the sediment placed at the bottom of the reactor and the cathode is immersed in the aerobic water column above the phase boundary with the sediment and the device operates on the potential gradient at a sediment-water interface. Unlike other MFCs, where proton-exchange membrane (PEM) and mediators are used to create the needed conditions for the bacteria to generate current, SMFCs are very cost-effective since the expensive PEM is not necessary.

To this state of their development SMFCs are mostly considered as energy sources for environmental sensors located at remote areas, where frequent maintenance is infeasible (Ewing et al, 2014). Although SMFCs are proven to be a reliable autonomous power source, their energy cannot be directly used without some additional processing. SMFCs have some limitations, such as nonlinear scaling-up, low and variable power generation (Donovan et al., 2013) and a theoretical maximum voltage of about 1.2 V, which is insufficient to power a conventional electrical device. Connecting several SMFCs is series is unreliable, because of the unpredictable and uncontrollable voltage reversal.

These facts enforce the use of a power management system (PMS), which stores the energy generated by the SMFC in ultracapacitors or rechargeable batteries, boosts the voltage and supplies power to the desired electrical device in short pulses.

In this study, we performed experiments aiming at determination of optimal operation mode of freshwater SMFCs as autonomous power sources. Several power management systems were explored in order to boost the voltage to usable values for supplying low-power electronic devices or sensors.

Experimental

Nine SMFCs were constructed using cylindrical polyethylene vessels and plane graphite disks (diameter 8 cm, thickness 1.5 cm) as both cathodes and anodes (Fig. 1). The sediment and water samples were collected from the river Struma in the area of Blagoevgrad, Bulgaria. The nine freshwater SMFCs were explored for over two years without any modifications except a periodical addition of water to compensate the evaporation losses.

In order to determine the optimal mode for operation of the examined SMFCs as autonomous power sources, several cells (3, 6 or 9) were connected in series or in parallel and applied to charge 1F ultracapacitor. The time for charging the ultracapacitor to predetermined voltage (0.5 V) was monitored.

To reach higher energy extraction rate, multiple switching frequencies were tested. For this purpose, the investigated SMFCs were connected to 1F ultracapacitor through an externally controlled switch and, as in the previous experiment, the time for charging the capacitor to 0.5 V was measured. The switching intervals between 0.5 and 5 seconds were applied.

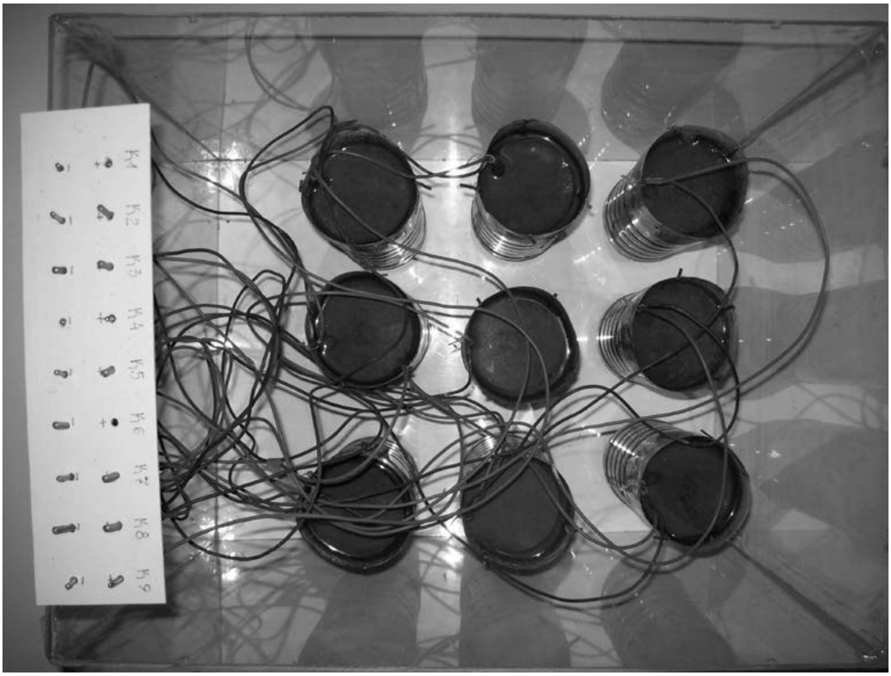


Fig.1. Nine identical lab-scale freshwater Sediment Microbial Fuel Cells

Multiple power management systems were constructed and tested on the base of LTC3105 and LTC3108 (Linear technology) step-up DC/DC converters and TPS61200 (Texas Instruments) synchronous boost converter (Fig. 2).

Results and discussion

The constructed freshwater SMFCs have been operated autotrophically for over two years and their electrical outputs (open circuit voltage, current and power density) have been monitored over time. The statistical evaluation of data collected has shown that the performance of all nine SMFCs becomes homoscedastic after reaching a steady-state (Mitov et al., 2015). The estimated values of standard and expanded uncertainties of the electric parameters have indicated a high repeatability and reproducibility of the SMFCs' performance, which reveals the opportunity for their practical application as autonomous power sources.

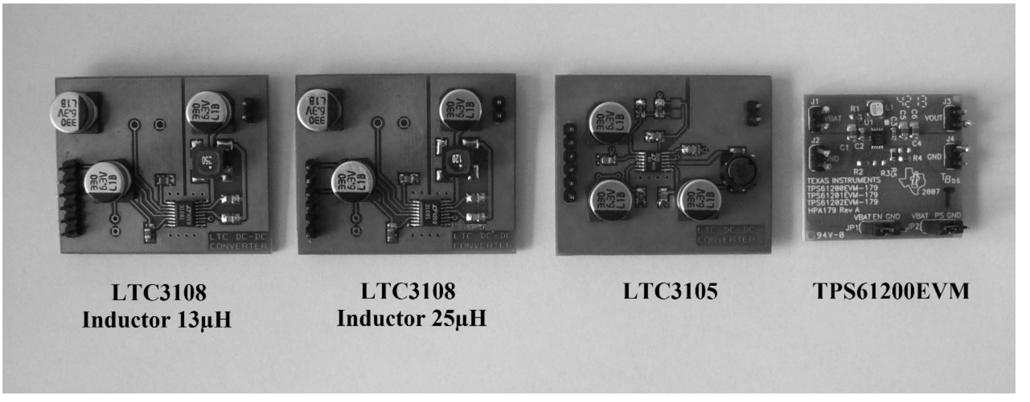


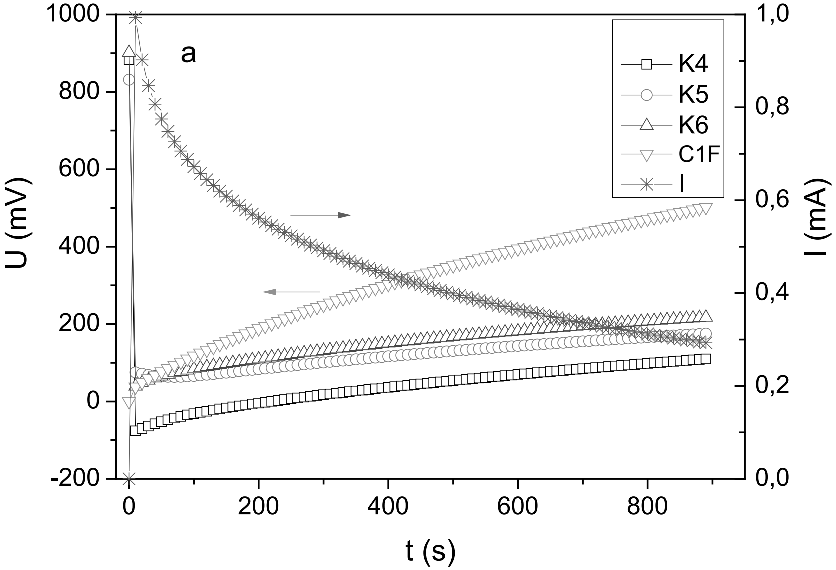
Fig. 2. The explored Ultralow Voltage Step-Up DC/DC converters

In the scope of this study, the effect of connecting multiple SMFCs in series and in parallel on the power generation was examined. Fig. 3 presents a charging of 1F utracapacitor to 500 mV by three of the investigated SMFCs connected in series (Fig. 3a) and in parallel (Fig. 3b). The charging of the capacitor is 2.5 times longer when the fuel cells are connected in series. In the first 210 seconds the voltage of SMFC 4 has a negative value and it acts as a consumer. Voltage reversal was observed in most cases when two or more fuel cells were connected in series. In all tests the voltage reversal appeared in a similar manner, starting immediately after switching and slowly decreasing over time, along with the decrease of current in the circuit. No relation of the open circuit voltage and the short circuit current of the individual fuel cells to the voltage reversal effect were found.

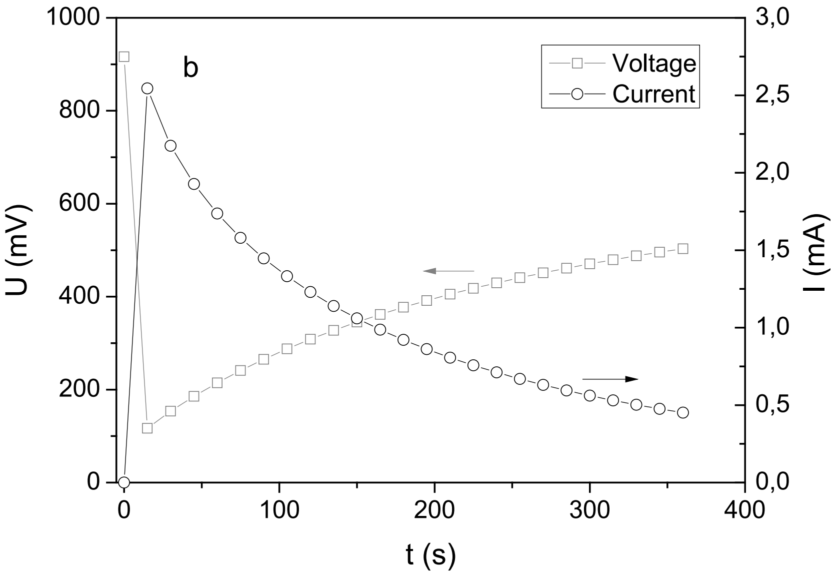
A proportional decrease of the time for charging the ultracapacitor with the increasing number of SMFCs connected in parallel has been observed (Table 1), which demonstrates the ability for scaling-up the system by parallel connection of multiple cells.

Table 1. Time for charging 1F utracapacitor to 500 mV at different number of SMFCs connected in parallel

Number of SMFCs	Time, s
3	350 ± 30
6	150 ± 12
9	73 ± 8



(a)



(b)

Fig. 3. Three SMFCs (K4, K6 and K6), connected in: a) series; b) parallel, charging a 1F ultracapacitor (C1F)

Fig. 4 shows the kinetics of charging of 1F ultracapacitor by single SMFCs, connected directly or through an externally controlled switch. Improvement in the performance of the fuel cells was observed only in the case of 0.5 s ON and 0.5 s OFF regime.

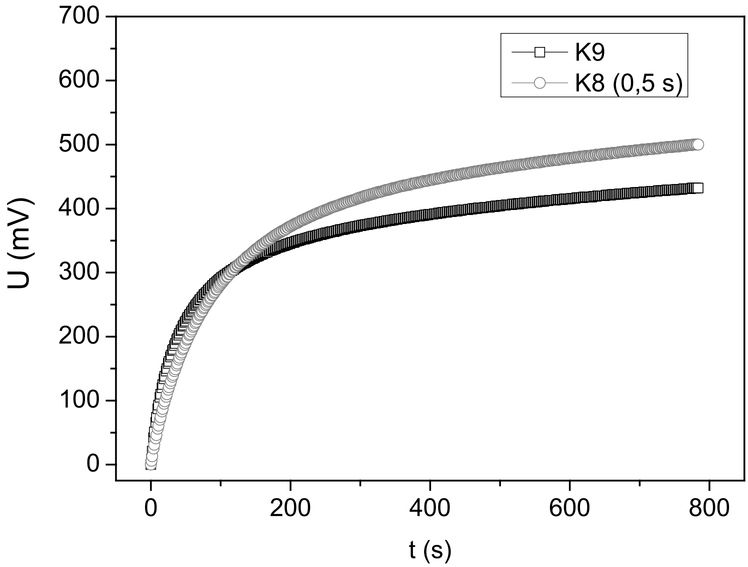


Fig. 4. Charging of 1F ultracapacitor by a single SMFC. K9 is connected directly and K8 through a switch, working in 0.5s ON – 0.5s OFF regime

The voltage reversal can be controlled by a PMS, which extracts electrical energy individually from multiple SMFCs. It should operate intermittently and control the amount current drained, based on the transitory condition of each fuel cell.

Among the explored voltage boosters, the LTC3105 was found to be the most suitable for our set-up. Connected to nine SMFCs it was able to simultaneously power a phototransistor, temperature sensor and a small LED (Fig. 5).

Conclusions

Freshwater SMFCs could be applied as autonomous power sources for low-power electronic devices and sensors. Increasing the power generation by stacking several SMFCs is reliable only in the case of parallel connection. In order to reach higher efficiency, a development of new power management system is required. The investigated set-up needs some additional adjustments prior to be used on the field.

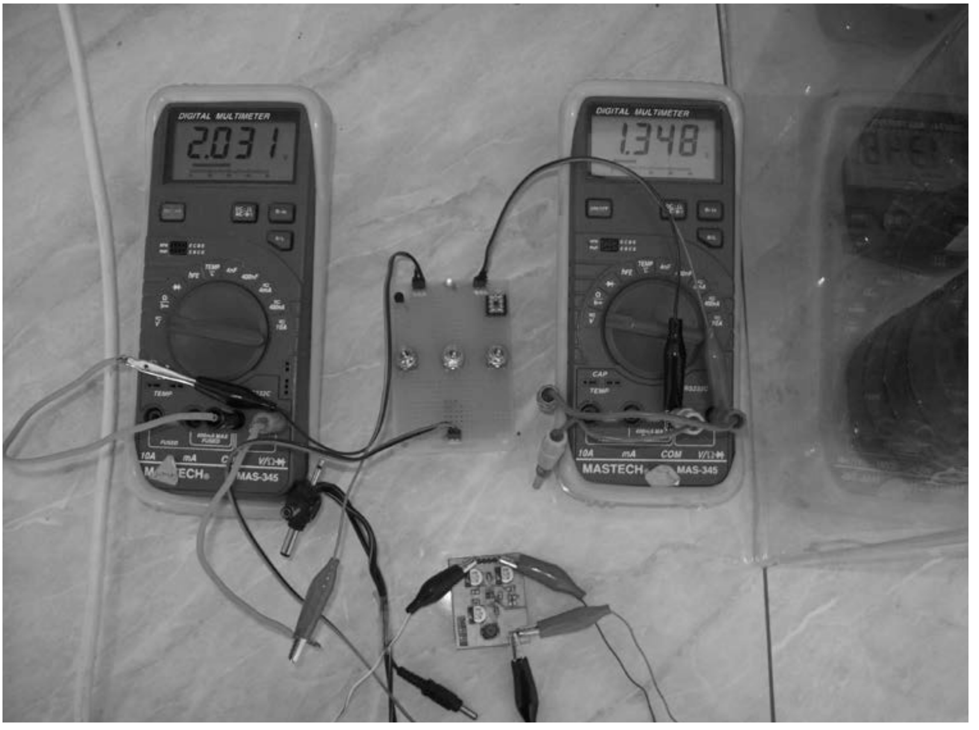


Fig. 5. Experimental set-up of two sensors and a LED powered by LTC3105-PMS connected to nine SMFCs

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REFERENCES

Donovan, C., Dewan, A., Heo, D., Lewandowski, S. & Beyenal, H. (2013). Sediment microbial fuel cell powering a submersible ultrasonic receiver: new approach to remote monitoring. *J. Power Sources, 233*, 79-85.

Ewing, T., Ha, P.T., Babauta, J.T., Tang, N.T., Heo, D. & Beyenal, H. (2014). Scale-up of sediment microbial fuel cells. *J. Power Sources, 272*, 311-319.

Liu, H., Cheng, S., Huang, L. & Logan, B.E. (2007). Scale-up of membrane-free single-chamber microbial fuel cells. *J. Power Sources, 179,* 274-279.

Mitov, M., Bardarov, I., Mandjukov, P. & Hubenova, Y. (2015). Chemometrical assessment of the electrical parameters obtained by long-term operating freshwater sediment microbial fuel cells. *Bioelectrochemistry,* BIOELECHEM-D-14-00301R2.

Potter, M.C. (1911). Electrical effects accompanying the decomposition of organic compounds. *Proc. R. Soc. Lond. B. Biol. Sci., 84*, 260–276.

Rabaey, K. & Verstraete, W. (2005). Microbial fuel cells: novel biotechnology for energy generation. *Trends Biotechnol., 23*, 291-298.

Rabaey, K., Clauwaert, P., Aelterman, P. & Verstraete, W. (2005). Tubular microbial fuel cells for efficient electricity generation. *Environ. Sci. Technol., 39,* 8077-8082.

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