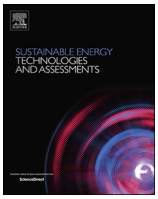
Sustainable Energy Technologies and Assessments 29 (2018) 164–170

Contents lists available at ScienceDirect

Sustainable Energy Technologies and Assessments

journal homepage: www.elsevier.com/locate/seta



Blocking oscillator-based electronic circuit to harvest and boost the voltage produced by a compost-based microbial fuel cell stack

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ARTICLE INFO

Keywords:
Capacitor
Electronic circuit
Green electricity
LED
Power management system

ABSTRACT

Energy obtained from microbial fuel cells (MFCs) is often considered low for practical applications; however, this issue has been overcome by developing electronic circuits that power low-consumption devices such as environmental sensors. Even with recent technical advances, power management systems (PMSs) that target household applications are scarce, while worldwide demand for green energy continuously grows. This research aims to design an electronic circuit to harvest and boost the energy produced by a MFC stack and demonstrates its practical application by powering an LED array. Ceramic and electrolytic capacitors were compared, and an electrolytic capacitor was selected (22 μF, 25 V, 0.11 s). A PMS was constructed utilizing an electrolytic capacitor (22 μF) linked to a blocking oscillator with a toroidal ferrite core that was used as the primary component to boost the MFC output potential. The circuit was operated with three compost-based MFCs connected in series as a power source. The open circuit potential of the MFC stack was 2.25 V, but the useful voltage was 0.837 V in a closed circuit, with a maximum power density of 173 mW m^{-2}. The harvest-and-boost electronic circuit increased the voltage of the MFC stack by 3.6 fold with respect to the pulse peak although the effective voltage increase was 71%, which could power a 10-LED array (3 V).

Introduction

The European Union aims to use renewable energy sources to meet 20% of its total energy consumption by 2020. The contribution of electricity produced from renewable energy sources to electricity consumption was 25.4% in 2013, with biomass and waste being the most important energy sources [1].

An alternative to supply clean and renewable electrical energy is microbial fuel cells (MFCs). MFCs are devices in which organic matter is oxidized by microorganisms that transfer electrons to an electrode. The electrons circulate via an external circuit from the anode to the cathode thus producing an electrical current. The circuit is closed in the cathode by the ions that cross a selective membrane and combine with an oxidizing compound such as oxygen. The final products are electricity, water in the cathodic chamber, and CO_2 in the anodic chamber [2].

Natural media has been exploited to inoculate and feed MFCs. Marine and river sediments, soils, and garden compost have been successfully utilized in MFCs to produce electricity [3]. Compost-based MFCs have mainly focused on pollution removal in wastewater [4,5] and more recently on enhancing the composting processes of organic solid wastes [6]. Soil and compost mixtures have also been used for the installation of plant-based MFCs. This type of MFC is complex and challenging to control because it depends on the soil-compost mixture characteristics, the type of plant, the microbiome developed on its roots, and the influence of solar radiation [7].

The power output obtained from compost alone can be as low as 4 mW m^{-2} [8], but the addition of a carbonaceous source such as xylose can increase the power to 590 mW m^{-2} [5], and acetate can enhance this value to 944 mW m^{-2} for an individual MFC and 779 mW m^{-2} for a three-MFC stack [9].

Researchers have worked continuously to improve the performance of compost-based MFCs, but until now, no installation of a garden compost-based MFC coupled to electronic circuits to harvest and boost the produced energy has been reported.

Although the amount of energy produced by current MFC designs is not sufficient to power high-consumption industrial equipment or for

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Abbreviations: MFC, microbial fuel cell; LED, light-emitting diode; PMS, power management system; DC-AC, direct current-alternate current; OCV, open circuit voltage; I-V, intensity-voltage

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https://doi.org/10.1016/j.seta.2018.08.007
Received 12 December 2017; Received in revised form 12 July 2018; Accepted 23 August 2018

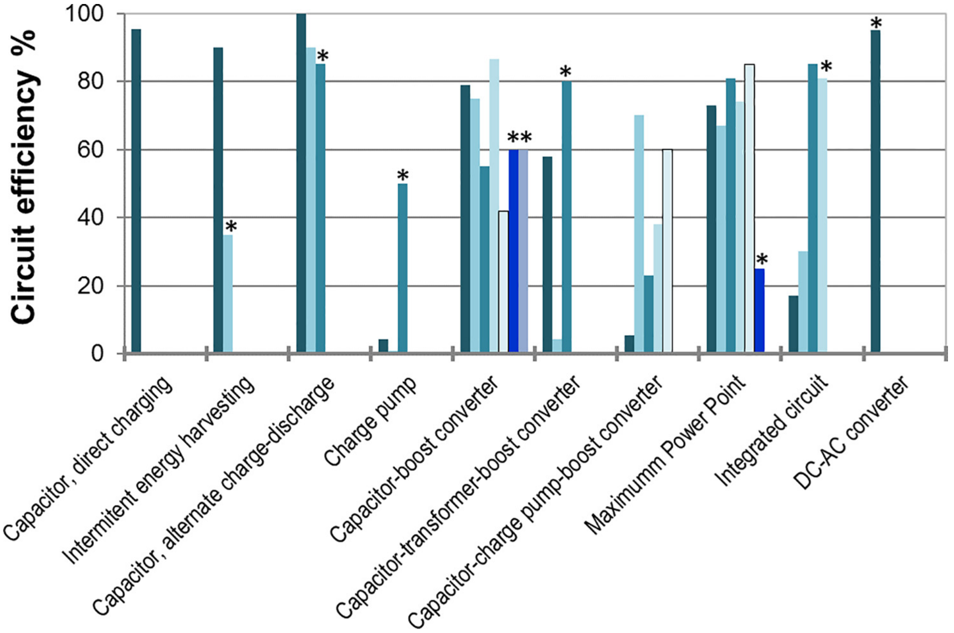

Fig. 1. Circuit efficiencies of PMSs coupled to a MFC or MFC stack. The number of bars indicates the number of investigations in each category. Data adapted from [10].

transport applications, low-consumption devices have been powered successfully using electronic circuits. Wang et al. [10] presented an extensive review on power management systems (PMS) based on a variety of electronic circuits that harvest and boost the energy produced from MFCs.

The most frequently reported PMS is composed of a capacitor and a boost converter. The simplest harvesting circuit is a charge pump and attains efficiencies of 0.5% to 50% [10,11], whereas one of the most complex circuits tracks the maximum power point of the MFC. This complex circuit regularly enables high efficiencies from 70% to 85% [10,12]. Fig. 1 shows an updated review of efficiencies for the most commonly used harvest-and-boost circuits with bioelectrochemical systems [10–19].

A more complex PMS will result in more challenges that might need to be addressed, including energy losses, the possible failure of any of the electronic components, the use of an external power source to start the circuit, incorporating a programming specialist, and a probable increased cost.

In 1957, a blocking oscillator circuit was described in patent US2816230 [20]. This type of circuit extracts the energy of a power source and generates voltage pulses at high frequency. The construction of a blocking oscillator is quite simple; it does not require an additional power supply to start, and no programming is needed. These advantages could be exploited to extract the low energy from MFCs to power electric devices.

The efficiency of a PMS does not always correlate with its complexity. For instance, some capacitor-based PMSs in intermittent or alternate charge-discharge operation have produced higher performances than continuous energy harvesting [21]. Clearly, new proposals for PMSs must balance simplicity and efficiency.

In addition to the circuit efficiency, the net energy harvested from the MFCs coupled to a PMS is an issue of great practical interest. The net energy from MFCs should not be considered a bottle-neck if the system MFC-PMS effectively powers a target device or process. Powering wireless sensors that currently require 3.3 V to operate has been extensively reported in the literature [10,22]. Other applications of the net energy harvested from MFC-PMS systems include hydrogen production in a microbial electrolysis cell (required voltage 0.44 V–0.48 V) and sulfur recovery by electrochemical deposition (required voltage 0.76 ± 0.15 V) [23,24].

Reports on MFC energy applications for public use are far fewer. Ieropolous et al. [25] demonstrated a functioning mobile phone powered with batteries that were recharged by urine-fed MFC stacks. That research group has continued to optimize their setup to better manage the battery charge cycles [26]. The same group demonstrated the feasibility of a modular urine-based MFC for lighting either directly or via supercapacitors. The authors designed a module comprising 432 MFCs (300 L total, 330 L/d), which lighted 6 LED modules that consumed 1.8 W [27]. Schievano et al. [14] reported floating plant-MFCs that were connected to DC/DC converters to produce up to 100 µW, which enabled one LED to be powered intermittently. Wu et al. [28] utilized *Shewanella oneidensis* inoculum in a three-MFC stack with a DC/DC boost converter. The PMS increased the output voltage from 0.3 V to 3 V, required an external power source to start up, and could power one LED. These descriptions show that more practical installations of MFC-PMS for extended domestic use still need to be developed.

The domestic use of the energy produced from MFCs seems impractical if sediments or sewage and industrial wastewater are used as the fuel and/or inoculum. Indoor use of sediment-based MFCs might require sediment transport, and wastewater must be handled by sanitary technicians because gray water is generally mixed with black water in common domestic sewage. Nevertheless, widely available, non-pathogenic materials, such as garden compost, could be exploited in MFCs to close the application of the energy produced for a household environment. Moreover, this approach allows the use of green electricity and is consistent with actual ecological tendencies [29].

This research presents an electrical circuit design for harvesting and boosting the energy produced by a compost-based MFC stack. A capacitor-based circuit was improved via the incorporation of a blocking oscillator. The energy produced by the MFCs coupled to the PMS efficiently powered a 10-LED array that simulated a household lighting device.

Materials and methods

Design and operation of microbial fuel cells

Two-chamber MFCs were installed in triplicate. Each compartment