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Energy Harvesting from Microbial Fuel Cell Using a Power Management System: A Review

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***Abstract*— Microbial fuel cells (MFCs) are renewable energy sources which generate electric current consuming organic substrate. Due to the low output voltage and current, the MFCs are not able to directly power most of commercial loads. A Power Management System (PMS) is a bridge between MFC and the device which stores the energy produced and discharges it in order to run a final load. Owing to the energy loss, and long charging time of PMSs a maximum power point tracking (MPPT) system has been integrated into the PMS to enhance the power efficiency of PMSs. This study aims to review and discuss the characteristics of preliminary PMSs and new generations that use MPP algorithms.**

Keywords: Microbial fuel cell, Power management system, Maximum power point tracking.

I. Introduction

Microbial fuel cell (MFC) is a renewable energy generator using an organic waste such as wastewater as feed to make electricity by exoelectrogenic microorganisms as catalyst. Although at 1911 Potter [1] had used bacteria to produce electricity for the first time and very few researches in that field for next 66 years (Lewis 1969), until 80 years later no especial survey was conducted. In 1990 decade the MFC's application began to increase [1] however these experiments needed some chemical mediators or electron shuttles for transportation of electron from inside the cell to exogenous electrodes. The turning point in MFC was at 1999 when it was detected there was no need for using the chemical additives and so the it could have a better prospective as a new energy resource[2, 3]. Up to now different types of investigations by various scientists in many countries have been carried out.

MFCs are in various configurations so that each device generally has an anode compartment in which microorganisms consume substrate and produce electron, proton and carbon dioxide through an oxidation reaction, and a cathode compartment in which Oxygen is reduced to complete the process. Cathode can have several structures for Oxygen oxidization such as air-Platine, ferric cyanide, etc. In addition a permeable membrane is applied to convey electrons to cathode and keep bacteria in anode part separated from oxidizer to enforce electrons to cross through the external direction. Therefore, the electricity flow would be accessible to get used. In figure 1 a schematic of basic components of an MFC with air-Platine catholyte is shown. The external electron path has been connected to a computer.

Although MFCs are promising Eco-friendly energy sources, their low output characteristics such as power density and voltage are still unsatisfactory. They need to be associated with particular systems to be able to run the desired load.

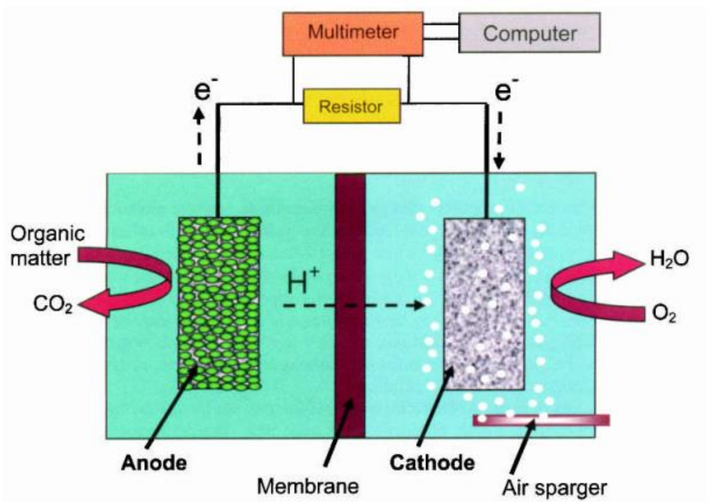

Figure1. Schematic structure of a microbial fuel cell

Typical MFCs provide an open circuit voltage in range of 0.3-0.9V [1,4] and a power range from 1 to 2000 mW/m^2 [5,6,7,8] while the common electronic devices need more energy to get powered. For instance, a single light emitting diode (LED) needs a minimum voltage of 2 V and power of 30 mW and many wireless sensors need a voltage range of 2.5-5V. The first method for increasing the output characteristics is building a larger MFC or connecting them in series or parallel. But their nonlinear nature doesn't allow a desirable power be achieved [9,10]. In addition, serial stacking of MFCs can even decrease the output properties in some cases due to the voltage reversal phenomena [11].

A power management system is an electronic circuit designed to extract power from MFC and stores it into capacitors. Then the capacitor discharges in order to turn an electronic device on. In fact, a PMS provides sufficient energy for running a specific device by using multiple electronics such as capacitor, charge pump, boost convertors, etc. The PMS harvests electrical energy with MFC as the power supply, saves it into a storage part and as long as the stored energy was enough, it would discontinuously turn the load on.

In this article, different technologies available for PMS is reviewed. These technologies rely on core electronics such as charge pumps, boost convertors, and advanced capacitors. The design and characteristics of PMS circuits using these devices has been discussed.

II. Power management systems technologies

PMS can be designed in different forms and include various components. All PMS circuits have been divided into three general groups.

A. *capacitor-based system.*

These circuits have been using a number of capacitors or super-capacitors and applying them in parallel or series. Further alternatively a boost convertor could get utilized to reach the requirements for running a terminal device. This convertor is such a DC-DC convertor which increases its input voltage to a particular voltage. These kinds of DC-DC convertors are voltage amplifiers that need a minimal voltage of 0.7 to 0.8V and provide higher than 3V voltage (L6920DB, STMicroelectronics).

As shown in Figure 2A, Meehan et al. [12] demonstrated a capacitor-based PMS with a boost convertor which three capacitors get charged in parallel and discharged in series by using especial switches. In Figure 2B, Kim et al. [13] proposed another type of PMS by utilizing 8 capacitors without using any boost convertor.

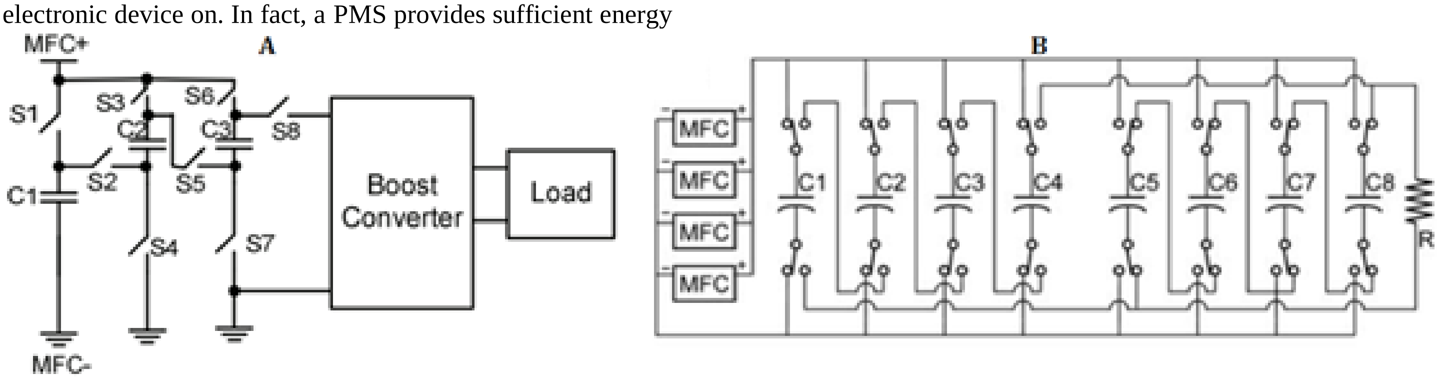

Figure 2. A) a capacitor based PMS with boost convertor. B) a pure capacitor based PMS

B. Charge pump- or transformer-based systems

Charge pump is a low-cost device that is similar to the DC-DC convertor with slight differences in its structure. It needs a lower input voltage and also make a lower output voltage, nevertheless it has been widely used to power a boost convertor or charge a super-capacitor [14]. For instance, S-882Z series charge pump requires a minimum input voltage of 0.3V to generate a discharge voltage of 1.8-2.4V.

A transformer can also be utilized instead of charge pump in a PMS [15]. Although it requires a shorter time and lower input voltage than a charge pump, its efficiency and output voltage are lower. Owing to their both low output characteristic, a pure type of these PMSs rarely have got used. A simple form of a charge pump-boost convertor and transformer-boost convertor are demonstrated in figure3.

C. Combinatorial systems

The common PMSs are consist of several elements like capacitor, DC-DC convertor, charge pump, etc. By combination of the devices and making a monolithic circuit energy harvesting, overall efficiency will significantly increase. For instance, as shown as figure 4, Yang et al. [16] proposed a power management system using several aforementioned components to drive an IEEE 802.15.4 wireless sensor intermittently.

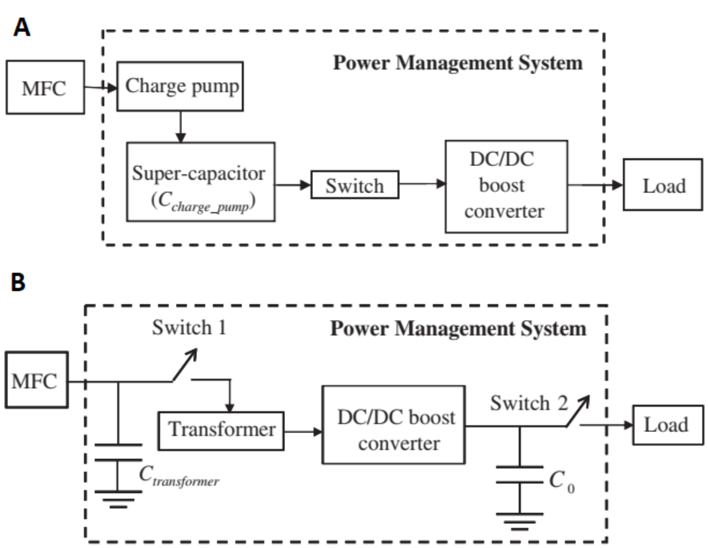

Figure3. A) charge pump-capacitor-convertor based PMS. B) transformer-capacitor-convertor based PMS

D. MPPT-integrated systems

Maximum power point tracking (MPPT) is one of the best techniques to dynamically extract maximum possible power from MFC and decrease energy loss. The method has been using in wind turbines and photovoltaic solar cells. In general, by the time the energy source generated power varies depended on external condition such as amount of sunlight falling on solar panels or bacteria activity rate, and the whole resistance of the connected circuit, the produced energy would be variable. Thus, if the resistance changes based on receiving energy, the generated power will be risen or maximized.

In this system by applying some algorithms the maximum power point continuously is detected then the system matches the internal impedance. In other word, if the total internal impedance of the PMS was equal to internal resistance of MFC, the MPP would be achieved.

The older PMSs had no MPPT part that caused more energy loss and longer charging time resulting in low efficiencies. By utilizing an MPPT part, not only has the loss been reduced, but the time for charging has gotten decreased and thus system's efficiency has been increased. MPPT based PMSs have various components and designs due to variations in MFC, load and other conditions. Design, programming and construction of PMSs is a bit complicated and needs to have sufficient knowledge. The MPPT-integrated PMSs can be divided in two main groups based on their algorithms for tracking MPP.

1) Constant coltage: As long as the output voltage of MFC was ½ of its open circuit voltage (Voc), whole system would work approximately at MPP condition. This is one of the MPPT algorithms which always regulates corresponded PMS impedance to half of Voc. Erbay et al. [17] demonstrated a novel PMS by using this method and as shown as figure 5. they ran a2.5V wireless temperature sensor every 7.5 min.

Additionally, they achieved 30% overall efficiency level. Their proposed PMS with MPP and the final capacitor voltage are shown in Figure6.

2) Control system: Owing to halving Voc not necessarily gives the MPP, a more accurate method is needed. Recently, new designs of MPPT-based PMSs have been applied in which voltage and resistance are continuously measured and power is directly calculated. In figure 7 the algorithm is explained. Afterward the internal impedance is changed to dP/dV=0. So, the MPP will be achieved. E. Songet al. [18] implemented this system to a MFC without connection to any load. They reached to 0.1A current and 0.7V voltage after one hour using the MPPT system.

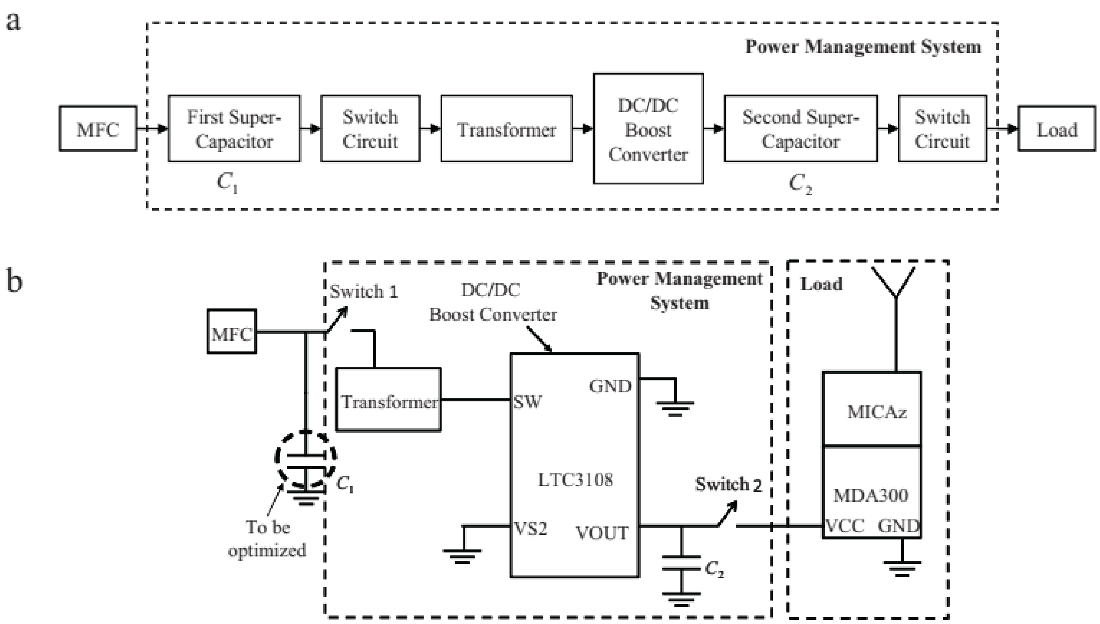

Figure 4. A) Transformer-based power management system and (B) PMS detailed circuit implementation

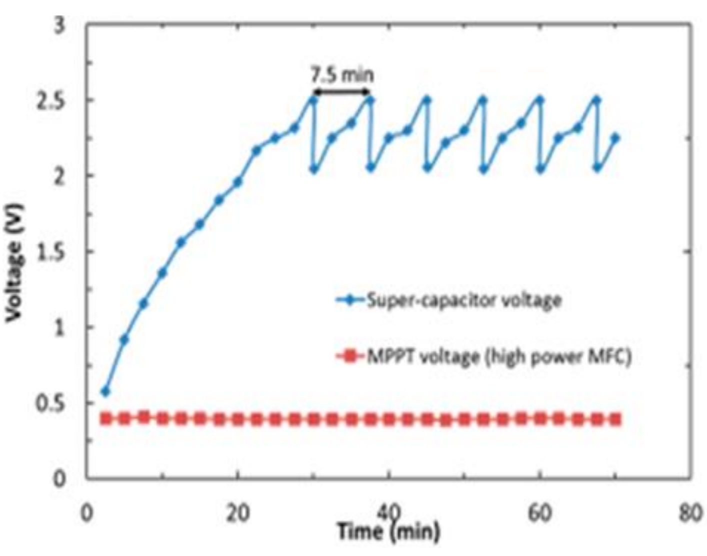

Figure5. supper-capacitor and MPPT voltage curves

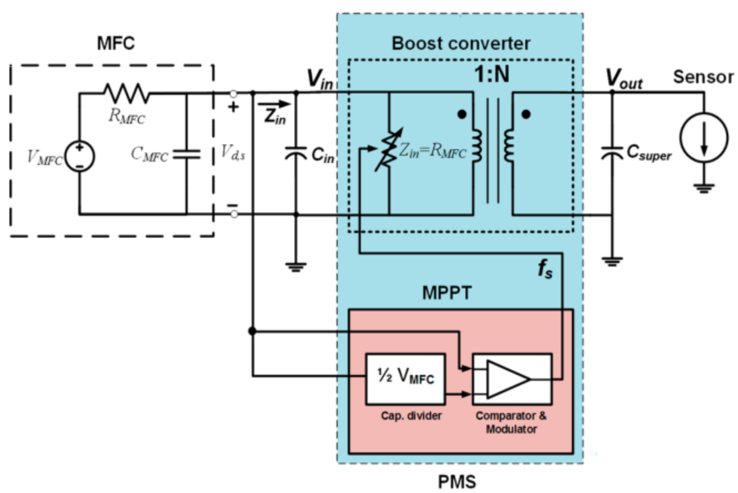

Figure 6. Schematic circuit of a MPPT-based PMS

III. Conclusions

Three types of PMSs were reviewed that vary from simple to complex types. Early PMSs were not optimized in terms of operational voltage and current. Integrating MPPT systems

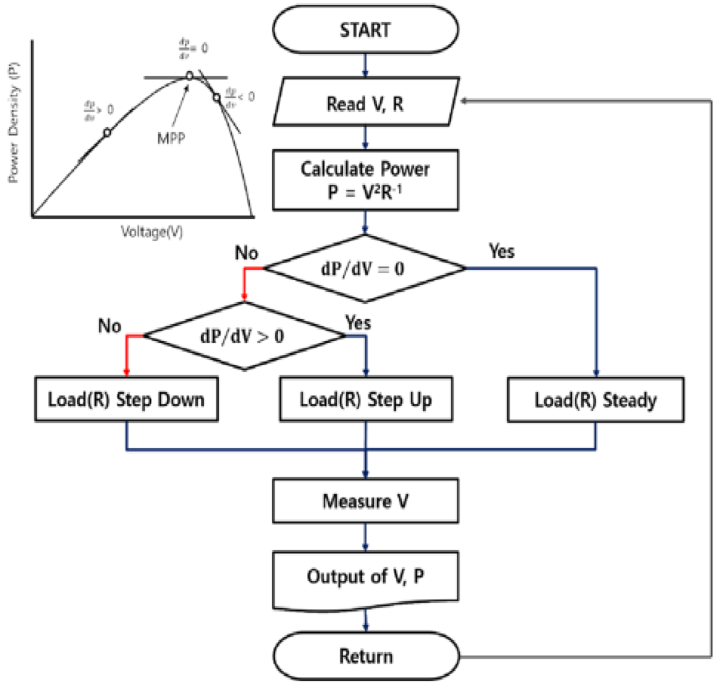

Figure 7. Algorithm of control system MPPT

into PMS, has reduced energy loss as well as charging time and enhanced total efficiency. More improvement on either MPPT or other parts of the system is needed to in future.

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