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Eco-Friendly Wastewater Treatment Solution Using Self-Powered Microbial Fuel Cell

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Abstract: Efficient monitoring and control of Waste Water Treatment Plant (WWTP) has turned into an important public issue as the cost of electricity continues to grow and the quality requirement of processed water tightens. A Microbial Fuel Cell (MFC) is a bio-electrochemical system that drives a current by mimicking bacterial interactions found in nature. Self-powered Wireless Sensor Networks (WSNs) are more suitable for this application to monitor the status of the waste water. A novel Wireless Sensor Network (WSN) is proposed in this paper which integrates Microbial Fuel Cells (MFCs), Field Programmable Analog Array (FPAAs) to design a self-powered, highly flexible and adaptive system. The profusion of bacteria and chemical ingredients in waste water processing tanks provides materials for MFCs to convert chemical energy into electrical energy. In wastewater treatment, water is aerated so bacteria in the liquid break down organic material in a closed series of containers known as a bioreactor. The simulation of the system is done and the results of which can also be hardware implemented.
Keywords: Microbial Fuel Cells, Field Programmable Analog Array, Self powered WSN, Wastewater Treatment Plants (WWTPs), Fuzzy Logic

I. INTRODUCTION

Wastewater Treatment Plants (WWTPs) are one of the most energy consuming industrial facilities. Nearly 3% of the total electricity supply is consumed by WWTPs and approximately 30% of WWTP operating budgets are dedicated to electricity. In WWTPs sensors are located in the inconvenient place for regular human maintenance, hence battery replacement is undesirable. Self-powered systems are more suitable as it provide maintenance free operation for many years. To meet these disputes an "Eco-Friendly wastewater treatment solution using self-powered Microbial Fuel Cell" is proposed in this paper. This novel integrates Microbial Fuel Cells (MFCs), Field Programmable Analog Array (FPAAs) and low power networking protocols into the sensors to make them self-powered, highly flexible and adaptive. The conversion of the bacteria and chemical ingredients in waste water processing tanks provides materials for MFCs to convert chemical energy into electrical energy. FPAAs are inherently parallel, which offers ultra-low power consumption and greater flexibility for the sensor signal processing. Efficient analog signal processing technique must be used to efficiently consume the harvested energy. Computations in FPAAs are advantageous being parallel, since there is no central processor. Multiple sensor inputs can be processed simultaneously and in real time using independently configured and programmed circuitry within the FPAA. FPAA composed of large arrays of interconnected components, similar to FPGAs.

II. MICROBIAL FUEL CELL (MFC)

A microbial fuel cell is an electrochemical device capable of continuously converting chemical energy into electrical energy for as long as adequate fuel and oxidant are available. The design of a microbial fuel cell usually consists of two electrodes, anode and cathode, placed in independent compartments divided by a proton exchange membrane. In the anodic compartment, organic compounds (glucose) are oxidized by microorganisms, generating electrons and protons in the process. When bacteria are placed in the anode chamber of a specially-designed fuel cell that is free of oxygen, they attach to an electrode. Because they do not have oxygen, they must transfer the electrons that they obtain from consumption (oxidation) of their food somewhere else than to oxygen -- they transfer them to the electrode. In a MFC these electrons therefore go to the anode, while the counter electrode (the cathode) is exposed to oxygen. At the cathode the electrons, oxygen and protons combine to form only water. The two electrodes are at different potentials (about 0.5 V), creating a bio-battery (if the system is not refilled) or a fuel cell (if we constantly put in new food or "fuel" for the bacteria). By adding a small amount of voltage (0.25 V) to that produced at the anode in a MFC, and by not using oxygen at the cathode, it can produce pure hydrogen gas.[1]

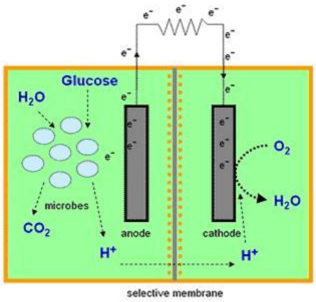

Figure 1. A Microbial Cell

III. FUEL CELL TREATS WASTEWATER AND HARVESTS ENERGY (WWTP)

A new microbial fuel cell creates energy during wastewater treatment and also vastly reduces the amount of sludge produced water is aerated so bacteria in the liquid break down organic material in a closed series of containers known as a bioreactor. [3]

Glucose and oxygen react to produce carbon dioxide and water

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6C_{O2} + 6H_2O$$

Instead of glucose and oxygen reacting to produce carbon dioxide and water, here glucose and water produce carbon dioxide, protons (positively charged hydrogen ions (H^+)) and electrons (e^-)

$$C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$$

In a MFC, this half of the process defines one half of the fuel cell. This portion is located in the rhizosphere with the plant roots, waste and bacteria. The other half of the cell lies in oxygen-rich water on the opposite side of a permeable membrane. In the second half of the cell, free protons and electrons combine with oxygen to produce water, like so:

$$6O_2 + 24H^+ + 24e^- \rightarrow 12H_2O$$

Protons reach this second half by flowing across the ion exchange membrane, creating a net positive charge -- and an electrical potential that induces electrons to flow along the external connecting wire.

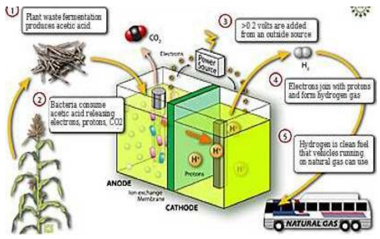

Figure 2. Fuel Cell Treats Wastewater and Harvests Energy

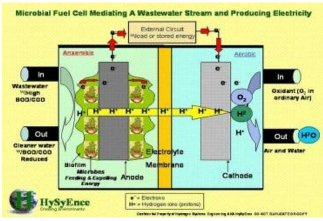

Figure 3. MFC mediating wastewater & generate electricity

IV. WIRELESS SENSOR NETWORKS IN WWTP

Wireless sensor networks (WSNs) are suitable for distributed sensing with lots of sensors, because they are cheap and easy to install since no wiring is required [2]. This is appealing for applications in wastewater treatment plants, where the measured variables (for example dissolved oxygen concentration or ammonium concentration) depend heavily on the sensor location. One interesting observation about wastewater treatment plants in general is that the system disturbances (incoming wastewater flow, ammonium concentration etc) are periodic, with a period of one day. This could be utilized in some repetitive control/iterative learning control strategy, where the daily input is iteratively updated each day. Major advantages of WSN are Power consumption constrains for nodes using batteries or energy harvesting, Ability to cope with node failures, Mobility of nodes, Communication failures, Heterogeneity of nodes, Scalability to large scale of deployment, Ability to withstand harsh environmental conditions, Ease of use.

V. FIELD PROGRAMMABLE ANALOG ARRAY

FPAAs are analog parallels of FPGAs, and they have been attracting a lot of recent attention from industry and academic research . They are comprised of a large array of analog components interconnected through a fabric of programmable switches. This large array of components enables highly parallel operations and significant flexibility of functions that can be performed. Non-volatile memories within the FPAAs allow them to be reprogrammed thousands or millions of times, while also ensuring that these devices will operate properly during intermittent power losses.

VI. ENERGY HARVESTING AND STORAGE

MFCs are the prime energy source for the sensor system. It is a challenge to provide a stable, continuous power supply for a long period of time using MFCs. However, MFCs can be used to partially recharge or supplement batteries, thus extending their lifetime significantly, but the batteries eventually wear out. It is infeasible to replace batteries embedded in sensor nodes that are submerged in wastewater processing tanks. On the other hand, the theoretical lifetime of capacitors and super capacitors is orders of magnitude longer than batteries. Therefore, super capacitors are an integral part of the proposed harvesting and storage scheme, which minimizes sensor node maintenance.[5]

VII. SIMULATION AND OUTPUTS

The system architecture consists of two blocks, namely controller and sensor subsystem. The fuzzy logic is used to keenly monitor the level of the waste water and the Rule Viewer displays a roadmap of the whole fuzzy inference process. The sensors provides the contents like Nitrogen , Silicon biomass and substrate which is present in the wastewater .The system architecture consists of two blocks, namely controller and sensor subsystem. A tank with a pipe flowing in and a pipe flowing out is designed. The valve controlling the water that flows in, but the outflow rate depends on the pressure in the tank which varies with the water level. A controller for the water level in the tank needs the current water level which is to be controlled automatically by setting the valve. Controller's input is the water level error (desired water level minus actual water level), and its output is the rate at which the valve is opening or closing.

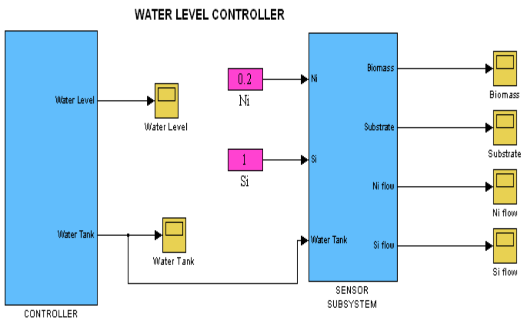

Figure 4. System Architecture

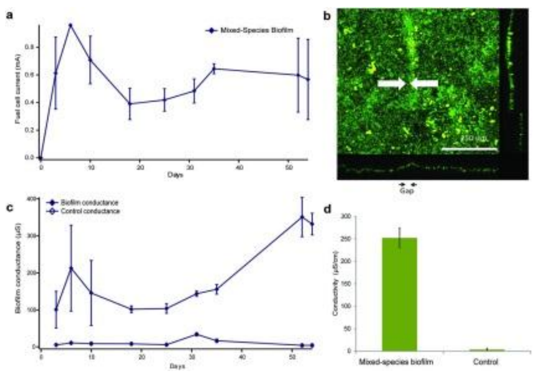

Figure 5. Response of MFC

VIII. RESULT & DISCUSSION

A novel "Eco-Friendly wastewater treatment solution using self-powered Microbial Fuel Cell" is proposed taking advantage of microbial fuel cells for energy harvesting and field-programmable analog arrays for very low-power signal processing. The Simulink model describes the sensor and controller subsystem. Sensor subsystem collects the information about the content of waste water and the level of waste water tank is controlled by controller subsystem. The system has several advantages, like having a high efficiency due to the direct conversion of the fuel energy into electricity, working at room temperature, having lower cost because of the type of fuel it uses. Use of FPAA and low power networking protocol makes the system highly parallelized computation, greater flexibility, ultra-low power consumption.[5] The hardware model of the network of sensors can be developed with the help of simulation results by using MFC, FPAA and advanced Micro controllers such as ARM or PIC series according to the requirement of the industrial scenario.

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