



KEMENTERIAN PENDIDIKAN TINGGI

PITRAM 2026

Pertandingan Inovasi Antara Asasi Malaysia

Extended Abstract Book



11 dan 12 APRIL 2026

Dewan Berlian

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KEMENTERIAN PENDIDIKAN TINGGI



MAJLIS DEKAN/PENGARAH ASASI
UNIVERSITI AWAM MALAYSIA

TERRA-VOLT

Ting Chai Lin, Christisia Jabariana, Fiona Chai Chiew Ngo, Noor Azie Azura Mohd Arif

Pusat Pengajian Pra Universiti, Universiti Malaysia Sarawak (UNIMAS), 94300 Kota
Samarahan, Sarawak

*tingchailin@gmail.com

ABSTRACT

The transition to renewable energy sources requires innovation that can directly integrate green technology into urban environments. This study introduces TERRA-VOLT, a hybrid green energy generation system that combines Plant-based Microbial Fuel Cell (P-MFC) technology and piezoelectric systems to produce electricity sustainably. This innovation utilizes two energy sources: kinetic energy from human movement and bio-electrochemical energy generated through the interaction between microorganisms and plant roots. The main issues addressed include dependence on fossil fuels, limitations in integrating renewable energy into public infrastructure, and the wastage of mechanical energy in high-traffic areas such as stairs and pedestrian walkways. Accordingly, the objectives of this study are to design an integrated hybrid system, evaluate the efficiency of converting mechanical and bio-electrochemical energy into electrical energy, and assess its potential applications in the context of sustainable cities. The system mechanism involves converting footstep pressure into electrical current through a piezoelectric layer, while the P-MFC generates electrons through the metabolic activity of microorganisms in the rhizosphere zone, which are then channeled into an external circuit. Preliminary results show that the hybrid integration improves energy output stability compared to single systems and is suitable for low-power applications such as LED lighting. In conclusion, TERRA-VOLT has the potential to serve as a micro-scale distributed energy model that supports SDG 7 (Affordable and Clean Energy) and SDG 11 (Sustainable Cities and Communities) through the development of smart urban infrastructure that continuously generates clean and environmentally friendly energy.

Keywords: Plant-based Microbial Fuel Cell, piezoelectric, sustainable energy, bio-electrochemical energy, hybrid green energy

1. INTRODUCTION

The growing urgency to find sustainable energy remedies, combined with the rising consequences of fossil fuel addiction and urban heat island influences, has added to the pressing requirement of novel, low-carbon technologies in urban areas. The city places create large volumes of untapped ambient energy that is not fully utilized, especially in high density pedestrian areas. Harnessing this wasted energy into workable electricity is an interesting prospect to aid the shift to sustainable and resilient urban infrastructure. TERRA-VOLT is suggested as a new hybrid energy system that can solve these issues with the combination of piezoelectric technology with Plant-based Microbial Fuel Cell (P-MFC) systems. This dual-energy is based on utilization of kinetic energy (human footsteps) and bio-electrochemical energy (plant-microbe interactions). Through the integration of these two complimentary sources of energy, the system increases the stability and reliability of energy production, surmounting shortcomings that are usually linked to isolated micro-energy harvesting technology.

The system is constructed as a system of tiles in the form of modules attached to concrete stairs as shown in Figure 1. The practical benefits of the use of moss as the biological element are that it is durable, requires low maintenance, and has a shallow root system, which can be incorporated into tight structural configurations. At the same time, piezoelectric transducers absorb mechanical energy that would be wasted otherwise (primarily in places with constant human activity).

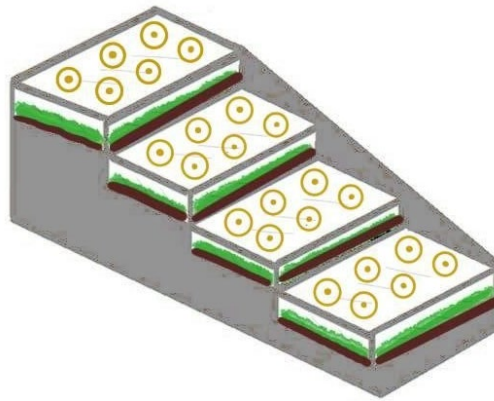


Figure 1. Hybrid Piezoelectric–P-MFC Energy Staircase Design

Although the concept is promising, the current system has restrictions in terms of energy output and can only be applied to low-power applications. However, its concept of integrating energy store and automated lighting systems underscores its relevance to practice in real life applications. As the electrode design is further optimized, achieving piezoelectric efficiency and scalability of the system, TERRA-VOLT has a high potential of becoming a viable solution in providing sustainable urban energy generation.

2. METHODOLOGY

TERRA-VOLT has been developed as a multi-layer hybrid construct that links together mechanical and biological energy harvesting. The system was digitally modelled and laboratory-scale testing was done to confirm the energy output of each component. The machine is designed in the form of a modular tile that is used on concrete stairs. Moss was chosen as the main biological agent of the Plant Microbial Fuel Cell (P-MFC) because of its low height (1-3 inches), high resistance to foot pressure, and low maintenance needs. The moss does not have deep root systems like other plants like the “Sedum” or the Portulaca that may damage concrete structures. Graphite was used as the electrode material (anode and cathode) since it was proved to enhance the current production by up to 39.5 percent relative to the conventional electrodes (Tang et al., 2011). The energy is then put into a capacitor in both sources. The circuit is automated by adding a light-dependent resistor (LDR). This enables the energy stored to automatically turn on LED lighting in the night.

Two different mechanisms are used in the methodology including piezoelectric and Plant-Microbial Fuel Cell. Piezoelectric transducers are located behind the tile. When mechanical pressure (footsteps) is used, electrical voltage is produced by converting the kinetic energy. When stepped by a person with weight of 50kg, this technology can produce approximately 0.555 mV. (Nworji et al., 2020). The frequency, body weight and amplitude also determine the voltage produced (Maiwa, 2016). But according to an experiment, 1 disk can produce approximately 2.5 V to 2.9 V with a few taps. The electrons emitted by the electrochemogenic bacteria in the degradation of organic matter released by the moss roots are captured by the P-

MFC. These electrons are made to move between the anode and the cathode by means of an external circuit to produce a continuous low-voltage current. The value of voltage varies in every plant. It was approximated that terrestrials plant can produce approximately 230mV (Kuleshova et al.,2022).

3. RESULTS AND DISCUSSION

Figure 2 shows a clear upward trend in voltage output from Monday to Thursday, indicating a progressive improvement in the system's energy generation performance over time. The voltage increases from approximately 0.65 V on Monday to about 1.0 V on Tuesday, followed by a slight rise to around 1.1 V on Wednesday, and reaching the highest value of about 1.4 V on Thursday. This gradual increase suggests that the TERRA-VOLT system may be experiencing stabilization or enhanced efficiency as it operates, possibly due to improved microbial activity in the P-MFC component.

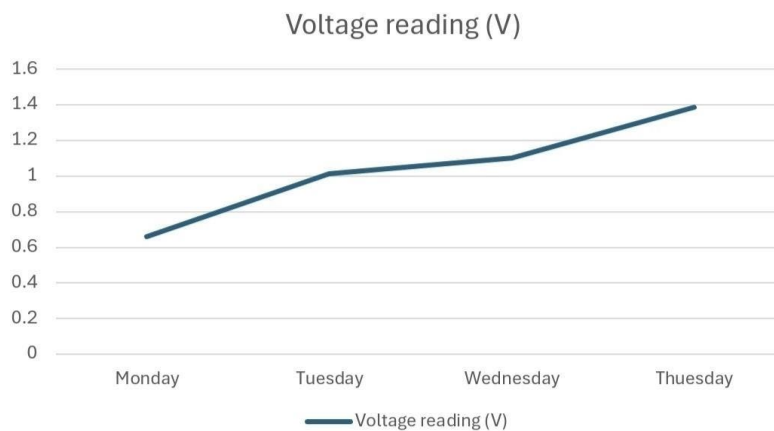


Figure 2. P-MFC Reading for 4 Days

Table 1 shows a consistent increase in voltage output across the four readings, rising from 2.562 V in the first measurement to 2.890 V in the fourth. This upward trend indicates that the piezoelectric transducer responds effectively to repeated mechanical stress, such as continuous footsteps or applied pressure. The gradual increase in voltage suggests improved energy conversion efficiency, which may be attributed to more consistent force application, better mechanical coupling, or stabilization of the piezoelectric material during operation.

Table 1. Voltage Generated by Piezoelectric Disc

Reading taken	Voltage (V)
1	2.562
2	2.606
3	2.731
4	2.890

4. CONCLUSION

TERRA-VOLT demonstrates a promising hybrid energy harvesting approach by integrating piezoelectric technology with Plant-based Microbial Fuel Cells (P-MFC) to convert both kinetic and bio-electrochemical energy into usable electricity. The system shows a consistent increase in voltage output over time, indicating improving performance and system stability, likely due

to enhanced microbial activity and sustained mechanical input from human movement. Despite these advantages, the overall voltage output remains relatively low, limiting its application to small-scale, low-power uses. Therefore, future improvements should focus on increasing voltage through optimized electrode materials, more efficient piezoelectric components, and series module configurations, alongside better energy storage and voltage boosting systems. With these enhancements, TERRA-VOLT has strong potential to be implemented in smart urban environments.

ACKNOWLEDGEMENT

The author gratefully acknowledges the Centre for Pre-University Studies for financial support and the Physical Laboratory for providing the necessary facilities.

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