Renewable Energy from Living Plants to Power IoT Sensor for Remote Sensing

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Abstract*: *Renewable energy which can be used to replace traditional energy sources from fossil fuel is in dire demand to protect the earth from the further negative effect of climate change resulting from mining or drilling of fossil fuel and its related pollution. There are various renewable energy sources available, however, there is none currently that does not compete for arable land in nature or land for food production to enable the installation of the renewable energy facility. Thus, in this research, it is proposed a novel type of electrical energy which can be harvested from living plants and coexist well with nature without competing for any arable lands and at the same time generate energy for human needs. Plants generate energy from photosynthesis, respiration, and intercellular activities, and this energy, although is minute, still can be harvested as a new potential energy source to power any ultra-low power sensor for remote sensing purposes. Thus, it is presented in this paper, a characterization of the specific setup condition to harvest optimum minimum 3V from living plants and a power management circuit that can further boost the energy to an optimum level to power a wireless IoT sensor for remote sensing purposes. It turns the living plant into a plant-based cell. As there is wide vegetation in forests, jungles, plantations, and agricultural lands on earth, the combination of this energy from the plants could be a promising source of new renewable energy to mankind as this vegetation can exist for both food and energy production while it does not compete for arable land for the installation of energy sources such as what happens in fossil fuel, solar or wind energy to create greener earth.

***Keywords*: Living plant, renewable energy, plant-based cell, remote sensing.**

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I. INTRODUCTION

During this era, the threat of climate change and global warming had brought serious catastrophes to humankind and all lives on earth which no longer can be ignored for its devastating effect covering intense drought [1], heat waves [2], warming oceans [3], melting glaciers [4], rising sea levels [5], and storms [6] that directly harm animals, destroy the habitats, and wreak havoc on people's livelihoods as well as creating harm to the communities, economy, and food production. These distressing threats are majorly caused by excessive usage of fossil fuel [7] and the vast environmental pollution which results from it. Thus, to overcome this dilemma, new growing energy demand for new sustainable, reliable, and renewable energy sources which are environmentally friendly [8] being sought after by various countries at various level of industry. Several common types of renewable energy are already implemented such as solar energy, wind energy, hydroelectricity energy, and bioenergy. With the usage of bioenergy being more widely demanded, the market share of bioenergy mainly on bioethanol, biodiesel, and bioelectricity is also on the increasing trend [9]. Nevertheless, bioenergy is not always sustainable, and it creates another problem where deforestation and competition for food production land to be replaced for bioenergy production [10] is also a crucial problem to be solved. Thus, it is always an ideal solution to find a bioenergy solution that is sustainable, renewable, has a clean conversion of energy without emission that cannot pollute the environment, and at the same time does not compete for arable land for food production or nature. The possible solution which can suit the criteria described above is the plant-based cell (PBC). PBC is a cell that harvests energy directly from living plants which converts the solar energy absorbed by the plants during photosynthesis and respiration processes into energy in the forms of bioelectricity which can be tapped out from the plants as usable energy by using suitable energy harvester medium such as electrodes. a usable energy by using suitable energy harvester medium such as electrodes.

Photosynthesis:
Solar energy + $6CO_2$ + $6H_2O$ ------> $C_6H_{12}O_6$ + $6O_2$

Respiration:
$C_6H_{12}O_6$ + $6O_2$ ----------> $6CO_2$ + $6H_2O$ + energy

Thus, the living plants can act as a source of bio-energy generator in PBC and this energy can be harvested as long as the plants remain alive and the ground is suitable for the plants' growth. In other words, the living plants must be able to carry out photosynthesis and respiration with ample water, light, and good air quality on a well-fertilized field to remain alive as a PBC to provide its continuous energy to power any remote sensor. Hence, this could enable the implementation of such technology for remote sensing to power IoT sensors on agricultural lands, plantations and in nature such as jungle and forest areas where a mutual benefiting and balance relationship can exist between energy production and arable land for food production [11] or nature wetlands [12].

Photosynthesis is a routine biochemical process used by plants to synthesize carbohydrate molecules from carbon dioxide, water, and light during the day. At night, respiration in plants converts the carbohydrate molecules into energy for the plant. These two processes which combine into a cycle generate the flow of electrons in the plant and can create a potential difference of as much as 50mV [13] between the leaves and roots. Furthermore, plants also generate electric potential signals from their intercellular processes in response to external stimuli [14]. Nevertheless, electrical conductivity differs among plants due to its complex conductive and insulated biological properties. [15]. It is discovered by previous researchers that the most promising plant that can generate a higher amount of electrical energy comes from the succulent family of plants such as the Aloe Vera plant [16]. Yet, the electrical energy generated by the plant can only be harvested to power a load if and only if a suitable energy harvesting setup with circuitry is used to transform the plant into a battery cell. Hence in this research, the main objective is to characterize the specific setup condition to harvest electrical energy measured to be higher than 3V and 1mA from the Aloe Vera plant. It also proposed a power management circuit that can store, boost and manage the energy to convert a plant into a plant-based cell. The whole paper is structured as; part 2, which explains the methodology covering the experiment setups condition and the design of the power management circuit, part 3, which discusses the results, and part 4, which concludes the paper.

I. Methodology

In this research, the first part is to characterize the optimum and feasible methods and setup conditions to harvest a higher amount of electrical energy from the plants via a feasible energy harvesting medium to be stored into a capacitor to reach a level of voltage at 3V or more. To do this, giant Aloe Vera plants are selected as specimens where each of the plants are measured to be around 50-60 cm in height and 50-70 cm in diameter and aged about 3 years old. The methodology starts with the identification of the best pair of anode and cathode electrodes which act as the feasible energy harvesting medium. A series of diverse electrode types are paired in combination covering copper, zinc, aluminum, and nickel are implanted into the leaf of the plant. A constant measurement is carried out to measure the generated output voltage and current from the plants. Then, an evaluation is conducted on finding the optimum distance between the electrode-pair embeds into the leaf to enable higher voltage generation while still sustaining lower internal resistance. The distance between the electrode pairs implanted into the leaf of Aloe Vera is varied to identify its effect on the harvested energy. Next, to maximize energy generation from a single plant, an investigation is carried out to find how many electrodes can be embedded into a single leaf of Aloe Vera to find how much maximum energy can be generated. Varying numbers of electrode pairs ranging between 1 pair to 6 pairs of electrodes are immersed into a single leaf to identify its effect on the energy harvested from the plant. Subsequently, the relationship of series and parallel connections of each 6 pairs of electrodes on each of Aloe Vera leaves are investigated to study the effect of the possible series-parallel connections on the amount of voltage and current collected from the plants under no-load conditions. Fig. 1 shows the setup constructed and the details steps carried out for this characterization process performed by the corresponding author in [17].

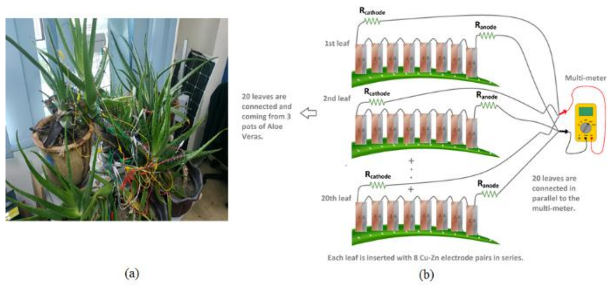

Fig. 1. Example of characterization setup arrangement (a) and simple schematic of the setup (b) to harvest electrical energy from living plants [17].

In the second part of the research, a suitable power management circuit that can manage the energy collected from the living plants is designed. Fig. 2 shows the proposed circuit designed by the corresponding author in [18]. The circuit consists of an energy storage system (ESS) and a voltage regulation system (VRS). The ESS comprises of an input capacitor C_{in} and a voltage detector circuit which is used to accrue enough energy from the Aloe Vera to attain a threshold voltage of 3.0 V and current of 1mA before intermittently triggering the circuit to boost the energy further to a higher level to power an IoT sensor for remote sensing. For the duration of the charging period of C_{in} towards 3.0 V, the voltage detector halts the operation of the VRS, the transmitter, and the load to ensure the energy harvested from the living plants are fully stored in C_{in} only. As the charge reached the threshold voltage of 3.0 V, it automatically discharged the energy from C_{in} to a rectifier circuit which consists of diode D_1, C_1, and C_2. The rectifier circuit is used as a smoothing filter to reduce any possible ripple that exists in the signal from C_{in} causes by the continuous charging and discharging process of the capacitor that may disrupt the boosting of the energy in the next step. After this process, the energy is transferred to the VRS for stepping up the voltage. The VRS consists of a self-oscillating boost converter linked to an LC tank circuit. It boosts the energy stored in capacitor C_2 into a higher voltage to be stored in the output capacitor C_{out}. The charge at C_{out} is then used to power a wireless transmitter module periodically to activate an IoT sensor remotely for remote sensing and environment monitoring purposes measuring the environment temperature and humidity.

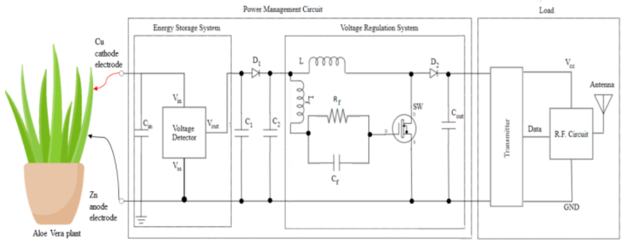

Fig. 2. Power management circuit designed to store, boost and manage energy harvested from living plants to power ultra-low power IoT sensor for remote sensing purpose [18].

I. RESULT AND DISCUSSION

From the research, the optimum electrode pair which can harvest maximum energy from the plant is discovered to be copper as the cathode paired with zinc as the anode. For the distance between the electrodes, it is found that the shorter the distance between the electrode pair the lesser the internal resistance between the electrodes. Hence, all the electrodes are maintained at a small distance of 1 cm between each. It is also found that by connecting a higher number of electrode pairs in series on a single leaf, a larger amount of voltage can be harvested from the plant. Hence, 8 pairs of electrodes are implanted into a single leaf measured approximately 20cm to 30cm each.

In addition, the author also observed that a series connection among the leaves increases the voltage while the parallel connection increases the current. Thus from the characterization of the PBC, the research set the specific setup conditions to achieve the desired voltage of 3V and current of 1 mA to be harvested from the plants by using copper-zinc electrodes arranged in the shortest distance of 1 cm between each electrode pair and to embed up to 8 electrode pairs on each leaf to increase the voltage up to 3.49 V while connecting 20 of the leaves in parallel to achieve a current at 1.1 mA as shown in Fig. 3 [17].

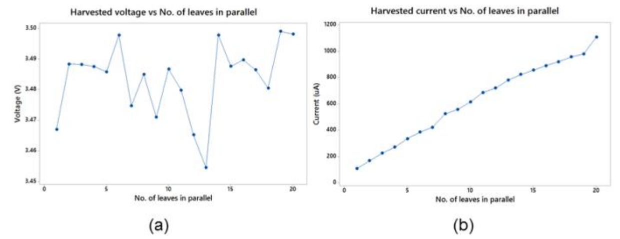

Fig. 3. Harvested voltage (a) and current (b) when varying the number of leaves connected in parallel [17].

The collected energy from the plants which is stored in the C_{in} capacitor is now directed to the power management circuit which contains the ESS and VRS to store, boost and manage the energy to an adequate level to switch on a TX-2B chip and a 315MHz RF transmitter module in an intermittent sequence manner to send a signal to turn on an IoT sensor to measure the surrounding temperature and humidity for environment monitoring purpose. The characteristic of the waveforms for input capacitor voltage V_{Cin} and output capacitor voltage V_{Cout} are portrayed in Fig. 4 [18]. It is shown that the energy harvested from the plants can charge the input capacitor C_{in} to a voltage level of 3.09 V maximum which then drops to 2.98 V as it discharged its energy to power the system as shown in Figure 3(a). This signifies that the collected energy from the plants inside the C_{in} is sufficient to reach the threshold level of 3V as per the objective of this research and is capable to trigger the circuit to channel the energy to the power management circuit for further boosting. The power management circuit then steps up the charge and stores it in the output capacitor C_{out}.

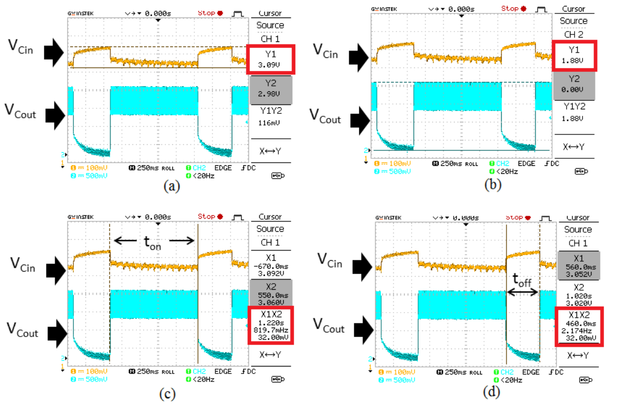

Fig. 4. The V_{Cin} and V_{Cout} waveforms when the power management circuit is connected to the transmitter load. (a) indicates the changes in V_{Cin} . (b) indicates the variation of V_{Cout}. (c) portrays the active transmission time, t_{on} when the transmitter load is triggered. (d) portrays inactive transmission time, t_{off} when the transmitter load is not triggered [18].

This scenario creates an output voltage of 10.9V V at the output if it is under a no-load condition which is sufficient to trigger the transmitter load as shown in Figure 3(b). If it is connected to the transmitter load, the output voltage will be consistent at 1.88V. The V_{Cout} maintains at 1.88V for the duration ton of 1.22 seconds before C_{out} fully releases its energy to 0V as indicated in Figure 3(c). Finally, the C_{in} automatically recharges back to 3.09 V for the duration toff of 460 ms to reactivate the transmitter for the next cycle as shown in Fig 3(d). Therefore, this process will persist in a fixed manner to activate the transmitter load for a period of 1.22 seconds to send a signal to the receiver circuit which contains the IoT sensor and deactivate the transmitter load for a period of 460ms to enable the recharging of the C_{in} by the living plants as shown in Fig. 5 [18]. This result shows that it is feasible to tap the energy from living plants as a novel type of renewable energy to power ultra-low-power devices such as IoT sensors as long as the plants remain alive in their ecosystem.

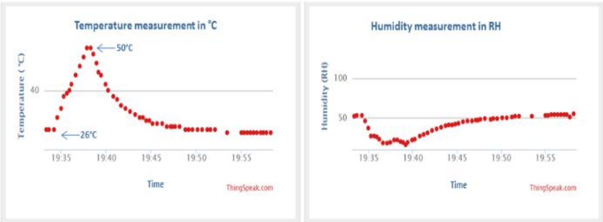

Fig. 5. Data log of the temperature and humidity measurement performed by the DHT11 sensor activated via the power management circuit and a PBC in intermittent manner shown as red dots for remote sensing purpose [18].

I. CONCLUSION

From this research, it is found that an appropriate amount of electrical energy can be harvested from living plants via a specific characterized setup condition in combination with a power management circuit to become a plant-based cell (PBC) to power an ultra-low powered wireless device or IoT sensor. This proves a significant finding that energy from plants can be a potential source of renewable energy to be applied on remote sensing sensors. This concept of the living plants acting as a battery source can offer substantial impact in IoT application to power low power consumption IoT sensors which are remotely installed in distant areas such as in large, industrialized agriculture lands and plantation estates for smart farming monitoring purposes or in the nature such as in deep jungle or forest for environment monitoring purpose without the needs for humans to replace the batteries for the IoT sensor in the future.

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