A STUDY OF ENERGY SCAVENGING STRATEGY IN A TAPPING TREE POWER

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ABSTRACT

Energy harvesting has become one of the newest research attraction for both academic and industry fields. The energy is captured from external sources (thermal, wind, solar, vibration and hydrodynamic) and the energy source for energy harvesters is present as ambient background and it is free. The energy can be harvested in term of sensors or direct applying which depends on the source applied to. One of the energy harvesting topologies is from tapping tree which is new topology that can be applied direct to the tree by inserting electrode into the tree while the other is into the surrounding soil. This project introduces a method for the energy to be harvested from a tree, where the voltage obtained is conducted to three types of trees (Palm, Agrawood, and Palm Oil). Both type of electrodes and *pH* value of the surrounding soil are considered in order to get maximum voltage. Furthermore, the depth of the electrode inserted and the height from the surrounding soil play a role for voltage variation. The maximum voltage can be obtained is from (Al Alloy with Al) electrodes, at neutral *pH*, dry mositure and in Palm Oil Tree which is almost 0.8V ~ 1.2V. However, at such small energy from tree source, converter is required to increase the power. Boost converter contains of BQ25504 IC is applied to increase the voltage from small input to 3V ~ 4V. As well as, buck converter with TPS62231 IC is introduced for the output voltage of the boost converter and can be applied for small voltage as 1.8V. Simulation using Tina software simulate the converters mentioned and get better results for the energy harvested with battery charging system and energy storage. Field test is conducted with the selected converter to insure the power observed from the plant. In addition, this work has been taken to enhance the growth of energy harvesting from small sources and to go further for nature sources that has a high impact for low applications in the future.

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LIST OF SYMBOLS AND ABBREVIATIONS

Al	-	Aluminum
C	-	Carbon
Ca	-	Calcium
$C_6H_{12}O_6$	-	Glucose
$C_6H_{10}O_5$	-	Cellulose
CO_2	-	Carbon Dioxide
$CO(NH_2)_2$	-	Urea-based fertilizers
CO_3^-	-	Carbonate
Cu	-	Copper
d	-	Parasitic Affect
d_g	-	Damping
e^-	-	Electron Ion
Fe	-	Iron
f_{res}	-	Resonance Frequency
g	-	Gram
g_{air}	-	Thermal Conductivity of the Air
g_{te}	-	Thermal Conductivity of the Thermoelectric Material
H^+	-	Hydrogen Ion
HH	-	Hodgkin-Huxley
HCO_3^-	-	Bicarbonate
H_2O	-	Water
k	-	Spring Constant of the Suspension
K^+	-	Potassium
m	-	Moving Mass
μ	-	Micro Ampere

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CHAPTER 1

INTRODUCTION

1.1 Project background

Over the past centuries, world economic growth is inseparable to the ever-expanding use of hydrocarbon energy sources such as petroleum, coal and natural gas. The trend of global economic currently hinges on increasing rates of production of these fuels. However, petroleum oil and gas, and coal are non-renewable energy resources that will cease in the future. The ever rising cost of fossil fuels not only causes inflation but also hinders the economic growth as the production of goods and cost of shipment are dependent on the cost of fuels [1]. In the view of the consequences of the normal energy sources to the world nowadays, so both academic and industry have much interest into the green energy by renewable energy [2,3,4].

Energy harvesting is the process by which ambient energy is captured from external sources (thermal, wind, solar, vibration and hydrodynamic). Energy harvesters provide a very small amount of power for low-energy electronics [5]. The energy source for energy harvesters is present as ambient background and it is free. The energy can be harvested in term of sensors or direct applying which depends on the source applied to. Energy harvesting devices converting ambient energy into electrical energy have attracted much interest in both academic and industry.

Due to this new field of harvesting energy from such sources which generate a green energy that replaced the normal sources, researchers are encouraged to further deep study in this field [6]. This small source of the energy is going to be implemented in many applications such as (fire alarms, tinny cameras, digital devices …etc). Today, industry is advocating a suite of new and emerging technologies energy harvesting transducers, thin film batteries, micro power integrated circuits, and Nano power microcontrollers coupled with star network topologies, to address the pressing challenges of energy harvesting operation.

It has been demonstrated that measureable, albeit small, electrical potentials exist in various common plants and trees. These voltages have recently been attributed to a pH difference between xylem tissue and soil content, types of the trees with chemical and environmental characteristics and types of electrodes that used to measure the potential of xylem and soil are introduced to harvest the energy from the trees, even though, it is so small. By using the properties of living trees, a natural source of energy is tapped to power electronic circuits, eliminating the need for conventional batteries [7]. This energy source could foster the development of new applications for electronics and expand the number of locations in which they operate. Power electronics is implemented in such fields to increase the voltage harvested from the trees which can be used for more applications. However, in this field the converter which can be implemented should be critical and flexible for the small voltage produced from the trees.

This work is going to propose some fundamental procedures to harvest weak electric energy from plants with different conditions and tests. The difference of pH between the xylem tissue and soil content of the tree, types of tropical trees that the tests can be conducted to, dry and wet moisture and types of electrodes used are going to be studied in this project to deliver a better voltage. These voltage differences are used in attempts to monitor plant activity and hypothesized to be due to various sources, most prominent of which appears to be the ‘‘streaming potential’’ mechanism , which is itself related to transpiration and sap flow. The harvested energy is going to be boosted using a boost converter to generate high output energy connected with a buck converter for low applications. However, the output power of trees may be a more significant physical quantity to reflect the magnitude of the electricity compared with the voltage or the current separately. This work is introduced to find more comprehensive relationships between the bioelectricity in trees and their surrounding environmental parameters.

1.2 Problem statements

In order to get an energy from the plant (tree), a few harvesting methods have been done in the last decade. The observation from these different harvesting methods is that, energy harvesting is a proportional to the characteristics of the tree itself and that what at least going to increase the voltage harvested by looking into pH, Moisture, Type of electrodes that inserted in the tree and the surrounding soil. As well as, the type of tree with the weather play a big rule which gives the tropical trees high impact for voltage potential difference.

While the voltage is too low, varied by time and not sufficient enough, there should be a way to increase it and make it constant in order to get a useful and applicable energy. Sensitivity and complication of the converter design for such small sources are considered due to the reduction of the voltage and current by the effect of the components and environment. However, the current is that too low as well which makes the application of the output energy harvested from the tree not applicable in most cases. This work is going to study and design a scavenging method that could be more useful for some of the Nano electronics such as sensors. Such study give an opportunity to use a natural source for small applications that can replace the limited sources such as batteries.

1.3 Project objectives

The major objective of this project is to scavenge energy from a tree
Its measurable objectives are as follows:

a) To explore the basic characteristics of the living tree with regards to energy transfer.
b) To propose an energy harvesting method for a maximum voltage extraction from selected living trees.
c) To recommend a proper converter for the harvested energy producing a useful power.

1.4 Project scopes

This project is concerned with the scopes as following:

a) Study the characteristics of the living trees in term of *pH*, moisture, electrode types, and types of trees that can conduct the test on.
b) The input voltage to the converter is to be ranged from 300mV to 1.5V due to the small source of the plant which can produce an output of 2V to 5V from the converter.
c) The output power obtained from this study shall be small due to low voltage and current which reduce the possibility of the power usage in the applications.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Energy is harvested from a tree in different ways movement, solar or Electric Potential Difference (EPD) between the tree and its surrounding soil. In this project, the energy is harvested from a living tree and this chapter discusses many topics that is related to the Tree characteristics and environment that could affect the energy harvesting. In 2.2 the study of the characteristics of the tree is described. However, 2.3 discuss the energy transfer and the types of tropical trees, as well as, in the *pH* difference of the tree and its surrounding soil is described in 2.4, types of electrodes that possible to be used in 2.5. There are different approaches for energy harvesting which mentioned and explained in 2.6 and the various harvesting energy methods from previous work are introduced in 2.7.

2.2 Tree architecture and characteristics

The tree has a full life cycle which depends on the environment and structure that can affect the tree growth and life. The necessity of the tree life is summarized in six key requirements mentioned in 2.2.1. Followed by the tree parts and Photosynthesis and Respiration functions that can affect the growth of the tree in 2.2.2 and 2.2.3. In term of the type of the trees, palm and non-palm trees are described in 2.2.3.

2.2.1 The necessity of tree life

The following are the six key requirements for trees.

1. Sugars supplied by photosynthesis. Air and water are chemically recombined to form glucose, which stores energy captured from the sun. Oxygen is a byproduct.

2. Water is required for most metabolic activities and serves as a vehicle to carry materials through a tree. A large tree may move as much as 50-100 gallons of water on a hot summer day.

3. Nutrients. It's not how much of a particular nutrient exists in the environment, it's a matter of how available the nutrient is to the tree. For example, the atmosphere is largely composed on nitrogen, but trees can only use nitrogen in forms that have been altered by soil bacteria and other organisms. The major chemical elements used by plants are: carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulfur, calcium, iron, and magnesium. It might be remembered by a jingle formed using the abbreviations for these elements, Hormones and enzymes. These chemicals are critical in the controlling the timing and activity of physiological processes. They are usually produced in the roots or leaves. However, it is not thinkable of plants having "hormone" deficiencies, but they are critical to the survival of any organism, including trees [8].

4. Mycorrhizae. Pronounced *"my-core-HI-zee"*, this a group of beneficial fungi associated with most tree roots. It represents an ecologically symbiotic relationship where the fungi receive food from the tree and the trees receive greatly enhanced nutrient and water absorption. Mycorrhizae will also protect tree roots from other invading fungi. There tends to be very specific species relationships between fungus and tree.

5. Environmental factors. A tree needs an appropriate mix of precipitation, temperature, sunlight, and soils in order to thrive. These factors need to occur at the right time. Each tree species has a different set of environmental requirements. Changing climate will lead to changing environmental factors, which can lead to changes in forest ecosystems [8].

2.2.2 Parts of the tree

The parts of the tree that have the high impact for the growth of the tree is explained and listed in Table2.1.

Table 2.1: List of the Tree Parts

Leaves	Broad-leaf or needles, the primary site of photosynthesis and the production of hormones and other chemicals
Twigs & Branches	Support structure for leaves, flowers, and fruits. Arrangement varies from species to species by growth strategy. Can sometimes have photosynthetic tissues. Two kinds of growth tissue, at the twig tips and cambium under the bark.
Crown	The upper region of the tree made up of leaves, twigs, branches, flowers, and fruits. Crowns of many trees are collectively called the "canopy".
Flowers	May have both female & male parts, or only one or the other. Some trees are either all female or all male (e.g. aspen). Flowers may have a full complement of flower parts, or may be missing certain elements. Conifers do not have petals and associated structures.
Fruits & Seeds	All trees have seeds. Most trees have seeds inside fruits. Most fruits are NOT edible, but many are, such as apples, cherries, nuts, etc.
Trunk or Bole	Most definitions of trees include a "single bole" concept, but many of our tree species sometimes occur with multiple stems. The main functions of a trunk are transport and support. The trunk has growth tissue called cambium.
Bark	A highly variable tree part. The main function is to protect the sensitive living tissues from weather and predation (by animals, insects, fungi, etc.)
Roots	Roots serve two main functions; collection of nutrients and water, and anchoring the tree. Roots also have growth tissue, bark, and wood. Like twigs and branches, roots have two kinds of growth tissue, at the twig tips and cambium under the bark. Fine root hairs are where absorption occurs

2.2.3 Photosynthesis and respiration of a tree

All trees (most plants) both photosynthesize and respire. Photosynthesis is a process unique to green plants and produces sugars, which are "tree food". Figure 2.1. shows how the Photosynthesis and Respiration of a Tree can be expressed chemically.

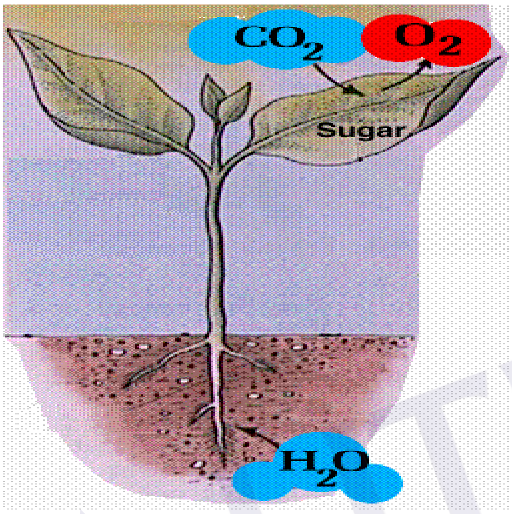

Figure 2.1: Overview of Photosynthesis and Respiration of a Tree

Photosynthesis can be visualized in a couple ways.

- Sugars produced are analogous to a "solar battery." The sugar is a chemical way to store energy for future use (metabolism).
- Trees produce their own food. We call "tree food" sugar. These sugars are not usually of the chemical structure of refined sugar and don't usually taste sweet, but the basic organic components are similar.

The basic chemical formula for photosynthesis is:

Inputs: 6 carbons, 24 oxygen, 24 hydrogen

Outputs: 6 carbons, 24 oxygen, 24 hydrogen

Note: Inputs and outputs must balance in a chemical equation. In other words, what goes in, must come out.

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

Carbon Dioxide + Water + Energy ⟶ Glucose + Oxygen (2.1)

Energy is stored in the bonds of sugar molecules such as "glucose" and "fructose." Oxygen is a by-product of photosynthesis. The oxygen molecules produced by photosynthesis are not necessarily the same oxygen molecules the plants use for respiration [9].

These sugars are later broken apart and the released energy drives a variety of metabolic actions. The process of breaking down these sugars is called "respiration" It is the same process that animals (and people) use when they respire (not to be confused with "breathing"). So, either the plant uses its own stored sugars, or some animal (or decomposer) consumes the plant, and uses the stored sugars. In either case, the sugars are valued chemicals because they contain energy, as well as important elements (carbon, hydrogen, and oxygen) [8].

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Glucose + Oxygen ⟶ Carbon Dioxide + Water + Energy (2.2)

The tree uses its photosynthetic for (glucose and fructose) in many applications in addition to energy storage and subsequent release.

- Cell walls are made of cellulose ($C_6H_{10}O_5$). Cellulose shows up in many plant parts in combination with other molecular elements. It is not only vital to the tree, but is also a very important material for people (wood, lumber, fuel, fibers, chemical extracts, energy, etc.).

- Production of carbohydrates such as sugars ($C_6H_{12}O_6$), starches ($C_6H_{10}O_5$), vegetable ivory (form of hemicellulose), pectins (for jellies, jams), gums (used in many products, including food products).

- Many fats and oils are common plant products (some of which come from trees). These are compounds of mostly carbon, hydrogen, and oxygen, but with lots more molecules of each.

- Proteins are formed when the *C*, *N*, *O* elements are combined with nitrogen, sulfur, and sometimes phosphorus. Certain proteins used by animals (and people) can only be obtained by ingesting plant products.

- There are numerous secretions produced by trees (and other plants) that are important to people, such as clove oil, cedar oil, resins, pitch, gums, balsam, camphor, natural rubber, pigments, drugs (legal and illegal), etc.

A note about energy allocation within trees. Energy is not a limitless resource for trees. A tree will typically move energy according to these priorities. As energy in the form of glucose becomes limited, a tree will begin to reduce resources spent beginning with the lowest priority. As you can see, a tree with a diminishing crown will become more vulnerable to insects and diseases rather quickly. That's one reason why foresters are so keen to maintain a vigorous growing environment [8, 9].

1. Maintain respiration of all parts.
2. Produce fine roots and leaves.
3. Produce flowers and seed.
4. Extend branches and roots.
5. Store energy rich chemicals.
6. Add wood to stem, roots and branches.
7. Create anti-pest chemicals for defense.

The tree zones which are roots, trunk and crown are shown in Figure 2.2 which explain the tree growth generally.

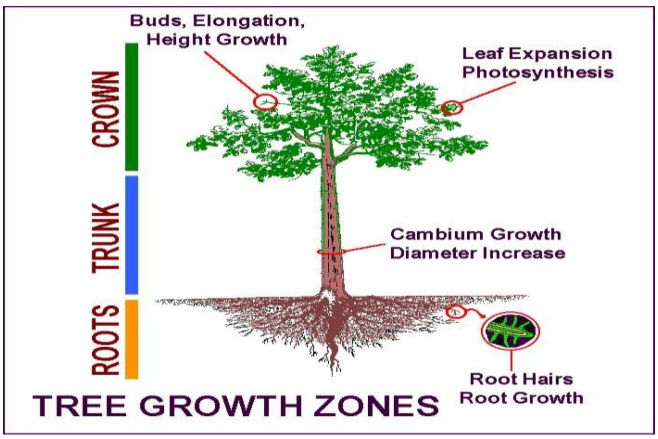

Figure 2.2: Overview of Tree Growth Zones

In photosynthesis, the plant uses water and nutrients from the soil, and carbon dioxide from the air with the sun's energy to create photosynthesis [9]. Oxygen is releases as a byproduct as shown in Figure2.3. Table2.2 differentiate the function of Photosynthesis and Respiration that is happening in the plant.

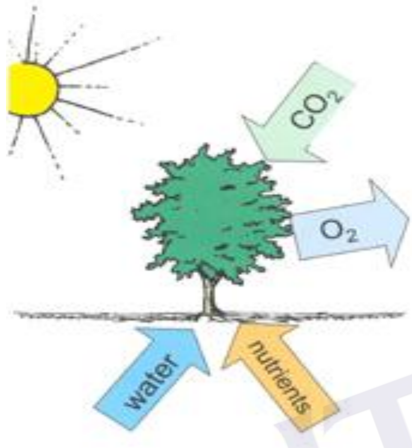

Figure 2.3: Necessties of Tree Growth

Table 2.2: Comparison of Photosynthesis and Respiration

Photosynthesis	Respiration
• Produces sugars from light energy • Stores energy • Occurs only in cells with chloroplasts • Releases oxygen • Uses water • Uses carbon dioxide • Requires light	• Burns sugars for energy • Releases energy • Occurs in most cells • Uses oxygen • Produces water • Produces carbon dioxide • Occurs in dark and light

2.2.4 Palm and non-palm tropical trees growth

Palms rarely get thick with age. In some palms, the very base may show a swelling that is a result of new roots pushing out of the trunk near the ground. Broad-leaved trees, like mango, avocado or live oak, and pine trees have thin twigs and thicker branches and a large trunk. Old branches and trunks thicken with age. The overview of the palm and non-palm trees are shown in Figure 2.4 which explains the function of each part in term of nutrition and support [10].

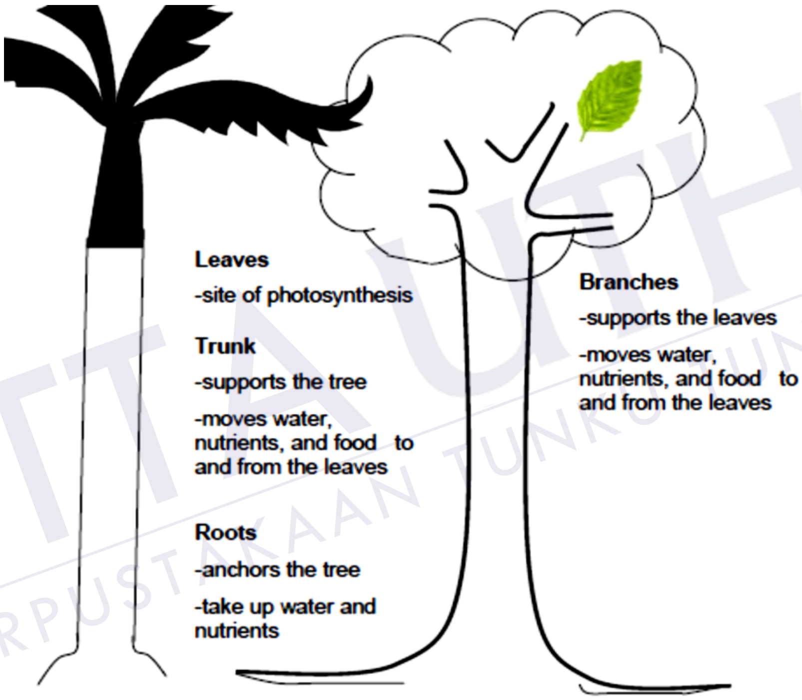

Figure 2.4: Palm And non-Palm Trees

In broad-leaved trees the center is woody and in the very center is a pith. When rings are present, the age of the branch or trunk can be determined by counting the yearly growth rings. However, some tropical broad-leaved trees grow all year and don't have growth rings such as ficus, mango, and avocado. Figure2.5 shows the layers of the broad-leaved trees for more understanding of the structure of these kind of trees.

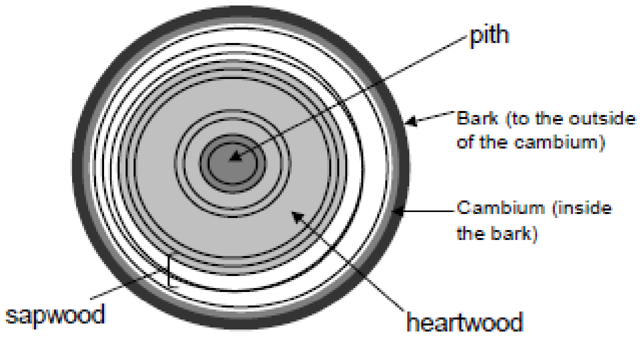

Figure 2.5: Layers of Broad- Leaved Trees

Trees grow wider by producing new wood. The new wood grows from a thin soft layer of dividing cells, called the cambium (X), that covers the outside of the wood and is protected by the bark to the outside of the trunk. The wood (xylem) gives the tree strength and transports water from roots to leaves. The inner bark (phloem) transport sugars and amino acids produced by the leaves down to the roots. The cambium produces new inner bark to the outside. When a tree is cut, the wood (xylem) and the bark (phloem and cork) are recognized as in Figure 2.6.

Figure 2.6: Cross Section of Xylem and Phleom

Pencil points to the cambium which is split in this dried log. Dark bark is to outside and wood (both sapwood and heartwood) is to the inside. The inner bark is protected by the outer bark and cork. Both inner and outer bark can be peeled from the trunk because the cambium is a soft and delicate layer that can be easily split [11].

Bark of gumbo limbo (*Bursera*).
The bark is smooth, reddish in color and the thin layers of cork peel off in thin sheets.

Bark of live oak
The thick bark is deeply fissured and makes a good surface for the resurrection fern to grow on.

Figure 2.7: Overview Bursera and Oak Plants

Birch bark for Indian canoes and cork for wine bottles can be removed because of the fragile cambium layer. A few bottle palms and even the royal palm have swollen regions of the trunk due to localized cell enlargement but not due to new vascular tissues (xylem and phloem). These barks of Oak and Bursera are shown in Figure 2.7.

2.3 Plant energy transport

Plants are classified as autotrophs because they manufacture their needed nutrients by photosynthesis, converting carbon dioxide and water to sugar fuels with the addition of energy from the Sun. In times of rapid photosynthesis, the main product is glucose, but it is usually converted to the larger sugar sucrose. These sugars that are synthesized in the leaves must be transported to other parts of the plant. Other structures in the plants such as roots and flowers require the energy but cannot manufacture it. Also, sugars may be stored in the roots and stem [12].

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