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Analysis on Plant Bioelectricity to Generate Power from Living Plants

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Abstract- *The paper reveals some fundamental investigations which are related to the potential difference of the plants. The main aim of the experiment was to harvest electricity from the living plants and make it useable for practical applications. The energy from the living plants has been harvested here by embedding electrodes into the plants. Comparing to the many electrode pairs which has generated highest voltage difference were used for further investigations. Other investigations including voltage profile against electrode spacing, source resistance, tree networks, embedding electrodes to the tree at different radius etc. has been tried to co-relate. This experiment also includes the measurement of power embedding the electrodes in the trees for long time. By this way, the probability of getting stable power from the living plants has been analyzed.*

Keywords: renewable energy, plant bioelectricity, trans-membrane potential, source resistance, tree networks.

1. INTRODUCTION

In physics, energy means the ability for doing work. Despite defining energy as the 'ability to do work', natural scientists rarely comment on the kind of work that is thereby enabled or on how this change. The energy source can be divided into two groups. One is renewable energy and another is non- renewable energy. Non-renewable energy includes Petroleum products, Hydrocarbon gas liquids, Natural gas, Coal, Nuclear energy etc. On the other hand, the renewable energy includes sunlight, wind-power, rain, waves, geothermal heat, bioelectricity etc. But the sources of non-renewable energy are continuously decreasing. People are burning wood more rapidly than it is grown for increasing population of human being. The present generation already facing the environmental crisis like as 'greenhouse effect' for excessive use of the non-renewable energy source. So, it is now mandatory for us and the future generation to change the direction of dependence on energy source and turn it towards the 'renewable energy'.

Nowadays, one of the significant renewable energy is "Biotechnology". In 1791, a renowned scientist 'Galvani' first introduced the world about the bioelectricity. But at first electrical phenomena in the living plant "Dionaea muscipula" was discovered by J. Burdon Sandersonat in 1873[1]. Researchers such as Calkins,Victoria Flexer and Nicolas Mano harvested electricity using the method of photosynthesis of living plants[2,3]. Other researchers such as Choo Ying Ying, Carlton Himes, Yamaguchi and Hashimoto also produced power from plants using metabolic energy[4-6].

The main concept of plant bioelectricity is the trans-membrane ion exchange process, photosynthesis process, water & nutrient uptake through the roots. A living plant takes the necessary nutrient from soil through roots in the form of ion. So, power can be generated from the living plants by electrolysis process. There are various reasons for voltage gradients in plant. The processes of photosynthesis, bulk fluid flow, chemical diffusion, water and nutrient uptake through the roots all are responsible to develop the voltage gradients within plants[5].

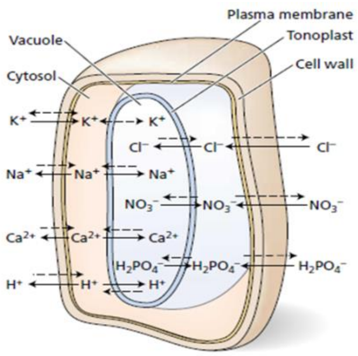

Fig.1: Trans-membrane potential in a complete cell[7]

Some fundamental investigations are presented in this paper to harvest electricity from living plants. To do this, selected electrodes were embedded into the living plants. Some multiple tests has been conducted to correlate the effect on voltage according to the electrode spacing, source resistance, tree networks, electrode embedding at different radius of the tree.

2. METHODOLOGY

Total procedure of the experiment is described briefly. The total experiment can be divided into six steps. These are- selection of living plants (Energy Source), electrode pair selection, electrode spacing, source resistance, embedding electrodes to the banana tree at different radius, tree networks etc.

2.1 Selection of living plants

There are different types of living plants around our environment. From the plant diversity in the locality, we have to choose that plants which are available in surroundings. If the stem of the plant is so hard and does not contain so much moisture, it will be difficult to embed the electrodes to the plants. So, the selections of living plants were based on easy embedding and stem moisture content.

2.2 Electrode pair selection

Since there are many types of electrodes available, the best pair that produces the highest power output has to be determined prior to any further optimization attempts. In the present work, material of electrodes has been selected which are locally abundant and easily available[8].

2.2.1 Voltage measurement by embedding electrode at the stems and roots

After selecting the living plants and electrodes, the selected electrode pairs were embedded to the plants. Then electrolysis process has been occurred into the plants due to the attendance of anion and cation. A multimeter has been used to measure the voltage across each electrode pair for 60 minutes interval of 2 minutes. Then a graph has been plotted to compare the capability of electrode pairs.

2.3 Electrode spacing

Spacing between the electrodes may affect the trees source voltage. So, an experiment has been conducted to observe how varying the vertical spacing between nails and their distance from the ground changed the output voltage. There were two separate tests that were conducted for the observation. These are-

1st observation: An electrode was kept stationary at the bottom side near the ground and other electrode was set at various position to the vertical spacing of the trunk of the plants. At first, both electrodes were set up at the horizontal position that means there are no vertical spacing between the electrodes and potential difference was measured at that position. Then the spacing were increased at the vertical position chronologically keeping one electrode stationary and voltage difference were measured at each point. A voltage vs. electrode spacing graph was drawn to correlate the voltage difference according to the electrode spacing.

2nd observation: one electrode was inserted at the soil and another electrode was inserted equally spaced at the vertical position. Then the voltage differences were measured where the ground voltage is always be zero. Then a graph of voltage vs. electrode spacing was drawn.

2.4 Source resistance

The internal resistance of a tree-based power supply is an important performance metric as it limits the useful power available to the electronics. To quantify the available power of the tree-based power supply, the voltage output of a tree for a varying resistance were measured [5]. For the experiment, one electrode was inserted at the trunk of the plant and other was at ground. Resistances were gradually increased between them. Then the voltage differences were measured according to the resistance. This data has been used to plot a graph of voltage vs. resistance.

2.5 Embedding electrodes to the banana tree at different radius

In this experiment, a electrode was scaled from 0 to 5 centimeter interval of 0.5 cm. This electrode has been embedded carefully. Embedding length has been increased by 0.5cm per penetration. The voltage was measured at each step.

2.6 Tree Networks

For better application, a larger useable voltage level and high current flow is needed. For higher voltage levels and higher current flow, multiple plants of the same species were connected and tested by running wires between them. To increase the voltage levels multiple plants were connected in series, where negative terminal of one plant were connected with the positive terminal of the other plant. Then the series connection was set in parallel position. The Fig.2, given below, shows the whole connection for increasing voltage and current. The total connection has been drawn below in Fig.2–

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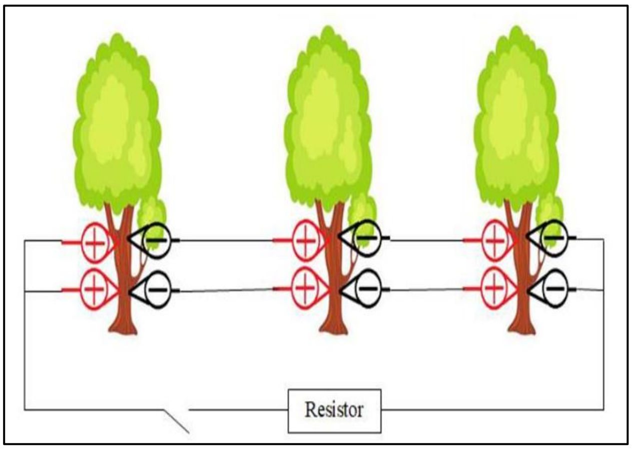

Fig. 2: Total circuit connection for increasing voltage and current

3. DATA COLLECTION & RESULT

3.1 Selection of Energy Source and Electrode Pair
The selection of living plants has been done based on the plant that have high steam moisture content and the electrodes can easily be embedded into the plants. In this experiment, two common and easily available plants "Banana" and "Aloe-vera" were used. In this experiment, three electrodes are taken in consideration. These are Copper (Cu), Zinc (Zn), Aluminum (Al). Using these metal bodies three electrode pairs can be formed. These are (Cu-Zn), (Cu- Al) and (Zn-Al).

Fig. 3.1: Electrodes used in the experiment

For the experiment, the three electrode pairs were embedded into the selected plants individually. Then the voltages were measured using the digital multimeter for 60 minutes interval of 2 minutes. Using the collected data a graph has been plotted where time in minute is in the X axis and measured voltage in volt is in the Y axis. In Fig.3.2, the graph has been found using the open circuit from the banana tree.

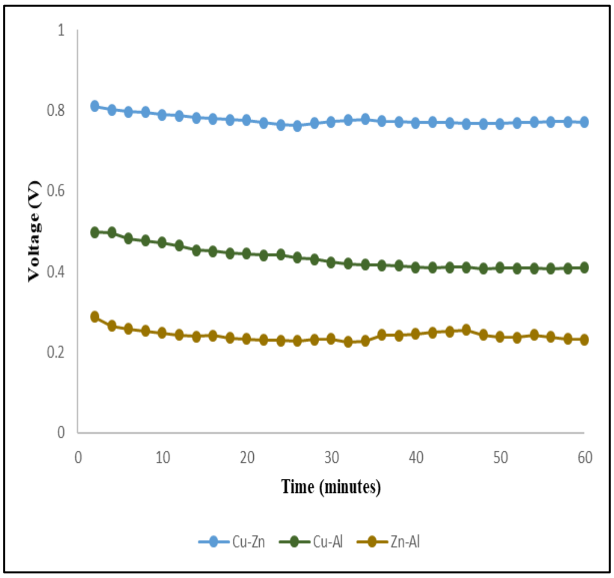

Fig. 3.2: Voltage profile over time obtained from banana tree using different pairs of electrodes

In this experiment, it indicates that Copper Zinc electrode pair produces highest voltage approximately 0.8V. In the reference [8] also, the Copper-Zinc electrode pair has generated highest voltage approximately 0.913V which is higher than the experiment. Other used electrode pairs in the experiment such as Cupper Aluminum electrode pair has produced voltage approximate 0.48V. In the reference[8] for Copper Aluminum has generated 0.48V approximately which is lower than the experiment. The Zinc-Aluminum electrode pair has generated voltage nearly 0.3V on average. The reference[8] indicates the produced voltage for Zn-Al electrode pair is nearly 0.38V. Applying the same experimental procedure on aloe- vera a graph has been plotted which is shown in Fig. 3.3 where voltage is at vertical axis and time is at horizontal axis.

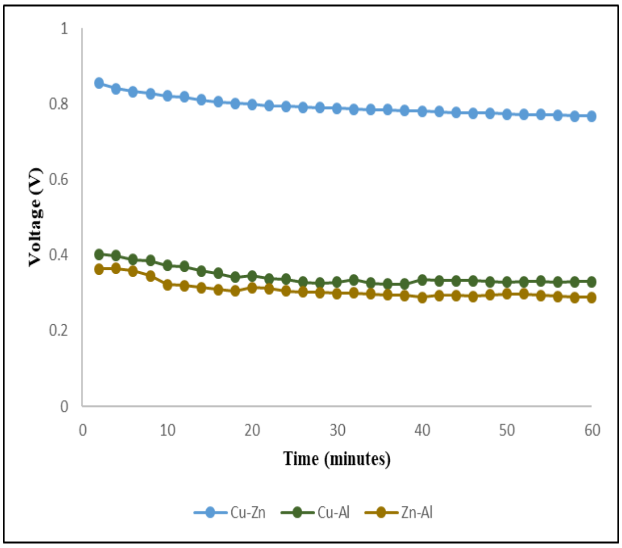

Fig. 3.3: Voltage profile over time obtained from Aloe-vera using different pairs of electrodes.

Fig.3.3 shows that different electrode pairs in aloe vera have been used to generate voltage using open loop circuit. A digital multimeter has been used to measure the voltage. In the experiment, the Cu-Zn electrode pair produces the highest potential difference approximate 0.81V. But from the reference[8], the generated voltage for Cu-Zn electrode is approximate 0.945V which is higher than this experimental voltage. Other electrodes such as Cu-Al produces 0.33V and Zn-Al produces 0.31V approximately in the experiment. On the other hand, the approximate voltage in the reference[8] for Cu-Al is 0.56 and Zn-Al is 0.45V. From above data and the graphs it's clear that Cu-Zn electrode pair is generating the highest power than other electrode pairs. So, Cu-Zn is best choice as electrode pair for generating the power from the living trees. Reference[8] for both experiment also indicates that Cu-Zn electrode pairs are generating highest potential difference both in banana tree and aloe-vera. So, there are no confusion to select the Cu-Zn electrode pairs for this experiment.
Comparing the experimental data of the Fig.3.2 and Fig.3.3, it can be seen that the output voltage obtained from banana tree and aloe vera using Cu-Zn electrode pair 0.8V and 0.81V. From the experiment, it can be

shown that the selection of electrode pair and the types of plant can influence the magnitude of potential difference.

3.2 Effects of Electrode spacing

3.2.1 Observation 1 result:

1st observation has been applied to the banana tree only. As aloe- vera is a small plant, it has no sufficient space for the experiment. In the 1st observation Zn electrode has been fixed at the lower level of the banana tree and Cu electrode as varying distance from down to top along vertical axis. The voltage has been measured using multimeter.
A graph is plotted which is shown in Fig.3.4 using this value found from the experiment. Voltage is at the vertical axis in volt and distance in centimeter between the electrodes is at the horizontal axis. The graph is given below–

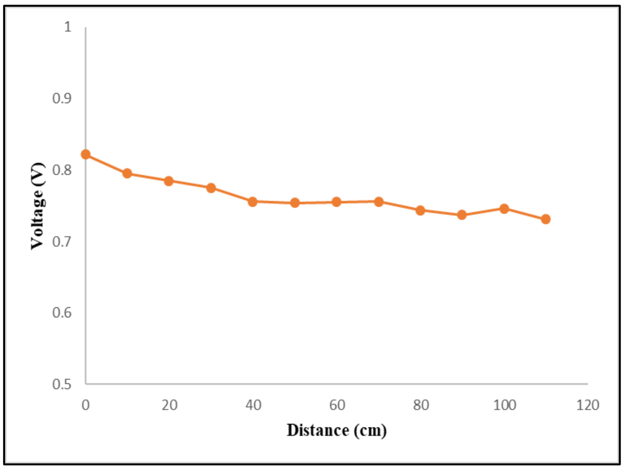

Fig.3.4: For Oboservation1 Measured potential difference across varying heights for Cu-Zn electrodes in banana tree.

In Fig.3.4, it is clear that when the distance between the electrodes is chronologically increasing, voltage is decreasing. When both the electrodes were at vertically zero distance, the value of the voltage was highest. But when the distance between the electrodes were increasing chronologically where Zn electrode was fixed at lower part of banana tree and Cupper electrode was varying height, the voltage was continuously decreasing.

3.2.2 Observation 2 result:

In observation 2, the Zn electrode is embedded at the ground and the Cu electrode is embedded at various distance. A graph has been plotted below in Fig3.5 where the electrode spacing distance is at horizontal axis and voltage is at vertical axis. Though observation 1 graph in Fig.3.4 shows that voltage has dropped for increasing the distance between the electrodes, the graph of observation 2 in Fig.3.5 does not uphold this phenomenon. The graph of observation 2 in Fig.3.5 is indicating that the voltage is decreasing up to 60 cm but more than the distance is increasing, the voltage is gradually increasing with it. So, the distance and the potential difference cannot be co related by the two observations.

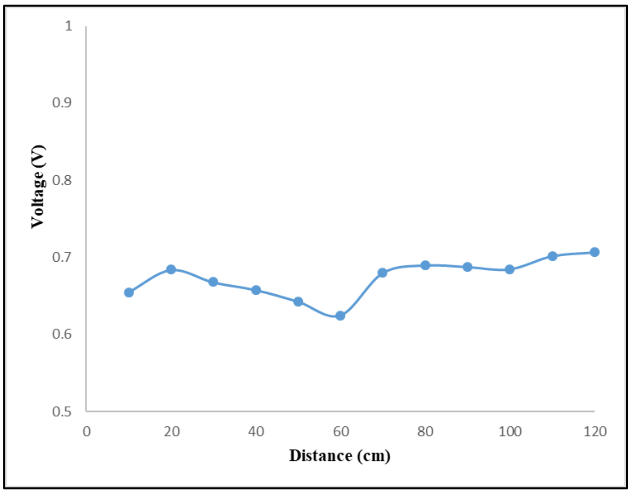

Fig.3.5: For Observation 2 measured potential difference across varying heights for Cu-Zn electrode pair where Zn is grounded and Cu is varying height.

3.3 Source resistance result

To quantify the available power of the tree-based power supply, the voltage output of a tree has to relate with load resistance by varying it. One electrode is embedded to the banana tree at a height of 60cm from the surrounding soil. Then the voltage is measured by varying loads. A graph is plotted below in Fig. 3.6 using the experimental data–

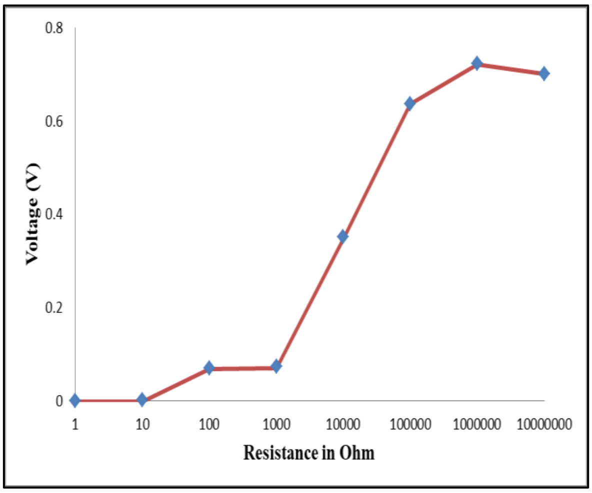

Fig.3.6: Measured voltages across various loads connected between a Banana tree and the surrounding soil using Cu-Zn electrode pair

This experiment was conducted on the banana tree to quantify the available power of the tree-based power plant. In Fig.3.6 the resistance is shown at X axis and voltage in Y axis. From the Fig.3.6, it is shown that when the resistance is very low, the potential difference is zero. After increasing resistance gradually, the voltage difference also increases. While the resistance was increased to 10^6 Ω to 10^7Ω, as a whole the value of the potential difference got stable. By this way, how much ability of the banana tree to generate power it can be predicted. From the Fig.3.6 it is seen that; the stable voltage of the banana tree was found as 0.700V for 10^7Ω resistance. So, for the meantime the available power can be found from the equation-

Power, $P = {V^2}/{R}$ where, V= Voltage, R= Resistance

So, from calculation, the available power from the banana tree found for instance is 4.9×10^{-8}W which is very low.

Now, same procedure is followed to the aloe-vera and a graph is plotted below according to the experimental data in Fig. 3.7 –

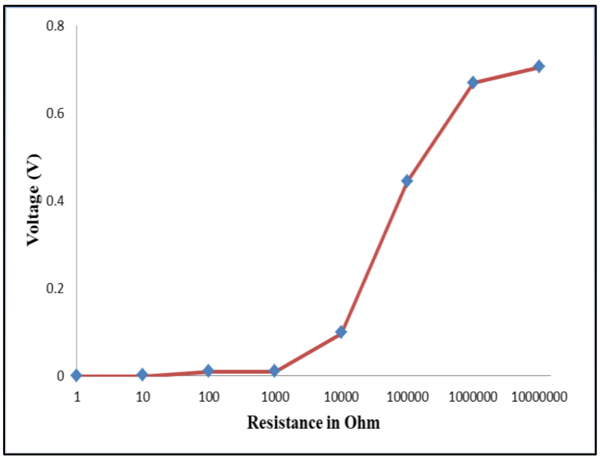

Fig.3.7: Voltage profile against resistance between aloe-vera and surrounding soil using Cu-Zn electrode pair.

The fig3.7 also shows that the voltage is gradually increasing due to increasing the resistance for aloe vera. The stable voltage 0.705V found for the $10^7\Omega$ resistance. So, the available power from the aloe vera is about 4.97×10^{-8} W which is slightly high than the power of banana tree for instance.

3.4 Embedding electrodes to the banana tree at different radius:

A Cu electrode was scaled 0 to 5 cm at the interval of 0.5cm and another electrode Zn was fixed. The Cu electrode was continuously penetrated in the banana tree. There 0.5cm Cu electrode put in per penetration and the voltage measured per penetration. The data of voltage according to the radius from the circumference was measured by multimeter. Using the data, a graph in Fig. 3.8 is drawn by Voltage in Y axis and radius from the circumference in X axis. The graph is given below-

In this graph in Fig. 3.8, it is notified that the voltage is continuously decreasing according to the increasing of penetration length. So, it should be careful in generating power from living plants that more penetration of electrodes does not mean more voltage.

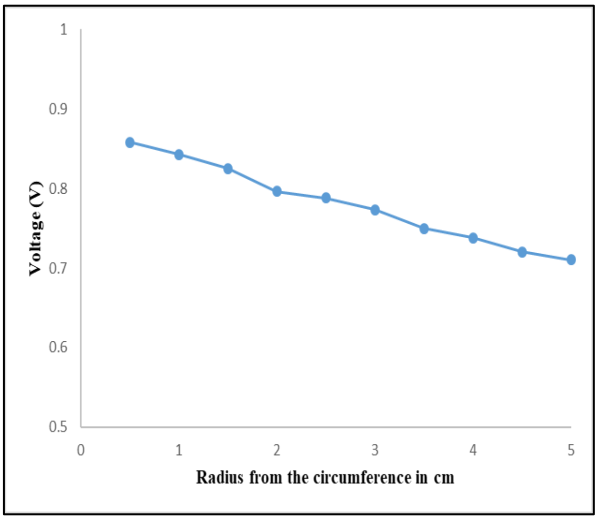

Fig.3.8: Voltage profile against radius from the circumference of banana tree using Cu-Zn electrode where Zn is fixed and Cu is penetrated gradually.

3.5 Tree network result:

The electrode pairs of three banana trees has been connected in series and output voltages are- for using one electrode pair, the measured voltage was about 0.715V. But when 2nd and 3rd electrode pairs were used, the voltage was increased respectively 0.909V and 1.12V. The output voltage vs numbers of electrode pairs are drawn in a graph which is shown in Fig.3.9. Theoretically it is known that if two or more voltage source are connected with each other, the voltage will be increased as the total summation of all voltage source. The graph of Fig. 3.9 also shows that when electrode pairs are connected in series, the potential difference increases.

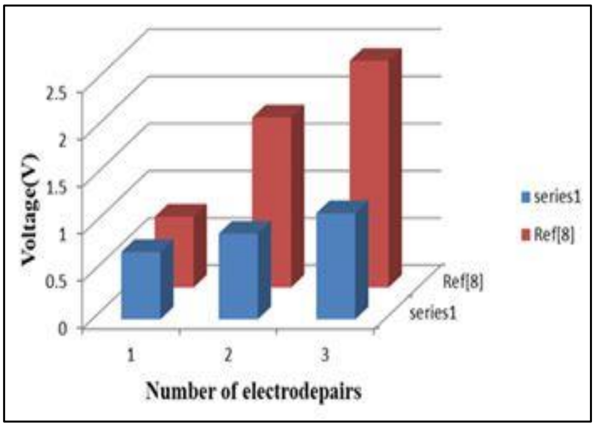

Fig.3.9: Voltage profile over number of electrode pairs with the combination of Cu-Zn in banana tree.

In Fig.3.9 when single electrode pair has been used to generate the voltage produced is very low. The value of the voltage is about 0.715V. But when two electrode pairs were connected in series, the voltage the voltage increased from 0.715V to 0.909V. Similarly, when tree electrode pairs were connected in series, the voltage increased from 0.909V to 1.125V. By this way, the magnitude of the voltage can be developed.

If two or more voltage sources are connected in parallel, the net voltage reduce but the total current increased. Connecting the tree electrodes in parallel, the following data were found. For one electrode pair, the measured current was about 8μA. But when two and three electrode pairs were connected in parallel, the magnitude of current has been risen to 16μA and 30μA respectively.

Using the data, a graph is plotted in Fig 3.10. The Fig3.10 clearly shows that current is continuously increasing when number of electrode pairs was in parallel connection.

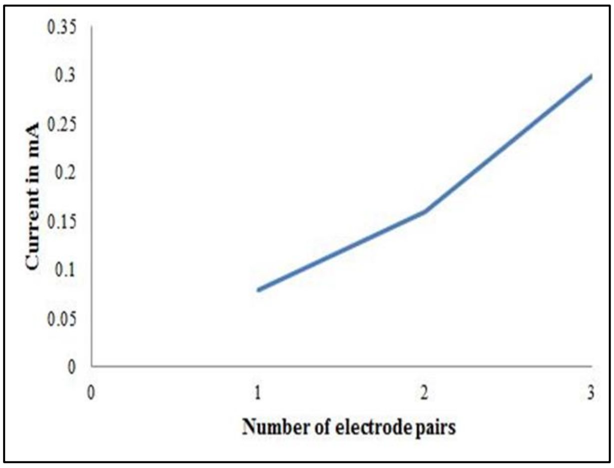

Fig. 3.10: Current vs number of Cu-Zn electrode pairs graph in parallel connection in banana tree.

A very important matter in the experiment is that, the power increases gradually in a tree when the electrode pairs are embedded to the tree and keep it for a long time for 24 hours or more time.

This experiment was conducted in a aloe-vera tree where the three Cu-Zn electrode pairs are embedded in the tree and connected in seris. Then the voltage and current were measured. The setup was kept for 24 hours with no change. After 24 hours the voltage and current were again measured. By this way, voltage and current were measured for 5 days at the interval of 24 hours.

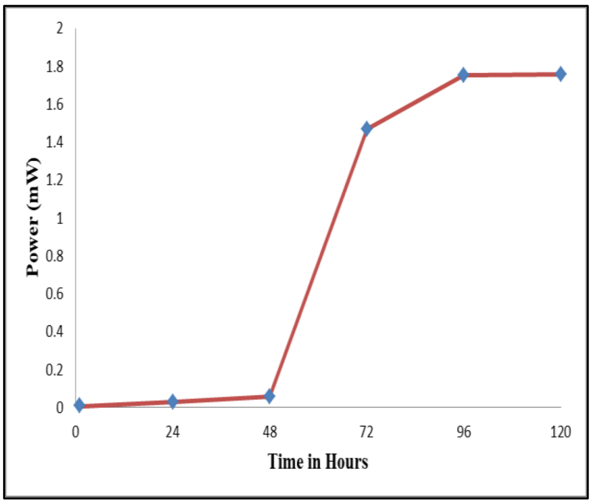

Fig.3.11: Power vs Time graph using Cu-Zn electrode pair connected in series in aloe-vera

From the Fig.3.11 it is shown that, for 24 hours the voltage increased from 1.025V to 1.477V. In 5day, the highest voltage found about 1.625V. At first hour the current was 0.9 micro Amp. But after 24hours the current flow gets doubled. At 48 hours, the current goes up 4th times the 1hour current. At 72 hours, the current goes up 10th times the first hour current. As, current has been increased as well as voltage and gets stable overall, so the power increases normally. It is seen that, after 5 days the power produced is nearly 200th times more than the power produced in first hour.

6. CONCLUSION

The main goal of the paper is to investigate broadly about the new renewable energy source biotechnology specially plant biotechnology. It may be expected that the plant biotechnology will be one of the most important factor of generating electrical power in the era of crisis of non-renewable energy. I tried to correlate the potential difference with the electrode spacing, resistance, tree network and penetration of electrodes at different radius of tree. I hope this data and graph will be helpful for future research.

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