

A CASE STUDY ON ENERGY HARVESTING PIEZOELECTRIC TREE TO PRODUCE RENEWABLE ENERGY

Roopa C

Assistant Professor, Department of Electrical and Electronics Engineering, New Horizon College of Engineering, Bangalore - 560103, India

Abstract: As fossil energy resources deplete, wind energy gains ever more importance. Recently, piezoelectric energy harvesting methods are emerging with the advancements in piezoelectric materials and its storage elements. Piezoelectric materials can be utilized to convert kinetic energy to electrical energy. Utilization of piezoelectric wind harvesting is a rather new means to convert renewable wind energy to electricity. Piezoelectric generators are typically low cost and easy to maintain. This work illustrates an overview of piezoelectric wind harvesting technology. In wind harvesting, piezoelectric material choice is of the first order of importance. Due to their strain rate, robustness is a concern. For optimum energy harvesting efficiency resonant frequency of the selected materials and overall system configuration plays important role. Existing piezoelectric wind generators are grouped and presented in following categories: leaf type, rotary type, rotary to linear type and beam type wind generators.

Keywords: Piezoelectric Crystals, Generators, Force And Harvesters

I. Introduction

When some force or pressure is applied on embedded piezoelectric crystals the energy is transformed into the electrical energy which can be seen as a clean source of energy. Recently, clean renewable energy sources become popular, since the world's usable fossil energy resources are depleting rapidly. Piezoelectric generators can be embedded in any place where energy exists in the form of force or pressure like applications in highways, railways, airports, pedestrian lanes. The resulting deformation of

piezoelectric material is converted into electrical energy. Though small in magnitude, the obtained energy can be stored or conveyed to direct usage areas. Apart from the applications areas listed above wind provides a natural primary source of energy to initiate this overall piezoelectric generation cycle. The wind potential is abundant and commonly available. The research on harvesting energy out of wind flow focuses on extracting maximum energy out of irregular flows as well as from low velocity wind flows.

The study done by Yan, demonstrated that by the usage of wind sources on piezoelectric materials can generate sufficient energy to use for sensors. For instance, 917 μ J energy can drive 5 words of 12 bit information for transmission period of 100msecs. Extraction of electrical energy based on piezoelectric materials involves the following steps; capturing or developing mechanical deformation of the piezoelectric material, conversion of mechanical energy to electrical energy and conveying this energy to a proper storage element or usage application. Figure 1, illustrates typical block diagram for piezoelectric generators.

In order to harvest the optimum wind energy, characteristics of the piezoelectric materials should be matched with the application areas,

and designs should be tailored for different weather and operating conditions. Therefore, developing optimum design with optimum materials is regarded as key to maximum harvesting. There is a direct correlation between the harvested energy and piezoelectric material deformation. The harvested energy from piezoelectric material is also proportional to frequency and strain where maximum energy can be extracted at resonance.

Recently, researchers developed models, controls and devices with different topologies in order harvest energy with relatively small vibrations. Arnaupresented a model of a spring-mass-damper mechanical resonator with piezoelectric electromechanical coupling. The study showed that maximum power can be obtained as excitation frequency approaches the resonance frequency. Besides, the study showed that application of controllable electrical impedance to the piezoelectric device can maximize the power harvested.

This study provides an overview of current piezoelectric wind harvesting techniques. First, general information on general piezoelectric applications and piezoelectric energy harvesting methods is presented. Efficiency of the piezoelectric materials is discussed with regard to energy harvesting usage. Then, recent piezoelectric wind generators such as leaf type wind generators, rotary to linear wind generators, rotary wind generators and beam type wind generators are studied.

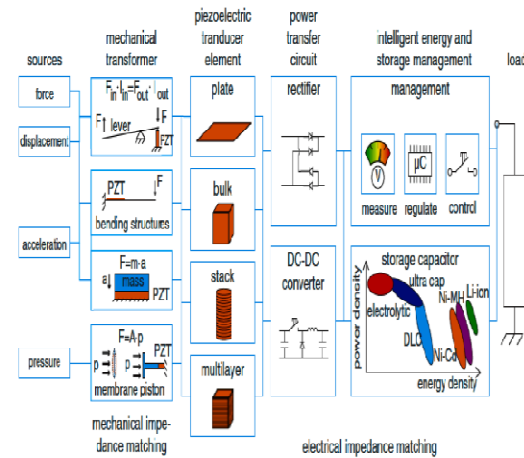


Figure 1. Block diagram for piezoelectric generators.

2. Piezoelectric history and Theory History

Piezoelectric materials (PZTs) are materials that can transfer mechanical energy to electrical energy and electrical energy to mechanical energy. This effect, which is known as the piezoelectric effect, is defined in the Encarta Concise Encyclopedia: the appearance of an electrical potential across some faces of a crystal when it is under pressure, and of distortion when an electrical field is applied. Pierre Curie and his brother Jacques discovered the effect in 1880. It is explained by the displacement of ions, causing the electric polarization of the crystal's structural units. When an electrical field is applied, the ions are displaced by electrostatic forces, resulting in the mechanical deformation of the whole crystal. Piezoelectric crystals are used in such devices as the transducer, record-playing pickup elements, and the microphone.

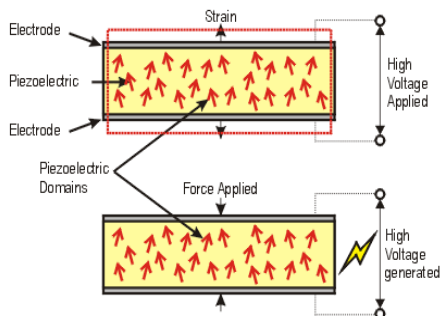


Figure 2. piezoelectric effect

Although the Curie brothers discovered the piezoelectric effect in 1880, it was not fully used until the 1940's. At this time, high input impedance amplifiers enabled engineers and scientists to amplify their signals and make use of piezoelectric materials. In the 1950's, the piezoelectric effect became commercialized with the advent of electrometer tubes. Piezoelectric materials are active electrical systems having crystals that produce an electrical output when they experience a load change. This effect occurs naturally in quartz crystals, but can be induced in other formulated materials. The most common material with this effect is a specially formulated ceramic consisting of Lead, Zirconium, and Titanium (PZT). Heating this mix of metals to its Curie temperature activates these PZT materials. At this temperature, a voltage is applied in a desired direction, realigning the ions to an axis known as the "polling" axis. When the material cools, the ions remember this polling axis and act accordingly. Piezoelectric materials (PZTs) are used in a wide variety of applications both in and out of the laboratory.

3. Mechanism of piezoelectricity

The nature of the piezoelectric effect is closely related to the occurrence of electric dipole moments in solids. The latter may either be induced for ions on crystal lattice sites with asymmetric charge surroundings (as in Barium Titanate (BaTiO_3) and PZTs) or may directly be carried by molecular groups (as in cane sugar). The dipole density or polarization (dimensionality $[\text{Cm/m}^3]$) may easily be calculated for crystals by summing up the dipole moments per volume of the crystallographic unit cell. As every dipole is a vector, the dipole density P is a vector field. Dipoles near each other tend to be aligned in regions called Weiss domains. The domains are usually randomly oriented, but can be aligned using the process of poling (not the same as magnetic poling), a process by which a strong electric field is applied across the material, usually at elevated temperatures. Not all piezoelectric materials can be poled.

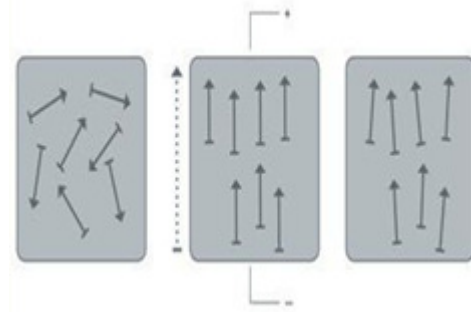


Figure 3 : Electric dipoles in piezoelectric materials before, during and after poling

Figure 3 Of decisive importance for the piezoelectric effect is the change of polarization P when applying a mechanical stress. This might either be caused by a re-configuration of the dipole-inducing surrounding or by re-orientation of molecular

dipole moments under the influence of the external stress. Piezoelectricity may then manifest in a variation of the polarization strength, its direction or both, with the details depending on

1. The orientation of P within the crystal.
2. Crystal symmetry.
3. The applied mechanical stress.

The change in P appears as a variation of surface charge density upon the crystal faces, i.e. as a variation of the electrical field extending between the faces, since the units of surface charge density and polarization are the same, $[C/m^2] = [Cm/m^3]$. However, piezoelectricity is not caused by a change in charge density on the surface, but by dipole density in the bulk. For example, a 1 cm^3 of quartz with 2 kN (500 lbf) of correctly applied force can produce a voltage of 12500 V.

Piezoelectric materials also show the opposite effect, called converse piezoelectric effect, where the application of an electrical field creates mechanical deformation in the crystal.

3. Piezoelectric Applications and General Energy Harvesting Methods

Since piezoelectric materials have good electromechanical coupling, these materials are suitable to use in “structural vibration control”, “health monitoring” and “energy harvesting”. Piezoelectric ceramics have importance for ultrasonic motors, piezoelectric and other devices. PZT materials are being used for gas igniters. The soft types are used for applications which require low-frequency, in high strain actuators and sensors with high strain actuators and sensors with high sensitivity. On the other hand, hard PZT ceramics have low depolarization and low losses. Therefore, they are used for high-power ultrasound

transducers, and high temperature stable sensors.

Piezoelectric materials make conversion of available ambient energy to electricity possible wherever vibration and pressure force is available. Lately, use of piezoelectric materials in train stations and dance floors are experimented. In a study by Rocha, integration of piezoelectric materials into shoe soles is also experimented. It is reported that the harvested energy out of human movements can be utilized to function electronics. In a recent study, Kim observed various high force and different frequency range effects on energy harvesting by placing piezoelectric materials in a bridge system. Piezoelectric materials are mainly affected by the strain rate but not simply proportional. Another study of Kim showed that by the usage of 10 layer ceramics instead of one layer, output current can be increased by 10 times. Their study showed that multilayered cymbal increased the output power 100% with the 40 times lower resistive load while current increased by 10 times. This study validated the usage of cymbal with multilayered piezoelectric layer is effective to harvest more energy.

4. Piezoelectric Energy Harvesting Materials

Piezoelectric material can mainly be divided in two: hard and soft piezoelectric material. Hard piezoelectric ceramics domain wall motion is restricted so that their piezoelectric constants are low and they have less hysteresis properties, on the other hand, soft piezoelectric are more preferable because of their high strains. Polymer piezoelectric materials (PVDF) have high impact resistance and their impedance values can be matched with that of water and human body due to the fact that their acoustic impedance

is comparable to a range of values in between those of piezo-ceramics and water. On the other side, polymer composites (PZT) has characteristics of high resistance to depolarization, small dielectric losses in the exposition of high electric fields, high electromechanical coupling, high resistance to depolarization under high mechanical stress and great deformation ability. Thunder, Active Fiber Composite, Macro Fiber Composite, Radial Field Diagram, Quick pack and Bimorphs are called as low profile transducers, since they are most used piezoelectric materials which have light weight, flexible, large response, low frequency response and low frequency operation.

MFC has advantages over PZT and bimorph since it has flexible, robust to damage and environmental effects and moreover it is more efficient for energy conversion, however MFC can produce low level of current which is not favorable. On the other hand, PZT is more efficient; however it is vulnerable to breakage so it is less robust. Their numerical analysis revealed the following efficiency formula

$$\square = \frac{V^2}{R F} \times 100\% = \frac{F^2 d^2}{m \Delta t} \times 100\% \quad \text{---(1)}$$

where \square is the efficiency, V is the voltage drop across R , F is the force applied to the base of the plate, d is the displacement of the plate, t is the time increment between data points, n is the data point index and m is the total number of measured data points. Results of the efficiency study with 3 different piezoelectric materials in different frequencies can be found in Table 1.

Table 1.0: Efficiencies of PZT, MFC and QP

Signal	PZT efficiency (%)	MFC efficiency (%)	QP efficiency (%)
Resonant	4.54	1.7871	0.4662
	4.51	1.7211	0.6094
	4.2312	1.7377	0.946
Chirp 0-500Hz	3.102	0.2927	1.6505
	3.0725	0.3033	1.2611
	3.0293	0.3368	1.492
Random 0-500 Hz	6.57	1.2103	3.097
	6.954	1.3013	2.9664
	6.8562	1.4663	3.1551

In the low frequency range, usage of bimorphs would be suitable since they have enough mechanical strength around 1-10 Hz under force of few Newton's. Also, their voltage coefficient is high so the charge developed is high. However, PZT materials are more suitable than MFC, since MFC generates lower current. Moreover, in the study of Kymissis, the experiments resulted that in the case of displacement is low the usage of bimorphs resulted with advantageous with respect to using PZT or Thunder, since it is capable of various distribution of weights and conditions.

5.Recent Piezo-Wind Generators/Piezo-Tree

Recently research on piezo-wind electric generators has been progressing with the increase trend on renewable energy sources. The wind energy can be converted to electrical energy via integrating piezoelectric material on leaves or converting rotary energy to linear energy to bend PE materials or PE materials can be directly utilized on rotary motion.

The piezo-tree is an artificial tree that generates electricity using the wind energy. The prototype behaves as a tree facing

breeze. The Piezo-tree's flexible plate and film oscillate just as a flag or leaf might flap in the wind. The flapping motion is generated due to instability of the aero-elastic system.

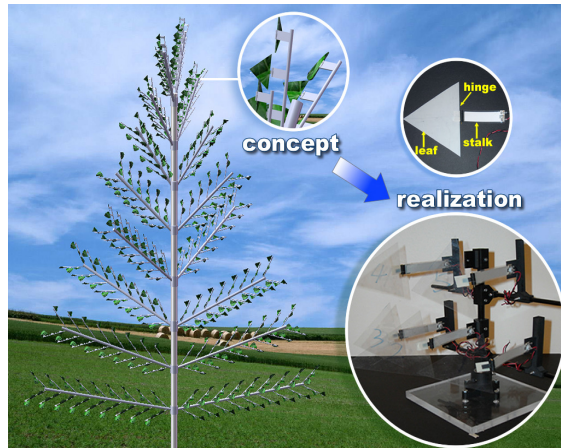


Figure 4: Recent piezoelectric Tree

Mr. Liproposed a novel vertical-stalk L-type design to harvest more energy which is composed of a polarized PVDF stalk, a plastic hinge and polymer leaf.

The main constituent of the “Piezo-tree” is of Polyvinylidene Fluoride (PVDF) which is a flexible piezoelectric material. Vortices cause the fluctuating pressure forces which are perpendicular to motion which leads vibrations and leaf is moving through the bending force and moment of PVDF stalk. Besides, S. J. Oh made a tree-shaped design to harvest energy by embedding PVDF's on leafs and PZT's on trunk part of the tree where the bending can be realized by strong wind. PVDF's are embedded on leafs since they are less stiff.

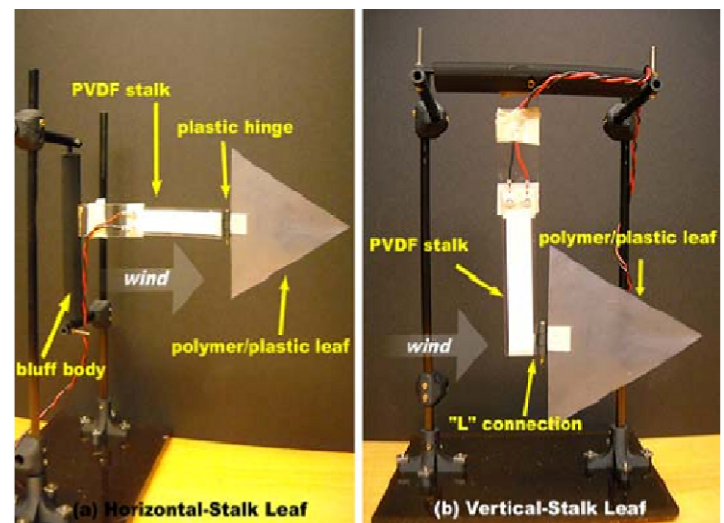


Figure 5. The design of piezo-tree

Various tests were conducted at different wind speed and different types of PVDF plates and the output power was measured. This was done in order to select the best design. The results of the experiments are as under.

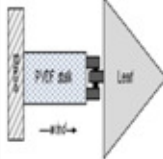
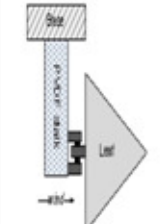
Configuration of Prototype	PVDF element	Max Output Power (Load=10 MΩ, Deviation ≈ 6%)
Horizontal-stalk leaf 	Long single layer PVDF stalk	17 μW (Wind speed = 6.5 m/s)
Vertical-stalk leaf 	Short single layer PVDF stalk	296 μW (Wind speed = 8 m/s)
	Long single layer PVDF stalk	76 μW (Wind speed = 3.5 m/s)
	Long air-spaced double layers PVDF stalk	119 μW (Wind speed = 6.5 m/s)

Figure 5.(a) Horizontal-Stalk Leaf, (b) Vertical-Stalk Leaf .

Air-spaced double layers could offer a good trade-off solution between increased strain and added stiffness of multiple layers stalk. So, many experiments were done to check the variation of the output results. Based on the results the graph is plotted which is as under.

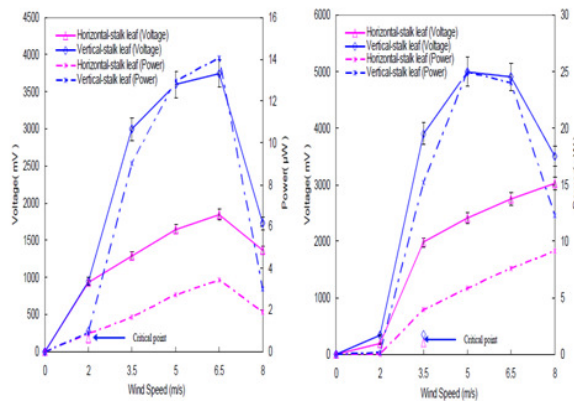


Figure 6: Air-spaced double layers could offer a good trade-off

The shape of the plastic leaf was not selected randomly. Many experiments were done on different shapes like rectangular, square, triangular etc. but most favorable results were obtained with triangular shaped leaves.

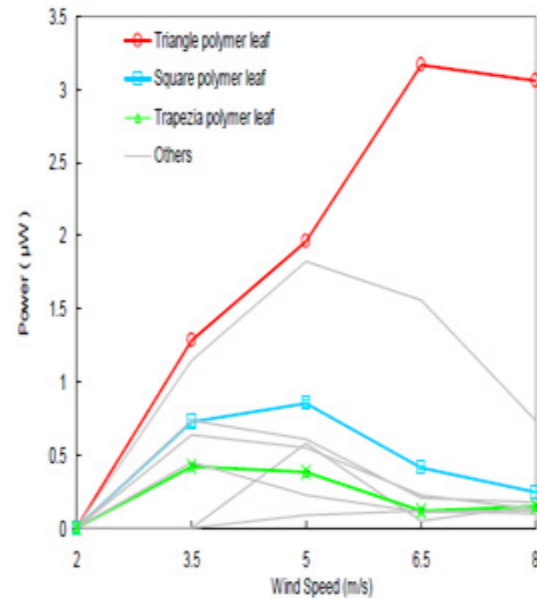


Figure 7: power Versus leaf shape

6. Energy Maximization and Required Circuit Designs for Piezoelectric Generators

The mechanical input power comes from ambient vibrations which may vary inproportion. To compensate for temporary level reductions of the surrounding vibration, or to overcome a power spike generated by the electronic load, an energy storage device must be included in the circuit. Moreover, the piezoelectric element delivering an alternating voltage, an AC-to-DC power converter must interface the energy storage device and the piezoelectric element. These considerations lead naturally to a circuit, herein called the interface circuit, used in most of the piezoelectric energy harvesting systems reported in the literature.

The simplest interface is an AC-DC diode-bridge rectifier followed by a filtering capacitance C_f , as shown in Fig.8.

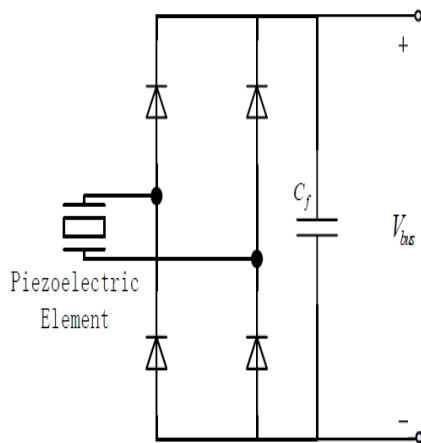


Figure 8: .Ac-dc rectifier circuit

In this circuit, the electrical energy is provided directly to the storage cell through the diode-bridge rectifier. The filtering capacitor is chosen to be large enough so that the rectified voltage V_{bus} is essentially constant to have a stable DC output voltage.

Under the concept of electrical impedance matching, the output energy will be maximized if the actual voltage of the storage cell is half of the source's open-circuit voltage, which is also the peak value of the open-circuit AC voltage of the piezoelectric device under certain excitation.

In actual applications, the storage cell voltage is often fixed, which may not satisfy the impedance matching condition, so an additional interface between the diode-bridge and the storage cell is required to satisfy the impedance match condition and maximize the harvested energy. A typical such interface is a switch-mode step-down DC-DC converter reported by Ottman. The resulting energy harvesting circuit is shown in Fig. 9.

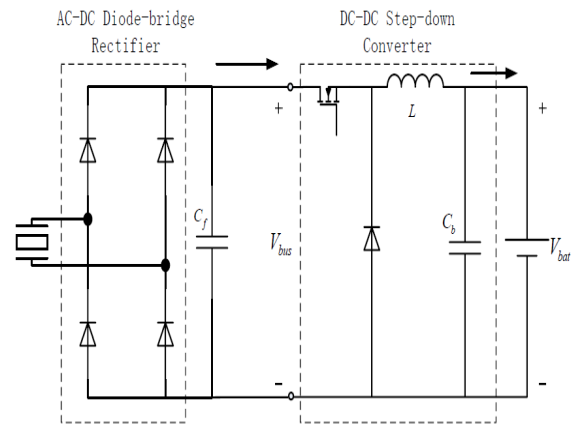


Figure.9.Ac-dc diode bridge rectifier circuit with dc-dc step down converter.

7. FUTURE SCOPE

Today much debate has been going on in scientific circles about how real is the phenomenon of global warming and what would be mankind's response in averting the consequence of it. Realizing this, steps have been taken to reduce the use of fossil-based energy and substituting the same with renewable sources such as solar and wind energy etc. Till now we are producing the electrical energy with the means of either wind mills (only the effect of wind) or solar panels (only the effect of solar energy) so far but all the two forms of these energies we are not using in same system. The answer of this problem is related to the piezo-tree or we can say that the future of piezo-tree will solve this problem and the name given to it is "NANO LEAF"

NANO LEAF

We know very well that piezoelectric crystals, photo voltaic cell and thermo voltaic cells are used to convert the one form of energy into electrical energy but till now we are not using these all the techniques in the single system. Think if we are mingling these

all the techniques in single system then surely different types of energies coming to the system can be converted into huge amount of electrical energy. So for this, the only and the best solution is the Nano leaves because the leaves on a tree get all these types of energies such as solar energy from sun, wind energy as well as stress from the rain and for converting these all the energies into electrical energy all the above mentioned techniques we are having in a single Nano leaf. The other main motive to choose Nano leaves is that the size is small and compact. The other main advantage of using Nano leaves is that it can produce more electrical energy than the solar panels.

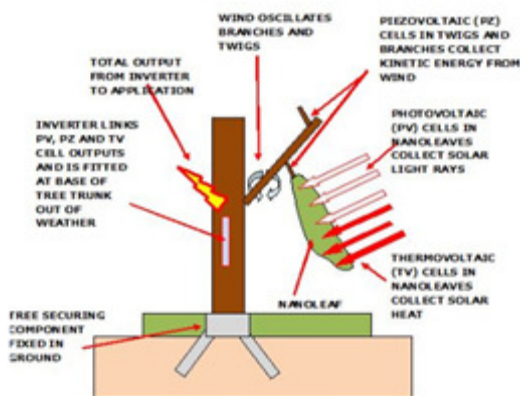


Figure 10: Solar and wind energy absorbed by nano leaf

The Nano leaves made from a flexible substrate, is exploited on both sides, using a process called thin-film deposition which will incorporate thermo and photovoltaic material for the purpose of converting solar radiation (light and heat) in addition we introduce piezoelectric connective elements that connect/affix the leaf to the plant or tree, this not only allows quick and secure assembly but it also serves for turning wind energy into electricity. Furthermore we

intend to get our Nano leaves as close to real as possible, one way to achieve this is to emboss the leaves, creating a three-dimensional leaf surface image, which is beneficial for harvesting and capturing solar radiation. The invention advances upon all prior art artificial leaves, needles and grasses including water based plants, this method not only foresees an economical and efficient way to harvest solar radiation and wind energy via incorporation of thermophotovoltaic and piezoelectric materials but also reveals a method for affixing artificial leaves that can harvest and capture solar radiation, wind energy and energy generated from falling rain and hail, providing an aesthetically pleasing and natural looking artificial leaves and needles that can be affixed to trees, plants, shrubs and water based plants. Furthermore the main advantage of these Nano leaves is that these leaves are converting more energy than the solar panels. When we comprised the energy produced from Nano leaf tree to the energy produced with the solar panels, we found out that artificial Nano trees are converting solar radiation (light and heat) and wind (3 in 1) 130kwh/in^2 per year and solar panels are converting sun light 90kwh/in^2 . As far as we concern about the usage of this energy, this electrical energy can be used for driving the car which will reduce the use of the fossil fuels and can be used to enlighten the house.

It concludes by stating that the scope of the renewable energy from the Nano leaf tree in a relatively modern field will tend to solve the very big problems for the world like global warming.

How it Works:

Piezoelectric is a simple concept to generate electricity that comes from the pressure. We

have used the exact meaning of the term, in order to create a sustainable energy resource by using light, heat and wind.

When the force from the outside, like the wind blowing the leaves (with the volume a little or a lot). Potential difference on the spot, mechanical stresses appear in the leaves, twigs, stems and braches. This process can then generate millions of watts of Pico which efficiently be converted into electricity. That way, the stronger the wind, the energy produced will be more and more distinguished. During the day, Nano leaves reflect the green light in sunlight and use photoelectric Nano spheres to convert the rest of the visible light into electricity. Thermoelectric Nano wires /antennas convert heat from infrared light, or thermal radiation, into electricity throughout the day, since the earth continuously absorbs thermal radiation and then radiates it, even after dark. It has also found out in the research that with the right material shape and size, Nano antennas could harvest up to 92% of the energy at infrared wavelengths

7. Conclusion

In order to get the optimum efficiency more research should focus on optimization and combination of existing researches. Also, since the most of the energy lost realized at storage elements, circuit designs should be advanced.

Piezoelectric energy harvesting can be seen as a future of self-powered systems source. Although, the efficiencies are not sufficient the meet to requirements of minimum energy for devices, the desired electricity could be obtained with the advancements of piezoelectric materials and the storage elements.

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