

Development of a Tree-shaped Wind Power System Using Piezo-electric Materials

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Abstract : This paper reports an experimental investigation to design a tree-shaped wind power system using piezo-electric materials. The proposed system has been designed to produce power if there's any wind strong enough to produce any bending in the energy converting elements, i.e., piezo-electric materials. Two different kinds of piezoelectric materials are used in the present study to produce power by scavenging energy from the wind. The soft flexible one is used to make the leaf element whereas the hard one is applied to the trunk portion of the tree requiring rather strong winds to generate any power. Although small, each leaf deems to play the role of a power producer as a current is continuously trickling down to a storage battery installed at the bottom of the system

Keywords: Energy Harvesting, Piezo Ceramics, PZT, PVDF, Wind Power System

1. INTRODUCTION

The universal environmental problems caused by a fast-growing economy and a scientific technological development have significant impacts on humans. Especially, global warming, ozone depletion,

desertification and other serious problems have been expanded on a global scale and become an important task that we are faced with. To cope with these problems, systematic development and usage of renewable energy resources as well as harnessing these resources in a more

innovative way are becoming more and more important.

According to the recent statistics given by various energy agencies around the world, 30~40% of the world's energy resources is consumed in residential and commercial buildings for heating and lighting where fossil fuels account for 70% of world energy resources. Our living space is part of the environment, which also could become one of the key culprits causing various harms to the environment. From our past lessons from the nature, it is also likely to suffer the most from its feedbacks, directly or indirectly. This is why we should consider its impact on the environment when exploiting any natural resources.

Energy harvesting is a process by which energy is captured and stored. A variety of different sources exist for harvesting energy, such as solar power, thermal energy, wind energy, salinity gradients and kinetic energy. From time to time, it is also referred to as energy scavenging, which means collecting wasted energy resources scattered around us.

The energy harvesting system considered in this study serves a good example of the related technologies and it is expected to perform a leading role in the acquisition of potential energy that wind carries.

In the present analysis, the outputs from Multi-bundle shaped PVDF have been extensively monitored. Also, the actual performance of a prototype tree-shaped wind power system fabricated with PZT and PVDF has been analyzed.

2. PRINCIPLE OF PIEZO CERAMICS

Certain single crystal materials exhibit the following phenomenon which explains the operating principle involved in applying piezoelectric materials to generate electric potential: when a crystal is mechanically strained, or when a crystal is deformed by applying some external stress, electric charges appear on certain faces of a crystal, and when the direction of the strain reverses,

the polarity of the electric charge gets reversed. This is called the direct piezoelectric effect. And the crystals that exhibit it are classed as piezoelectric crystals. (See Fig.1).

Conversely, when a piezoelectric crystal is placed in an electric field, or when charges are applied by external means to its faces, the crystal exhibits strain, i.e. the dimensions of the crystal change. When the direction of the applied electric field is reversed, the direction of the resulting strain is reversed. This is called the converse piezoelectric effect. (See Fig.2)

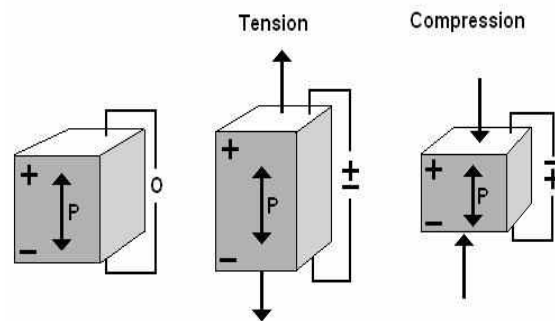


Figure 1: The direct piezoelectric effect.

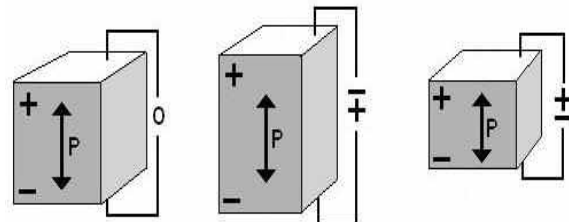


Figure 2: The converse piezoelectric effect.

2.1 PZT[pb(Zr,Ti)O₃]

There are many kind of piezo ceramics that exhibit the piezoelectric effect. Of these materials, PZT[pb(Zr,Ti)O₃] is widely used due to its outstanding performance.

PZT is a complete solid solution between PbZrO₃ and PbTiO₃ and is popular as a commercial material due to its temperature stability in link with the piezoelectric effect(phase transition temperature is over 350°C).

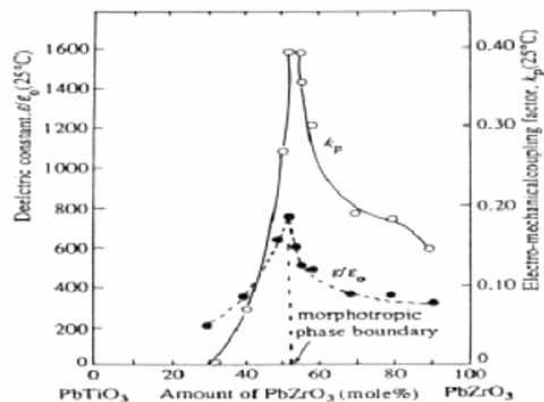


Figure 3: Composition dependence of the dielectric constant and electromechanical coupling factor of PZT ceramics.

PZT has Pervoskite structure that is consisted of oxygen octahedral in which Zr or Ti is placed.

The piezoelectric effect of PZT ceramics appears differently with the composition and temperature of Zr/Ti. The dielectric and piezoelectric effect indicates the peak near 52/25~53/47 as shown in Fig.2.

This composition is also called MPB (Morphotophic Phase Boundary) in which it has been known that tetrahonal and rhombohedral coexist together. Hence, this composition is invaluable commercially.

2.2 PVDF(Polymer Polyvinylidene Fluoride)

PVDF(Polymer Polyvinylidene Fluoride) is a high-molecular-weight polymer of vinylidene fluoride with the predominant repeating unit – CH₂-CF₂-, which is widely used in sensor elements. Currently, a wide range of piezo film sensors made from PVDF are available in the market. A PVDF film is made in such a manner that a thin protective cover wraps around the piezo film element.

3. MAJOR COMPONENTS AND FABRICATION

3.1 The specification of PVDF and PZT

The major efforts of this work are made to generate electricity by using a number of thin piezoelectric films (LDT4-028K/L) which deems most appropriate to harvest wind energy without undue difficulties. A stacked thin film assembly is designed and fabricated in the form of a leaf such that it is pliable in any wind speed.

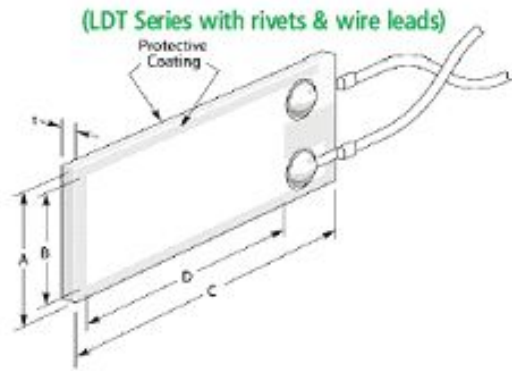


Figure 3: Dimension of the piezo film LDT4-028K/L.

When bending is induced to this LDT4-028K/L, it generally produces more voltage than the other PVDF that doesn't have a protective film. This is because the central axis is not embedded in a piezo film element itself but in the protective film.

Fig.3 shows the shape of LDT series and Table 1 shows the dimension.

Table I: Dimension of the LDT4-028K/L.

A Film	B Electrode	C Film	D Electrode	t (μm)	Cap (nF)
21	18	170	155.70	205	11.0

The model of PZT used in this study to extract energy from a strong wind is Q220-A4-503YB (one of Quick-Mount Bending Generator models , PIEZO SYSTEMS, Inc.),

which appears to be rather inflexible compared to PVDF.

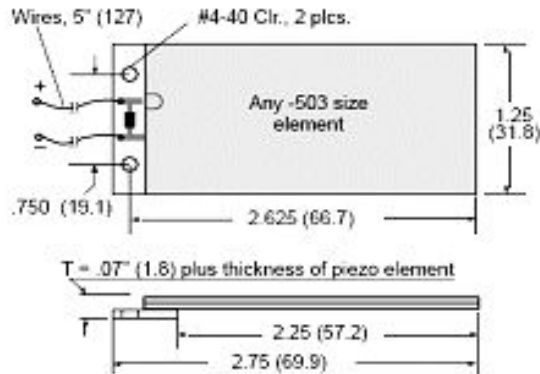


Figure 4: Dimension of Q220-A4-503YB.

Table II : Performance of Q220-A4-503YB.

Weight(grams)	9.5
Stiffness(N/m)	245
Capacitance(nF) [parallel Operation]	260
Rated Tip Deflection(mm _{peak})	±1.57
Rated Frequency(Hz)	45
Open Circuit Voltage(V _{peak}) [At rated deflection, parallel operation]	±18.1
Closed Circuit Current(μA _{peak} /Hz) [Per sinusoidal cycle, at rated deflection, parallel operation.]	±46
Rated Output Power(mW _{rms}) [At rated deflection and frequency]	4.7

This product consists of two polarized PZT layers and when one layer is compressed, the other layer becomes expanded (see Fig.1). And correspondingly, it generates an electric charge. Fig. 4 shows the shape of Q220-A4-503YB and its dimension is given in Table 2.

3.2 Measuring current produced from piezoelectric films

10 piezo films were connected in parallel to analyze the performance of PVDF in generating electricity and the output from this arrangement was constantly monitored

by using an oscilloscope as shown below, Fig. 5.



Figure 5: Experimental setup to measure any electric current from a series of piezofilm connected in parallel

3.3 Manufacturing a tree-shaped wind power system

The major objective of this study is to design a wind power generating system cable of harvesting wind energy at any wind speed. To implement this, a system which consists of PVDF and PZT is fabricated and tested which has the shape of a tree.

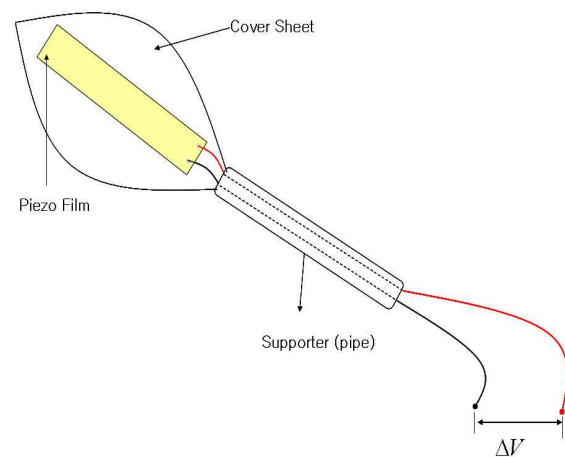


Figure 6: The portion of tree-shaped wind power system using PVDF, which comprises a leaf

Fig. 6 shows a leaf made with flexible PVDF(LDT4-028K/L) film capable of generating relatively high voltages even by a weak bending.(See Fig.6)

Piezo film was glued on a leaf-shaped cover sheet. The wires of piezo films were inserted into a hollow supporter and the end of wire was connected to the circuit. The number of leaves was 18 in total.

PZTs were placed at the bottom portion of the tree where the trunk is connected to the roots. This is to generate electricity when wind is blowing at high speeds. As previously mentioned, PZTs are quite stiffer but still bendable.

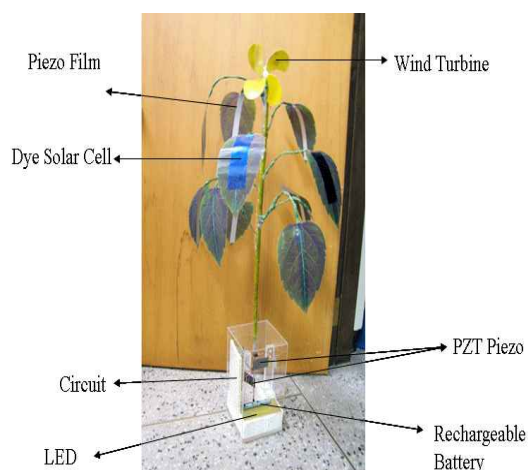


Figure 7: A prototype tree-shaped wind power system.

It could make a simple hybrid system combined with solar by adhering a flexible solar cell on the front side of the leaf. This would allow the system to produce power even on a windless day. Also, a compact flower-shaped wind turbine could be integrated to produce power in a more conventional way.

3.4 Circuit construction

The power produced by PVDF and PZT(as applied) was not enough to directly drive any electric devices. To resolve this, a certain storage medium was required such as a rechargeable battery capable of storing electricity.

A more sophisticated control circuit construction is necessary to charge the battery capable of rectifying and amplifying the output signal from piezoelectricity materials.

Fig. 8 shows a simple Whitstone bridge circuit in link with an oscilloscope was constructed in the present study to measure and analyze the signal outputs from various components of the system.

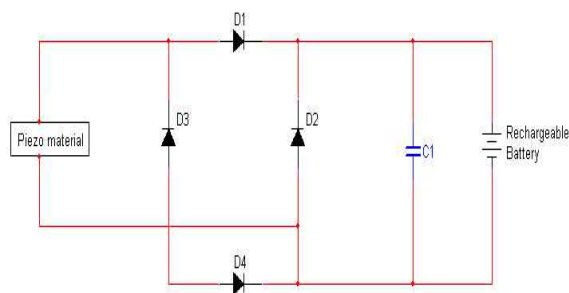


Figure 8: A simple circuit constructed to monitor power generation from the system.

4. RESULT AND DISCUSSION

4.1 Output of PVDFs connected in parallel

Measurements were made on the output of 10 PVDF films connected in parallel subject to a uniform flow of wind generated by an electric fan. Two different cases were tested concerning the direction of wind :

(case 1) Wind blows from the front

(case 2) Wind blows from the sideways

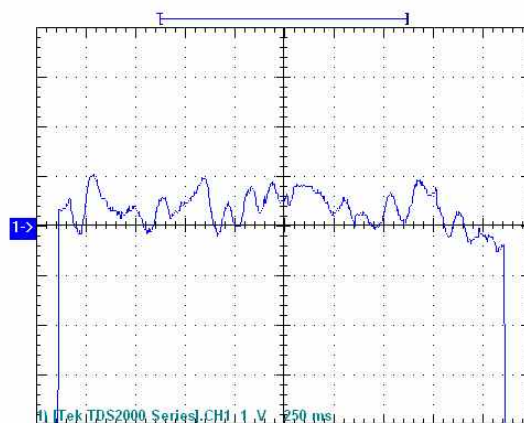


Figure 9: Output wave patterns when wind blows from the front (case.1).

Fig. 9 shows the output wave patterns for case 1 whereas Fig. 10 corresponds to case 2.

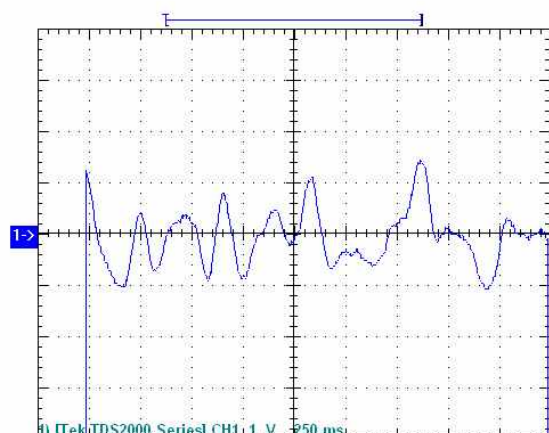


Figure 10: Output wave patterns when wind blows from the side (case.2).

The maximum voltage measured was $\pm 1.2V$ for case 1 and $\pm 1.0V$ for case 2, respectively.

4.2 Output of the integrated system

Similar measurements were also carried out for the tree-shaped integrated system whose output yield crucial technical data in predicting its potential

Fig.11 and Fig. 12 show the rectified wave patterns that passed through the bridge circuit, respectively.

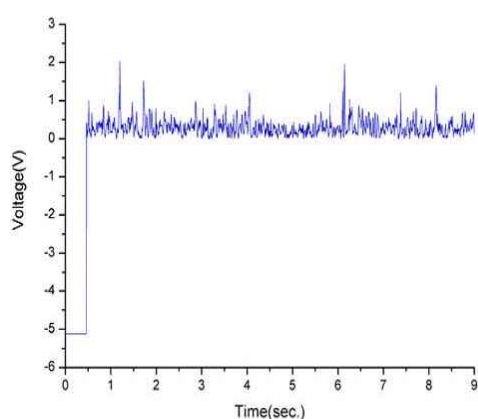


Figure 11: Rectified wave pattern observed after the bridge circuit (serial connection).

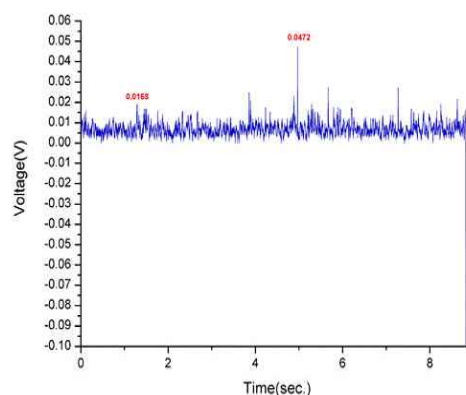


Figure 12: Rectified wave pattern observed after the bridge circuit (parallel connection).

Fig. 11 shows the variation of voltage with time when PVDF and PZT were connected in serial. A maximum voltage of 2.04V was observed with 1 M Ω resistance. This corresponds to a maximum current of 2 μA .

Fig. 12 shows a similar result for a parallel connection. As shown, a maximum voltage of 0.0472V was measured with a reading of 47 μA for the current. 1 k Ω of resistance was also used for the case.

When PVDF and PZT are connected in serial, voltage was measured to be higher than current. Opposite results are, however, obtained for parallel connections.

Storing electricity in NiCd batteries, generally, requires fast charging (charge time : about 1 hour) due to the memory effect. If the maximum charge time is limited to 1 hour, the input should be, at least, $V_{in(pk)}=13.8V$, $I_{in(pk)} = 10.4mA$. This requires more piezoelectric elements and more sophisticated control circuit for the system.

5. CONCLUSION

A small scale tree-shaped wind power system has been fabricated and tested to analyze its potential in harvesting energy from wind. Test results show the possibility

of generating appreciable amount of electricity depending on the number of piezoelectric materials applied. A sophisticated control circuit also might be very useful to enhance the system performance considered in the present analysis.

ACKNOWLEDGEMENT

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