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Energy Harvesting from Wind by Piezoelectric for Autonomous Remote Sensor

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ABSTRACT. Reduction in fossil fuels sources in earth has caused the humans to think about using renewable energies such as wind. Collecting precise data from wind and particularly its speed is the most important step in using the wind energy as power plants. In this article, a system has been designed, analyzed, and fabricated to use wind energy by applying a piezoelectric convertor to supply the required power for a remote sensor network and wind measurement. Thus, the efficiency of the system is analyzed by performing some practical experiments. The developed system in this experiment is capable of producing 245 microwatt of energy per 200 kilo ohm resistance in an 11 m/s wind speed by using only one single piezoelectric convertor. Piezoelectric Sensor with two piezoelectric needs more force to reach the piezoelectric break point and optimized wind speed value is equal or greater than 14 m/s. In this case, the internal resistant value for piezoelectric is doubled (400 kilo ohms) and the value of produced electrical power at wind speed of 14 m/s and resistant load of 400 kilo ohms is equal to 483 microwatt. Also, it works as a sensor for measuring wind speed by producing pulses in different speeds. Therefore, it would be possible to measure wind speeds in remote areas and also wind speeds higher than the threshold level and to send alarms in warning systems in cases of thunderstorms.

Keywords: Wind energy; Sensor; Potential measurement; Piezoelectric; Receiving circuits.

INTRODUCTION

Wind speed sensors are used in order to measure wind speed to calculate the extractable energy in the region and its atmosphere. Usually, electrochemical batteries are used to supply the energy required for wireless sensor networks, but since these batteries have a limited life time and require recharging, their replacement is costly as well and they are not suitable for network security. Therefore, using piezoelectric sensors for changing mechanical energy to electrical one is a suitable solution to overcome these problems.[1] D. Marioli and A. Taroni modeled an independent sensor in 2006 using piezoelectric energy and RF transmitter.[2] Li and Lipson designed a kind of piezoelectric energy user like stem and leaf in 2009.[3]. Resonance frequency is the frequency at which the system impedance will be minimal.[4] Seo started to produce small piezoelectric sensors in 2010 in order to analyze the resonance frequency variations in different wind speeds.[5] Marinov and Bekov designed a sensor in 2012 based on PVDF for analyzing weather and speed and direction of wind and used it as a sensor to measure the potential of wind speeds.[6] Zhang and Liu developed a piezoelectric sensor with producing energy in 2012.[7] In comparison with the small usual sensors, the piezoelectric sensors do not need an external source of energy like rechargeable batteries. These sensors act as an independent system and convert the mechanical stress from wind which is on the piezoelectric surface to the electric energy and send the data wirelessly to remote areas.[8] Other researches on the wind energy by piezoelectric convertors have been done in the past and some of them

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have used polymer piezoelectric with low efficiency and some other have used accelerators to increase the speed of wind.[9] The energy obtained in those researches was much less than what was reached in this article (approximately 155 microwatts). In some other researches the obtained energy was not even enough to run the system and a PULL-UP system was used to increase the efficiency.[10] Moreover these works were not considered to be suitable because of using lots of mechanical parts, being too heavy, and having low efficiency. This article has a great importance because it uses ceramic piezoelectric with high efficiency and better performance of piezoelectric convertor and obtaining a power of 245 microwatts without voltage regulator and using only one resistor as consumer. In most previous studies, the obtained power was delivered to passive load and then measured, but in this article a voltage adjustor is used to produce a constant voltage for the end users. With the fabricated piezoelectric sensor, some experiments were performed to analyze the effect of wind speed on sensor performance and to obtain the best suitable wind speed. Furthermore the effect of piezoelectric series connection was analyzed. The designed system in this article not only produces the energy required to run a wireless sensor network without battery, but also measure the wind speed.

MATERIALS AND METHODS

Design and Analysis of Mechanical Part of Piezoelectric Sensor

The goal is to design, analyze, and produce suitable piezoelectric sensor to measure potential of wind power. Therefore, the mechanical part of piezoelectric sensor was first designed and fabricated using ceramic diaphragm piezoelectric type. The following relationships are true for piezoelectric design.

$$\Delta x = \frac{3}{4} d_{33} . g_{33} . T . \frac{L^2}{t} \quad (1)$$

$$V = \frac{Q}{C} = g_{33} . T . t \quad (2)$$

$$P = \frac{1}{2} . C . V^2 . f \quad (3)$$

In eqs. (1-3):

Δx: displacement of piezoelectric element compared to its original status, in m/s

d33, g33: piezoelectric constants

T: mechanical stress, in Pa

L: piezoelectric element length or diameter, in mm

t: piezoelectric thickness

C: piezoelectric static capacity, in Farad

f: piezoelectric fluctuating frequency, in Hz

P: electrical power, in watt

In fact, according to eq. (1) which is the relation between applied mechanical stress on piezoelectric element and its displacement, the increase in wind speed results in increase in displacement of piezoelectric element (Δx) and then increase in applied mechanical stress over the surface of the element.

Although ceramic piezoelectric have little flexibility and are vulnerable, but have high electromechanical coupling and high piezoelectric coefficient which makes them to have high efficiency and high capability to produce energy from wind and to run the RF transmitter.[11] Therefore, in environments protected from impacts, ceramic piezoelectric is a better choice in obtaining energy from wind. The ceramic piezoelectric is shown in Fig. 1 and is a diaphragm piezoelectric type. This model with the code of FT-50T-1.0 A1 Has the following features:

- Resonant Frequency: 1.0±0.1KHz
- Resonant Impedance: 500Ω
- Static Capacitance: 30±30%nF
- Φ50
- Brass
- RoHS

with dimensions 50mm for metal sheet diameter (D), 25mm for electrode surface diameter (d), 0.2mm for metal sheet thickness (t), and 0.52mm for the total thickness (T).

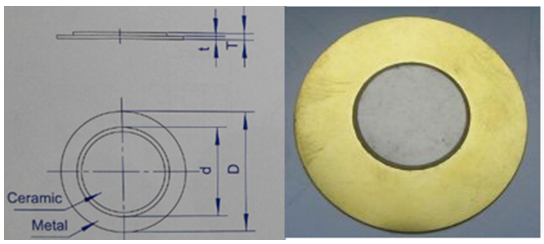

Fig. 1: Piezoelectric ceramic.

The mechanical part of a system is the main factor in operation and better performance of that system. Therefore, the mechanical part of piezoelectric sensor must be designed in such a way that the most mechanical pressure be applied on the element surface and the converted energy should have the highest efficiency. Since the aim of this article is to convert wind energy, a computer fan is used which runs with wind. Then a wooden blade (Fig. 2a) is designed and attached to the middle of the computer fan to apply the stress on the element surface. The wind turns the fan and the wooden blade. This wooden blade is designed in such a way that in each turn, it moves the piezoelectric element vertically. The mechanical structure of this sensor is shown in Fig. 2b. As shown, a piece of cardboard is attached to the edge of ceramic piezoelectric to protect it from damages.

a)

b)

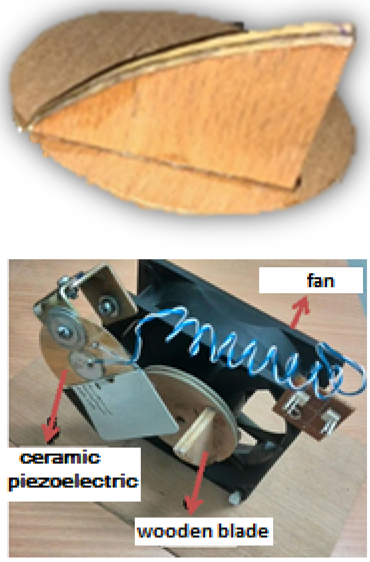

Fig. 2: a) Wooden stick in center of fan. b) Mechanical structure of piezoelectric sensor.

Designing Electrical Part of Piezoelectric Sensor

When the piezoelectric ceramic bended, it produces AC electrical signal. In order to use this signal as an energy source, the output port of the converter is connected to a rectifier in the form of Diod Bridge with little losses (microWatt). Then the rectified signal is stored on a capacitor to be used later. Fig. 3 shows a block diagram of energy receiving system based on piezoelectric. Since the voltage of the capacitor is not constant, it was necessary to use a voltage regulator to produce a constant voltage for circuit. Therefore, a regulator which has a low value of losses named LTC3588-1 made by Linear Technology Co. was used. This regulator with its relevant energy circuit is designed and fabricated in the form of a small energy storage board (Fig. 4). Piezoelectric sensor is connected to PZ_1 and PZ_2 ports of regulator named LTC3588-1. The produced electrical energy by sensor is transferred to the LTC3588-1 regulator via these two ports. After rectifying AC signal by Diode Bridge, the intended regulator stores it inside the 22 µF electrolytic capacitor, which is connected to CAP port of the regulator. The capacitor, then starts charging and as soon as reaching a charge of 5 volts, the regulator would send a voltage of 3 volts to the external port. Transmitting module of UD-TX-V18, with an approximate range of 30 meters and working voltage of 3 volts, is connected to Vout, the external port of the regulator. This module receives the 3 volts from regulator LTC3588-1 and sends the information about the wind flow in pulses during the discharging of the capacitor. Fig. 5 shows the receiving wind energy system in the transmitting side.

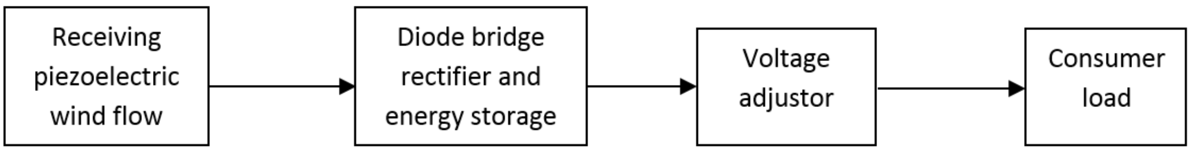

Fig. 3: Block diagram of receiving energy system based on piezoelectric.

Fig. 4: Small energy storage board with using LTC3588-1 regulator.

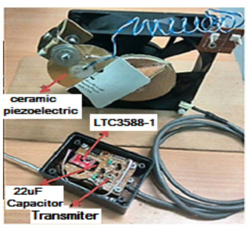

Fig. 5: Receiving wind energy system in transmitting side.

Sensor Performance in Transmitting Side of RF Transmitter

In designing the electrical part of piezoelectric sensor, we need a transmitting module with low working voltage and low current to transfer information wirelessly. In this research, a transmitter module RF named UD-TX-V18 with working voltage of 3 volts and WJ-813Ja receiver module used. The electric energy produced by the mechanical stress caused by wind on ceramic piezoelectric surface has been used in the transmitter side as a transmitting energy source. Fig. 6 shows the schematic of electrical circuit in transmitting side.

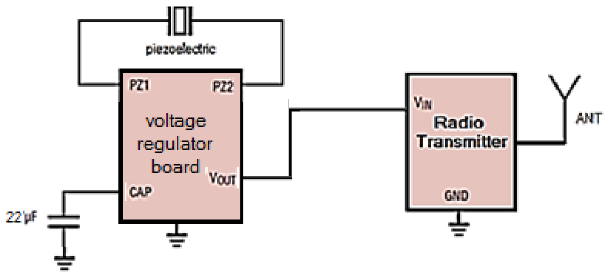

Fig. 6: Electrical circuit schematic in transmitting side.

Performance of the Sensor in Receiving Side of RF Transmitter

Fig. 7 shows the electrical circuit in receiving side. As it is shown in the figure, the receiving module, WJ-813Ja which requires a voltage of 9 volts, receives the signal from transmitting side and delivers it to microcontroller, Atmega8 with voltage of 5 V and current of 4 milliamps.

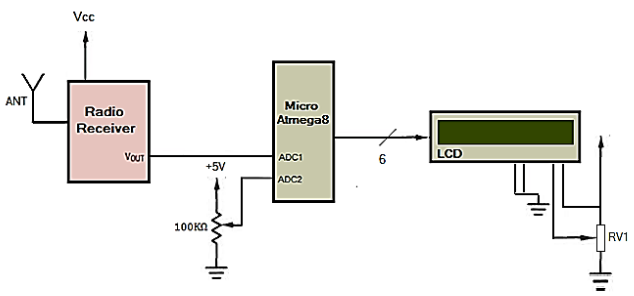

Fig. 7: Electrical circuit schematic in receiving side.

This microcontroller has two comparative ports which are sensitive to receiving signals. Since the receiving signal by receiving module contains DC voltage, then a dividing voltage circuit for the reference port has been used so that the voltage level in both ports to become the same. When a signal is given to the other port, a counter stores the data and shows the number of incoming signals during the last 10 seconds on a LCD monitor. The numbers shown on LCD monitor indicate the number of turns on of transmitter. Fig. 8 shows the wind energy receiving system in receiving side of RF transmitter.

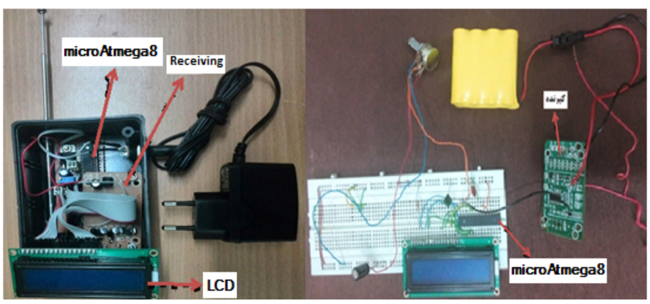

Fig. 8: Wind energy receiving system in receiving side.

RESULTS AND DISCUSSION

Analysis of Piezoelectric Sensor in Laboratory Dimensions

In order to perform practical experiments on fabricated piezoelectric sensor in laboratory dimensions, a fan was used which can create wind speed from 5.5 m/s to 14 m/s. The produced voltage resulted from the mechanical stress from wind flow over the piezoelectric surface is transferred by transmitter in the form of pulses after being processed by LTC3588-1 regulator. Within 10 seconds the pulses are received by receiver and are stored by Micro and after 10 seconds the number of received pulses are shown on the LCD monitor.

Fig. 9 shows the graph of the number of produced pulses in different wind speeds. As shown, the number of produced pulses by transmitter is increased up to the optimum value of 11 m/s for wind speed.

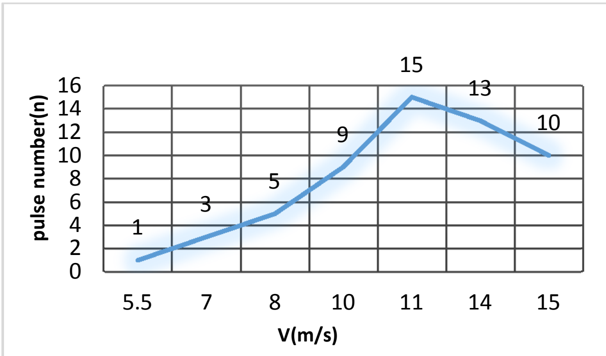

Fig. 9: Graph of produced pulses vs. wind speed.

At the wind speed of 11 m/s, the number of produced pulses by transmitter (15 pulses) is Maximum and the number of produced pulses is decreased to 13 pulses at the wind speed of 14 m/s because of reduction in displacement of piezoelectric element. Therefore, it can be concluded that intended piezoelectric sensor has reached its piezoelectric break point (a point after which the piezoelectric resistance to wind flow starts to decrease) at wind speed of 11 m/s.

But too much increase in wind speed causes the increase in rotation of blades in fan and the wooden stick in the middle of fan in such a way that the wooden stick do not give a chance to piezoelectric element to lower down and keeps it up at all times. Therefore, the displacement of piezoelectric element and amount of mechanical stress over the surface will decrease in some degrees. According to eq. (1), the reduction in applied mechanical stress over the surface will result in reduction in produced electrical voltage. On the other hand, the reduction in displacement of piezoelectric element in high speeds not only reduces the electrical voltage, but also reduces piezoelectric fluctuating frequencies which according to eq. (3) reduces electrical power and consequently reduces the number of produced pulses.

Furthermore, the produced electrical power was measured with placing different resistant loads on both ends of piezoelectric sensors which are in wind flows and without voltage regulator. The graph of measured electrical power in different wind speeds and for different resistant loads are shown in Fig. 10.

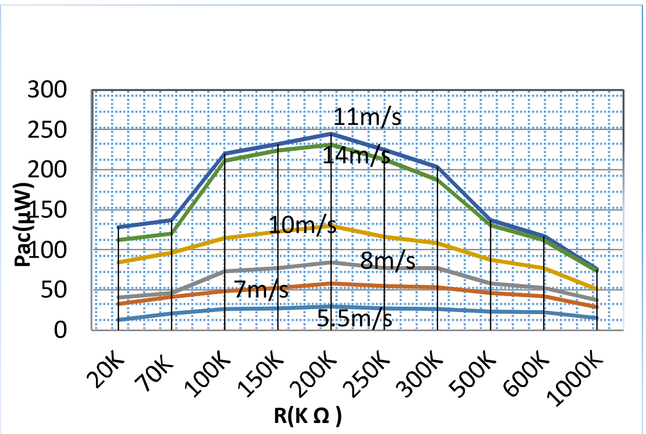

Fig. 10: Graph of produced AC power for different resistant loads.

According to Fig. 11, when the resistant load is equal to piezoelectric internal resistant (200 kilo ohms) the produced electrical power is Maximum and for the resistant loads more than 200 kilo ohms, the electric power reduces. Moreover, at optimized wind speed (11 m/s), the produced electric power for resistant load of 200 K ohm is Maximum and to equal to 245 microwatt; and for wind speed more than the optimized value (14 m/s) the electric power reduces to 231 microwatt. Therefore, it can be concluded that the produced sensor in speeds higher than 11 m/s produces less electrical voltage, less electrical power, and less number of pulses because of reduction in piezoelectric element displacement and reduction in piezoelectric resistant.

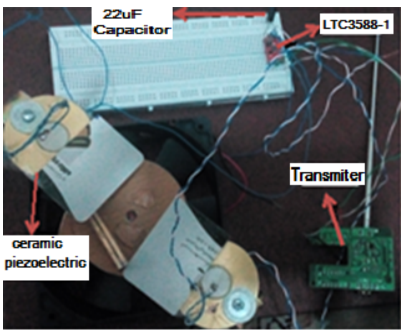

Fig. 11: Piezoelectric sensor with two piezoelectric connected to the edges of fan.

Using Two Piezoelectric Ceramic

This experiment was also performed on a piezoelectric sensor which works with two series connected piezoelectric. In this case, as shown in Fig. 11, the two piezoelectric are connected to the edges of square shaped fan and are connected in series. Fig. 12 shows a graph of the number of produced pulses versus the wind speed. According to this graph, with increasing the wind speed up to 14 m/s, the number of produced pulses constantly increases. Thus, the optimized wind speed, at which point the number of produced pulses is Maximum, is equal or greater than 14 m/s which is not measurable because of physical limitations for piezoelectric element. In fact, since the piezoelectric is placed on different edges of the squared shape fan, the friction effect occurring between the wooden blade and element surface is increased and therefore the wooden blade needs more force to reach the piezoelectric break point, consequently, the value of optimized wind speed is increased.

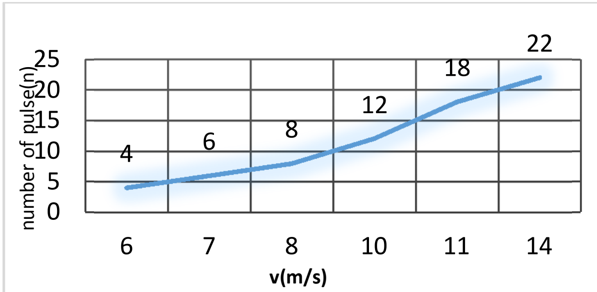

Fig. 12: Graph of the number of produced pulses for two piezoelectric converters.

In this case, different resistant loads were placed on both ends of piezoelectric sensor and the produced electrical power was measured. The graphs of produced electrical power at different wind speeds and resistant loads are shown in Fig. 13.

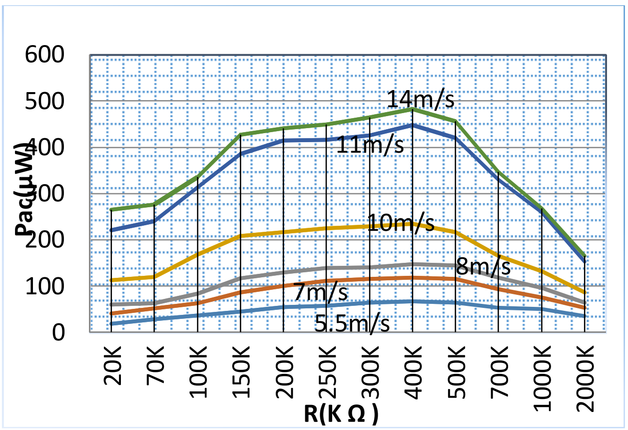

Fig. 13: Graph of produced AC power for different resistant loads.

According to the results obtained in this experiment, the produced power and electrical voltage are doubled when two piezoelectric are connected in series. Therefore, it is obvious that with using several layers or an array of converters, the produced power can be increased.

CONCLUSION

The produced energy from wind is stored by piezoelectric converters and can be used in a wireless sensor network using a very low consuming voltage adjustor. The measurements performed showed that, it is possible to produce 245 microWatt of energy at 11 m/s wind speed using only a single converter. Also, by connecting two piezoelectric converters in series, the produced power is increased to 483 microWatt; therefore, it was proved that by placing another converter on the other edge of the fan or by placing two converters on top of each other in series, the produced energy doubles. Also it is possible to use several layers of converters or an array of them to increase several times the produced energy. This increase in produced energy causes the optimum value of wind speed to increase to higher than 14 m/s which was not possible to be measured exactly because of the existing physical limitations in piezoelectric element in sensor. Therefore, with developing this system, it is possible to measure wind speed in remote areas and to identify wind speeds higher than threshold level and alarm the warning in storm recognition systems.

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