Application of Piezoelectric Material In Power Generation

Nandini Suresh Sharma[1], Sakshi Subhash Gawande[2], Yash Sudhakar Kadam[3], Pratham Babaso Hupare[4], Prof. Ashwini Deshpande[5]

[1, 2, 3, 4, 5] Dept of Applied Science and Humanities

[1, 2, 3, 4, 5] Pimpri Chinchwad College of Engineering, Pune, Maharashtra

Abstract- *The process of obtaining electric energy by converting or transforming other forms of energy to electric energy is termed as power generation. Presently electricity is one of the most extensively used sources of energy. With the increase in consumption of energy we are exhausting the natural resources hastily. There has been persistent research to bring about advancement in technology and power generation for better means of gaining sources of energy. One such conclusion is Piezoelectricity; it is a phenomenon where electric charge is produced in response to a mechanical stress applied on the material. This property of a piezoelectric material can be extensively beneficial in the field of power generation. Piezoelectric materials are substantially used as actuators and sensors. In this paper we discuss the research performed to understand more about capabilities of piezoelectric material and how a fitting electric circuit is designed to generate an appropriate amount of electric charge as an output. This shows how piezoelectric material can substitute the consumption of non-renewable sources of energy and open doors to further development to power generation techniques. In this paper we have tried to implement multiple electric circuits using piezoelectric material to harvest power.*

Keywords- Piezoelectric material, piezoelectric sensors, Full Wave Bridge rectifier, Mechanical stress, Synchronized Switch Harvesting on Inductor energy harvesting circuit Power generation

I. INTRODUCTION

In recent decades, electricity has become a necessity in modern technology and requires a great amount of electric power to carry out its various applications. This requirement has resulted in a great gap between the demand and supply of electricity at the same time the worldwide population is increasing; such factors have made humans explore alternate and sustainable sources of energy. Researchers have been studying macro and micro energy harvesting technology systems. Macro energy technologies include solar energy, wind energy and geothermal energy obtained from natural sources. Micro energy harvesting technology is on the basis of mechanical stress and strain, mechanical vibration, thermal energy obtained from heaters, friction sources and furnaces which can generate milliwatt or microwatt levels of power. With advancements in our technology, micro and nano fabrication is paving the ground which needs micro power supply. Our discussion is in conformity with micro power generation through pressure and mechanical stress using piezoelectric material.

II. THEORY

Piezoelectricity

Piezoelectricity is the electric current concentrated in materials such as batteries in return to pressure applied mechanical stress or strain. This phenomenon was discovered in 1880 by Pierre brothers, Paul-Jaques Curie and Pierre Curie. Term 'Piezoelectricity' is acquired from the Greek word 'piezein' meaning press 'elekton' meaning amber, an ancient source of electric charge. The piezoelectric property is exhibited by various materials such as sucrose, Rochelle salt, silk, polyvinylidene fluoride and many ceramics. The cause for such materials to show piezoelectricity is that they are crystalline without having a center of symmetry.

The piezoelectric effect is the result of rearrangement of net charges. When some mechanical stress or strain is applied on the material, there is charge distribution within the unit cell. This sort of deformation induces net charges on the unit cell and results in net dipole moment. The summation of net charge of all the unit cells provides electrical polarization as an outcome. Hence, applied pressure induces a voltage over the material. The reverse phenomenon, that is, the material deforms as voltage is applied to it, is called converse piezoelectric effect.

Piezoelectric material

Piezoelectric material is a material that develops polarization on the application of pressure. Various materials possess piezoelectric properties as demonstrated in the table.

Naturally occurring crystals	Quartz(SiO_2), Sucrose, Rochelle salt ($NaKC_4H4O_6–4H_2O$), Topaz, Tourmaline, Berlinite ($AlPO_4$)
Man Made crystals	Gallium orthophosphate ($GaPO_4$), Langasite ($La_3Ga_5SiO_{14}$)
Piezoelectric ceramics	Barium titanate ($BaTiO_3$), Lead titanate ($PbTiO_3$) Lead zirconate titanate (PZT), Potassium niobate ($KNbO_3$), Lithium niobate ($LiNbO_3$), Lithium tantalate ($LiTaO_3$), Sodium tungstate (Na_2WO_4)
Lead-free piezoelectric ceramics	Sodium potassium niobate (NaKNb), Bismuth ferrite ($BiFeO_3$), Sodium niobate ($NaNbO_3$)
Biological piezoelectric material	Tendon, Wood, Silk, Enamel, Dentin, Collagen
Piezoelectric polymers	Polyvinylidene fluoride (PVDF)

That said, its applications are oftentimes restricted due to its high temperature and susceptibility to liquid. To curb such limitations natural piezoelectric material is synthesized which improves their performance. A few examples of piezoelectric material apart from natural piezoelectric material are mentioned in Table 1.

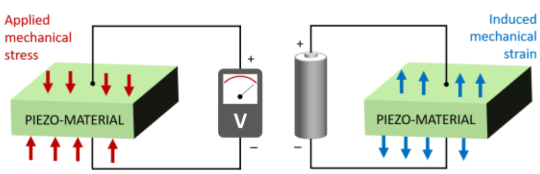

Fig. 1. Piezoelectric material

Piezoelectric Sensors

It is a device based on the piezoelectric effect which measures strain, force, pressure, tension, acceleration, or temperature by converting them to electricity. There are many types of piezoelectric sensors some of them are Piezoelectric Accelerometers, Piezoelectric Force Sensors, and Piezoelectric Pressure Sensors. An accelerometer measures the force of acceleration.

Piezoelectric sensors are distinguished into two types. One having two divisions, an ultrasound generating section, and a detecting or receiving section. They are mainly used as ultrasonic sensors in sonar systems of automobiles, medical equipment, and gas flow meters. They are also used for piezoelectric gyroscopes. Another only consists of a detecting part and function based on the piezoelectric effect. They are mainly used as knocking sensors and shock sensors.

Working

Initially when a piezoelectric crystal is positioned between two metal plates, it remains neutral without conduction of any electric charge. On application of an external mechanical pressure a rearrangement of net charges occurs an accumulation of positive and negative charges on each side of the crystal. The summation of net charge of all the unit cells of the crystal provides electrical polarization as an outcome. The net charge is collected by the plates which result in voltage that provides electrical current throughout the circuit. Piezoelectricity is a source of micro energy harvesting as whenever stress is applied a small-scale and discrete amount of charge is produced. This bears a resemblance to a capacitor. The output can be conditioned before use through different electronic components such as transformer for converting the voltage to a required scale, rectifier, a storage element, a supercapacitor and AC-DC or DC-DC converter with respect to the required form.

III. IMPLEMENTATION OF PIEZOELECTRIC SENSOR

In Tires of Vehicles

When a car is moving on the road there is pressure on the tires of vehicles due to the weight of passengers and some miscellaneous weight. It also experiences some mechanical vibrations while applying brakes. Due to the pressure along with vibration on this part of the vehicle, mechanical energy is generated that is utilized to generate electric energy using piezoelectric material. To convert this mechanical energy to electrical energy, a layer of piezoelectric sensors should be introduced in tires while manufacturing. Since the piezoelectric material is subjected to mechanical stress it gives output in the form of electrical energy. It can be achieved by manufacturing tires containing piezoelectric sensors, i.e., piezoelectric tires. In regular vehicle tires, there are distinct layers of different material such as inner liner, ply, bead and apex, breaker, tread, etc. While manufacturing piezoelectric tires there should be a layer of piezoelectric sensor that should be applied in between these layers. This piezoelectric layer is applied on the top of the ply layer. Before applying the other layer on the layer of piezoelectric sensor wiring of the piezoelectric layer is to be taken outside for later connection. When the car having piezoelectric tires is moving on the road the tires experience pressure and vibrations which causes the piezoelectric sensors inside the tires to continuously deform and relax in a cyclic process. The mechanical stress acting on a piezoelectric sensor converts to electric energy which can be used for charging the battery.

IV. OBSERVATION AND RESULT

SIMULATION

AC-DC Piezoelectric energy harvesting circuit

Rectification of alternating current (AC) power using the piezoelectric sensor can be done through an AC-DC energy harvesting circuit with the electronic components placed between the sensor and the energy storage device. We use a bridge rectifier for converting the output voltage of dual polarities into a single polarity. The AC-DC energy harvesting system connects the capacitor to the resistor on closing of the switch (Fig.) which generates an effective voltage.

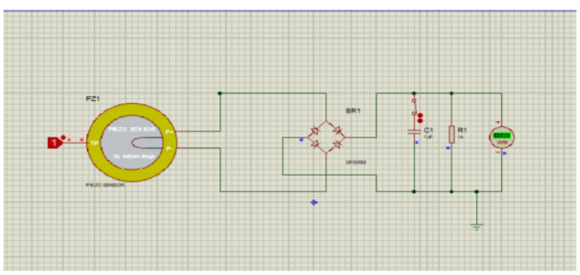

Fig. 2. Standard AC-DC energy harvesting circuit using piezoelectric sensor

Capacitor	Resistance	Voltage
1µF	1kΩ	3V

Synchronized Switch Harvesting on Inductor (SSHI)

Synchronized Switch Harvesting on Inductor is a form of non-linear technique.it helps in power harvesting from a weakly coupled system. It consists of an internal capacitor and an external that nullifies the effect of the capacitor instantly. The two distinct types of SSHI circuits are namely parallel and series synchronized switch harvesting on inductor circuits. In a parallel circuit the switch path is connected in parallel while in series it is connected in series. SSHI circuits give an increased output voltage in comparison to standard AC-DC energy harvesting circuits since, when the capacitor voltage becomes maximum in opposite polarity the switch automatically opens which flips the capacitor voltage.

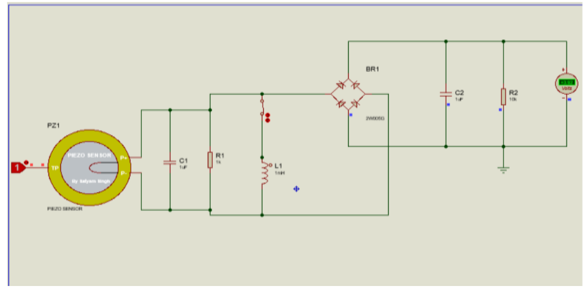

Fig.4. Parallel Synchronized Switch Harvesting on Inductor energy harvesting circuit

Capacitor	Resistance	Voltage
1µF	10kΩ	3.92V

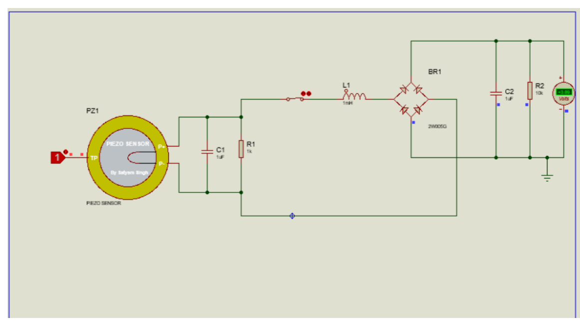

Fig. 5. Series Synchronized Switch Harvesting on Inductor energy harvesting circuit

Capacitor	Resistance	Voltage
1µF	10kΩ	3.89V

Advantages

1. It does not require any external source as it is self-generating.
2. It is convenient to use because of its compact dimensions and broad measuring range.
3. Quartz and Barium titanate ($BaTiO_3$) are easy to produce in desired shape and form.
4. It has a large dielectric constant; the crystal axis can be selected with respect to the direction of orientation.
5. It gives a high frequency response.

Disadvantages

1. The output varies with variation in temperature of the crystal.
2. If the relative humidity rises than 85% or falls below 35%, the output can be affected, in that case it is required to cover the device with polymer material or wax.
3. It is unsuitable for measurement under static conditions.

V. CONCLUSION

The simulations of the distinct electronic circuits are successfully demonstrated. On comparing the voltage generated in different circuits we understand that AC-DC standard energy harvesting circuit produces a decreased output because the generated voltage and output current do not remain in the same phase due to negative power generated. This causes in losing a portion of the obtained power since some obtained energy returns to the mechanical portion. However, this limitation is overcome by using the SSHI technique. This is done by connecting a switch path, when the voltage of capacitor gets to maximum in opposite polarity the switch opens flipping the capacitor voltage. This benefits in obtaining the capacitor charge rather than being dissipated. We have used a single unit of a piezoelectric sensor but since piezoelectricity is a small-scale energy harvesting system in practical model multiple sensor disks can be placed to give a substantial output.

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