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ENERGY HARVESTING FROM PIEZOELECTRIC MATERIALS

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Abstract - *Energy harvesting is raising area of research now as the whole world is looking for clean and green energy as an alternative source. This paper describes energy harvesting from piezoelectric materials. The proposed model of Energy Harvester from piezoelectric Materials has been presented. The MATLAB simulation model of piezoelectric energy harvester has been developed and results are obtained in the form of waveforms. The generation of electric energy when some force is applied on the sensors depends upon various factors such as number of piezoelectric transducers, electromechanical coupling coefficient of piezoelectric sensors, amount of load applied, and also on the scheme of arrangement. This paper also describes the process of making an efficient piezoelectric harvester. The model design is purely for studying the energy generation and capturing phenomenon in an efficient manner. It can be implemented to generate large power.*

Key Words: Piezoelectric materials, Energy harvester, Piezoelectric sensor, Piezoelectric transducer, converse piezoelectric effect.

1. INTRODUCTION

The demand of the fossil fuel is increasing day by day. Due to this the future of the generation of power using non-renewable energy will come to an end. This overconsumption and risks in using non-renewable energy sources is pressuring the environment as well as the economy. The use of non-renewable energy sources is creating many problems such as the global warming is increasing day by day and due to this the temperature of earth is rising every year causing more heat, erratic rainfall, storms and droughts and therefore affecting farming also. This will also result in scarcity of energy sources for the future generation. Therefore alternative energy sources are very essential for the sustainable development. Dependency on non renewable sources is decreasing day by day and on the other hand renewable energy sources are becoming popular. The renewable energy sources includes solar energy (solar cell), wind energy (wind mills), geothermal energy (geothermal power plant) etc. The use of solar energy is taking place at large scale but the drawback of solar energy is that it is limited to applications that are sunlit.

One of the ways to get a green and clean energy is by using piezoelectric materials. Piezoelectric energy harvesters are capable of generating energy through the vibrations produced in the piezoelectric materials. The main advantage of using piezoelectric energy harvester is that it can utilize the vibrations i.e. muscular or mechanical strain on various infrastructures which otherwise gets wasted. So by using piezoelectric transducers it is possible to convert the mechanical energy (vibrations) into electrical energy. This generated electrical energy is alternating in nature and can be further utilized either directly or may be stored by a storage device

The process of extracting energy out of a system and transforming it in to usable electrical energy is "Energy Harvesting". The key idea is to use piezoelectric material and harvest wasted energy caused due to vibration of a system. These wasted vibration source may be from various source like a mobile host, transport system (like road, railway, airline and runway) etc. Piezoelectric materials have crystalline structure which provides them with ability to absorb the mechanical energy from their surroundings, usually ambient vibration and transform it into electrical energy; this electrical energy thus produced can be further used to power other devices. In the recent years a lot of research has been performed in this field and finally we are able to generate sufficient energy out of a system containing piezoelectric materials. The demand of devices having independent power supply has been increasing and also we need to reduce the dependency on the coal and other non renewable sources of energy and to develop an alternate source of power facilitating green and clean energy. A vibrating piezoelectric element electrically behaves as a capacitive ac source which is rectified at later stage at a desired dc voltage level to be useful for providing power to electronic devices. Piezoelectric energy harvesting can be carried out on small scale for low power electronic system as well as on large scale to light up the city. The low power harvesting is carried out for microelectronics, wireless sensors, portable devices, remote sensing, GPS tracking, aerospace technology, biomedical instruments, nanotechnology, implantable & wearable power supply etc. The generation of high power is being carried out for consumption purpose in a green way for example "Road to electricity, Rail to electricity, piezoelectric floor mats etc."

2. FUNDAMENTAL OF ENERGY HARVESTING FROM PIEZOELECTRIC MATERIAL

2.1 Piezoelectricity

Piezoelectricity is the electric charge that accumulates in certain solid materials (notably crystals, certain ceramics, and biological matter such as bone, DNA and various proteins) in response to the applied mechanical stress. The word piezoelectricity simply means electricity resulting from pressure. This word is derived from the Greek word piezo which means to press, and electric or which stands for amber, an ancient source of electric charge. The principle of piezoelectricity depends on the crystals. The piezoelectric effect can be understood as the linear electromechanical interaction between the mechanical and the electrical state in crystalline materials. The piezoelectric effect is a reversible process which means the materials that exhibit the direct piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force) also contain the reverse piezoelectric effect.

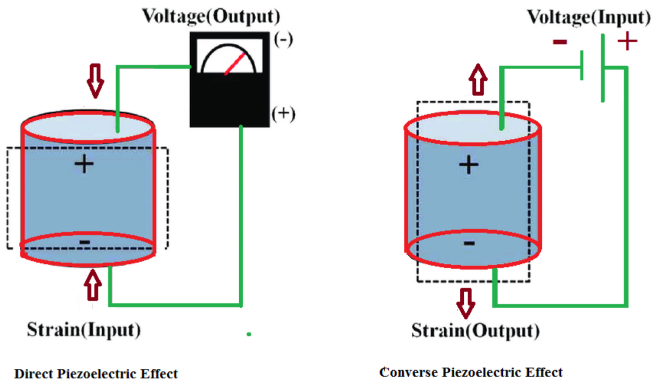

Fig -1: Disk showing direct and converse piezoelectric effect

2.2 Mechanism

The character of the piezoelectric effect is closely related to the occurrence of electric dipole moments in solids. The importance for the piezoelectric effect is the change of polarization P when applying a mechanical stress. This may be due to 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 be then manifest in a variation of the polarization strength, its direction or both, with the details depending on the orientation of polarization P within the crystal, crystal symmetry and the applied mechanical stress. The piezoelectric material can be classified on the basis of the piezoelectric properties. The classification is shown in the figure 2.

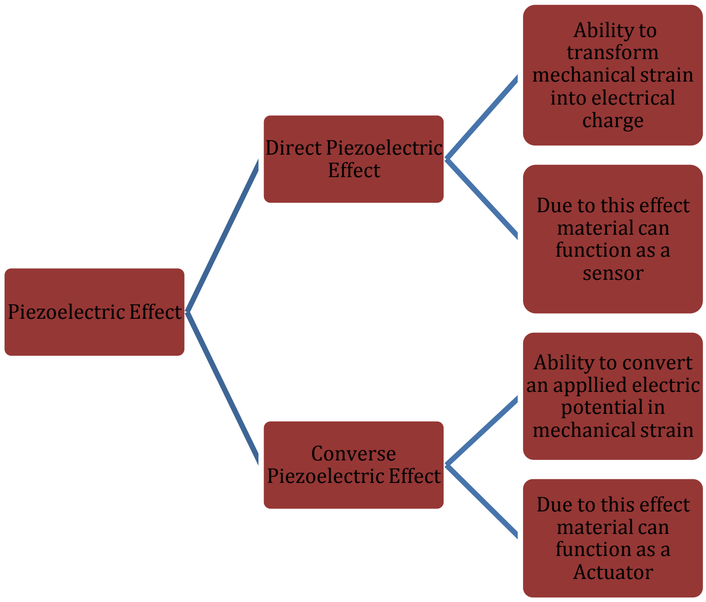

Fig -2: Classification of piezoelectric materials

2.3 Mathematical description

Piezoelectricity is the combined effect of the electrical and mechanical character of the material:

$$D = \varepsilon E$$

Where the notation D is for the electric charge density displacement (electric displacement), ε is permittivity and E is the electric field strength, and Hooke's Law:

$$S = s\,T$$

Where the notation S is for strain, s is compliance and T is stress. These may be combined into coupled equations, of which the strain-charge form is:

$$\{S\} = [s^E]\{T\} + [d]\{E\}$$
$$\{D\} = [d^t]\{T\} + [\varepsilon^T]\{E\}$$

Where [d] is the matrix for the direct piezoelectric effect and $[d^t]$ is the matrix for the inverse effect that is for the converse piezoelectric effect. The superscript E indicates a null, or constant electric field; the superscript T indicates a zero, or constant stress field; the superscript t stands for transposition of matrix. Where the first equation indicate the relationship for the converse piezoelectric effect and the latter equation represent the relationship for the direct piezoelectric effect.

2.3 Electrical Equivalent Circuit

The equivalent electrical circuit of a piezoelectric diaphragm can be given by a current source in parallel with a resistor and a capacitor. This current source is alternating in nature with the frequency of the vibration applied to the piezoelectric diaphragm. If these piezoelectric diaphragms are connected in parallel then current output of the harvester increases which is needed for various uses like charging the battery and super capacitor and also for the operation of many low powered electronics.

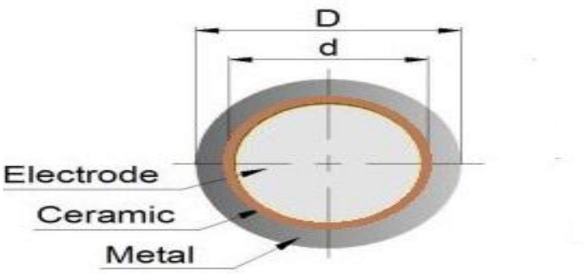

Fig -3: Piezoelectric Diaphragm

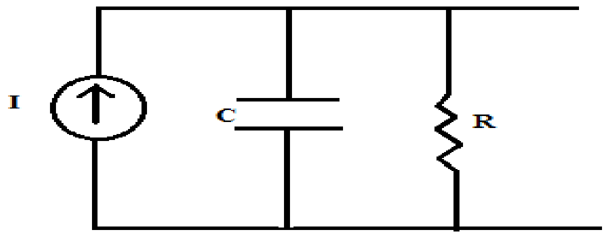

Fig -4: Electrical equivalent circuit

3. SIMULATION OF ENERGY HARVESTER MODEL

In our proposed model for the simulation and testing purpose we assumed the electrical equivalent model and connected 6 numbers of piezoelectric diaphragms in two groups i.e. 3 piezoelectric diaphragms are connected in parallel in each group. The output of these parallel connected piezoelectric diaphragms is then given to two full bridge rectifiers circuit of each group with a resistive load and a capacitor filter. This model has been created in MATLAB. The circuit diagram is shown in figure 5.The waveform is observed through scope block connected in the circuit. The waveforms are also shown in figure 6, figure 7 and figure 8 respectively. Two operations were performed i.e. one on the energy harvester circuit with resistive load but without capacitive filter and another operation on energy harvester with resistive load having capacitive filter also. In the each equivalent piezoelectric diaphragm we assumed current source of 1mA with a resistor of 10K Ohm and a capacitor of 1micro Farad connected in parallel. The frequency of each current source is taken as 10 Hertz. The rectifier taken in the circuit is full wave rectifier. The load taken is purely resistive load of 1kilo Ohm with a capacitive filter of 1 micro Farad. The above described arrangement is simulated with MATLAB in Simpower System.

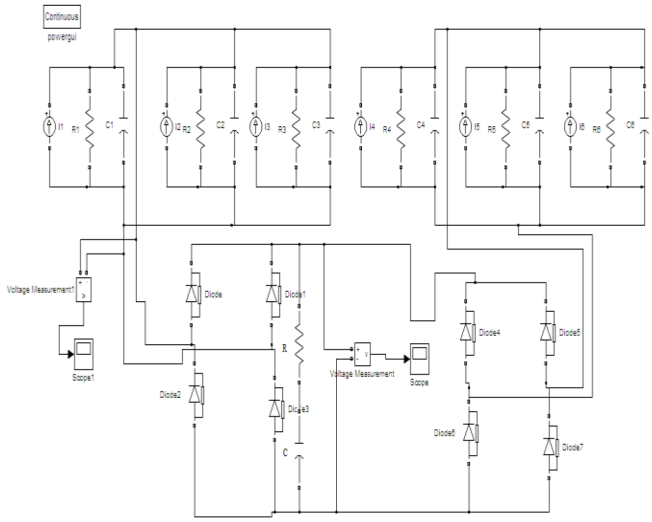

Fig -5: Simulation model for equivalent piezoelectric energy harvester

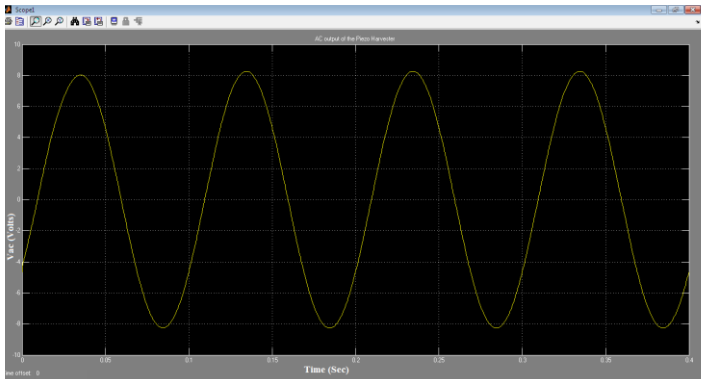

Fig -6: *AC output waveform of the piezoelectric harvester*

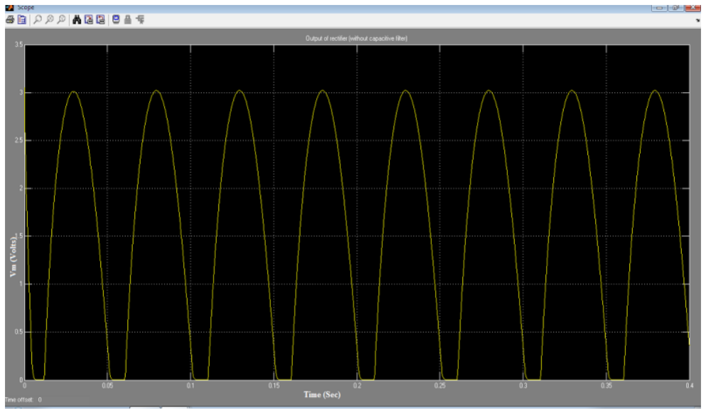

Fig.7 Rectified Output of energy harvester (without capacitive filter)

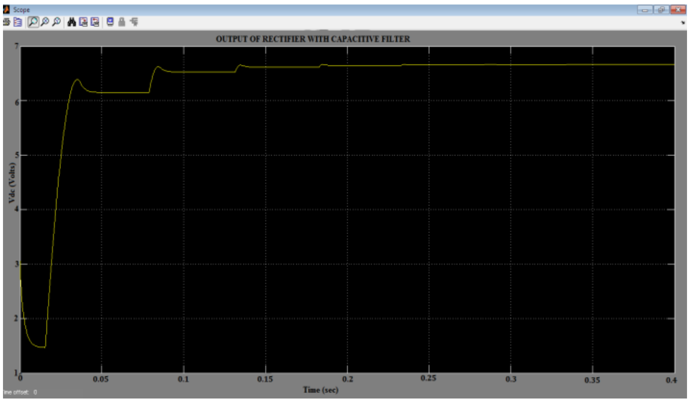

Fig -8: *Rectified output of the energy harvester (with capacitive filter)*

3.1 Results of piezoelectric harvester circuit

- The output of the piezoelectric diaphragm circuit is AC waveform. Here in this paper the circuit consists of two groups of piezoelectric equivalent diaphragm. The output of both the groups of piezoelectric diaphragm is alternative in nature as shown in figure 6. This alternative output is further passed through the full wave bridge rectifiers of each group.
- When this obtained alternative output passed through the full wave bride rectifier of each group we get the rectified output.
- If the circuit consist only resistive load i.e. without capacitive filter, the output waveform of the full bridge rectifier is a pulsating DC .It contains ripples or harmonics and the output is not smooth. This pulsating DC is not suitable for the load application. So to get low ripple output, capacitive filter is required which results in reduction in harmonics in the output.
- If the circuit consist of capacitive filter also then the ripples or harmonics get reduced hence we get a smooth waveform i.e. The filter result in smooth output waveform obtained from the rectifier and gives the DC with less harmonic component. Since the harmonic or the AC component of the signal is reduced so the ripple factor is also less which is desirable. This DC output with low ripple may be further utilized for load application for example, charging the battery or storing the power to an ultra capacitor. For an efficient and optimum harvester model a very efficient rectifier is required which rectifies and stores the energy with very low loss across it, so that there is no or very low amount of energy dissipation across it. Such an arrangement will prove to be efficient for the "Harvester Model".

The matrix arrangement is shown in the figure 9.

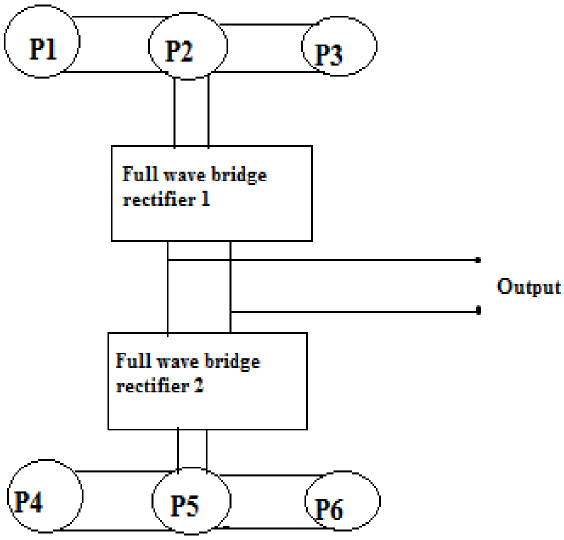

Fig -9: Matrix arrangement of the piezoelectric

4. PROCESS OF DESIGNING THE HERVESTER CIRCUIT

The process of design includes following steps:
1. Selection and arrangement of the Piezoelectric Material
2. Design of the Base on which every section will lie
3. Design of the "Shaker Model"
4. Design of the "Harvester Circuit"
5. The Storage section
6. The Boost Converter Section.

To get a efficient piezoelectric energy harvester each of the section of the circuit must be selected with a great care.

5. CONCLUSION AND FUTURE SCOPE

A piezoelectric energy harvester has been simulated successfully and the results in the form of waveforms are obtained on the scope block of the simulation circuit. It is clear from the results that to get smooth rectified output i.e. with reduced or no harmonics and ripples, capacitive filter is required and to use the generated energy can be utilized directly or can be stored in a storage device for further use. The expected result is obtained from the circuit model developed in MATLAB. There is wide scope of improvement of this energy harvesting techniques to meet the demand of the users and to make it more efficient. Improvements may be done at the rectifier stage to reduce the losses i.e. voltage drop. The storage section may also be improved. A circuit using microcontroller and logic circuit may be designed to optimize the capturing of the energy harvested. Methods of increasing the amount energy generated by the power harvesting device or developing new and innovative methods of accumulating the energy are the key technologies that will allow power harvesting to become a source of power for devices such as portable electronics and wireless sensors. Innovation in power storage such as the use of rechargeable batteries with piezoelectric materials must be discovered so that power harvesting technology will be used widespread.

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