Analyzing usage of Environmental Noise for Electricity Generation by Piezoelectric Systems

Abhishek Rajan, Akshay Krishnani, Siddharthsingh K. Chauhan

Abstract: ***In recent years with increased industrialization as well as population growth, the demand of energy is increasing day by day and as a result of which, the conventional resources are declining. Hence, the need of replacing conventional sources by renewable energy has become an issue of great importance. Due to this, now the focus is to generate electrical energy from renewable sources and piezoelectricity is one of them. This paper projects a state of technology for generation of piezoelectricity from sound using piezoelectric materials.***

Index Terms: Piezoelectricity, sound energy, mechanical vibration, energy harvesting.

I. INTRODUCTION

The increase in demand of energy has created requirement to focus on alternate sources of energy. Considering current scenario, micro-level electricity is used everywhere in the industries for low power application such as operation of microcontrollers etc. Alternate sources of energy like solar energy, geothermal energy etc. are available and piezoelectricity is one them. Piezoelectricity is generated when piezoelectric material experiences mechanical vibrations [1].

One of the example is a plan proposed in California by Energy Research and Development Division to fix a layer of piezoelectric material under the road. When vehicles pass over this road, continuous force is exerted on the piezoelectric material which generates electricity in AC form which is further rectified to operate the street lights. In this case waste energy is converted into usable form of electric energy [2]. Another example is Nike, which is introducing shoes with piezoelectric material beneath their sole so that the pressure created by foot on the piezoelectric material is converted into electricity and further used to charge appliances of micro-level power rating [3]. These materials are also used in sensors, microphones.

Piezoelectric material can be natural like a quartz crystal. But due to its low efficiency, artificially produced piezoelectric materials like tourmaline, lithium sulphate, barium titanate, Plomb Zirconate titanium (PZT) are used. Among them, PZT is preferred most of the times because of its higher efficiency compared to other materials [4]. PZT is made artificially and easily, hence abundantly available.

Revised Version Manuscript Received on July 29, 2017.

Mr. Abhishek Rajan, Department of Electrical Engineering, Institute of Technology, Nirma University, Ahmedabad, India, E-mail: abhishekrajan25@gmail.com

Mr. Akshay Krishnani, Department of Electrical Engineering, Institute of Technology, Nirma University, Ahmedabad, India, E-mail: akshay.krishnani05@gmail.com

Dr. Siddharthsingh K. Chaunhan, Department of Electrical Engineering, Institute of Technology, Nirma University, Ahmedabad, India, E-mail: siddharthsingh.chauhan@nirmauni.ac.in

Noise can be used as source of vibration which can be further used to generate electricity from piezoelectric material. Many sources of noise are available to us like noise generated by vehicles, machines and people.

This paper discusses about various noise produced in the environment and how piezoelectric material can be utilized to convert this noise into electrical energy. It also discusses about the circuitry used to rectify the output of piezoelectric material, configuration of piezoelectric material, efficiency of the process.

II. EXTRACTION OF ELECTRICAL POWER FROM NOISE

Sound wave is a form of mechanical energy which possesses energy in the form of vibrations. When a sound wave travels, it propagates through compression and rarefaction. When compression takes place, the particles come closer to each other and so the density of the medium increases. Conversely, in rarefaction, the particles move away from each other which results in the decrease of density of the medium. When this sound waves hit any material in its way of propagation, this repeating sequence of compression and rarefaction cause the material to vibrate mechanically. At this point, the sound energy is converted into mechanical vibrations.

The unit of measurement of sound level is decibel (dB). As the dB value increases, the amount of mechanical vibrations also increases. Human ears can safely listen to sound levels having dB range up to 50-55dB and in the frequency band of 20 Hz to 20 kHz. Above this, listening is possible but prolong exposure to such high level noise will eventually lead to many ear and brain related problems and can prove to be harmful.

But this high level dB level of sound can be put into use for other applications. This kind of sound produces more vibrations than that of the normal sound waves. These vibrations can be used by piezoelectric materials to generate electrical energy. When a piezoelectric material vibrates, it aligns the dipoles inside the material in one direction [3]. This creates a potential difference across the piezoelectric material. The material vibrates about the mean position in both the direction. Due to this, there is periodic alignment of the dipoles in both the directions. As a result, the potential difference available is of alternating fashion. The frequency of this AC voltage is dependent on the frequency of the sound wave that is incident on the piezoelectric materials.

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication Pvt. Ltd.

III. FREQUENCY OF THE SOUND AND VARIOUS SOURCES OF NOISE

In order to produce electrical energy from noise, the sound wave should have high intensity but this is not the only governing factor. The frequency of the sound wave also plays an important role for the vibration of the piezoelectric material [4]. The potential sources for the sound and their dB level is given in Table 1 [5]. It is clear from the table that a significant amount of energy is available in day to day life which is left unused.

Table 1: Sound level at Different Places

Place	Sound Level(dB)
Plane take-off (25m distance)	150
Aircraft deck	140
Loud music (concert)	140
Steel Mill	110
Riveting	110

Focusing on the highest potential source of energy, airports would be an ideal place from which maximum energy harvesting would be possible. Before construction of the airports, a master-plan of the same is made beforehand. A graph showing the intensity of the sound at different dB level and the frequency at the Oakland International airport is shown in the Figure 1. From the figure, it is clear that the maximum sound produced is at the frequency of 20 Hz.

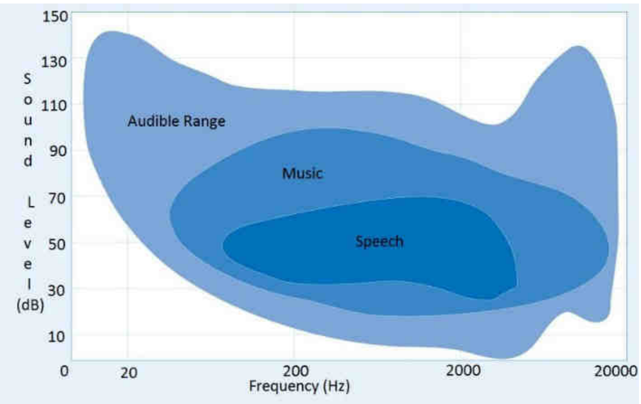


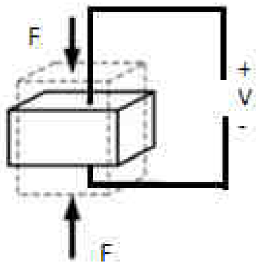
Fig. 1: Sound level at different frequency at Airport [6]

Now, the piezoelectric material that is used to absorb the sound waves also need to be tuned at certain frequency. When the sound waves of tuned frequency is incident on the piezoelectric material, then due to the mechanical resonance, the vibrations of high magnitude are produced and thus more electrical output is available. Various experiments have been done in the past regarding the same and it has been found that the maximum extraction from piezoelectric material is possible when the material is tuned for 10-30 Hz [6]. So, if a piezoelectric material is tuned for around 20 Hz and is placed at airports then it would be able to resonate with sound waves of high dB level which eventually leads to high output of piezoelectric material.

IV. ALIGNMENT OF THE PIEZOELECTRIC MATERIAL

Now, the arrangement of the piezoelectric material i.e. where the mechanical stress is applied and from where the voltage is collected, is of much importance. Such an arrangement in denoted by d_{xy} where the 'x' shows the direction along which the mechanical stress is applied and 'y' shows the direction from which is electric potential difference is obtained[7]. For e.g. d_{31}, d_{33} etc. where 1, 2 and 3 denotes the conventional positive y, x and z axis respectively. So, d_{31} means that the mechanical stress is along z-z' direction and the voltage is obtained from y-y' direction i.e. voltage and mechanical stress are perpendicular to each other as shown in Figure 2(b).

But it has been found from experiment that the maximum electrical output is available to us when the piezoelectric material is used in d_{33} mode i.e. when the mechanical stress and voltage obtained is from the same direction as shown in Figure 2(a).



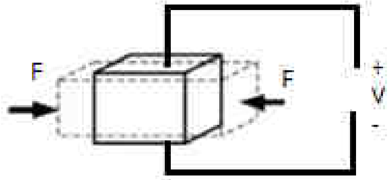


Fig. 2(a): d_{33} mode **Fig. 2(b): d_{31} mode**

V. RECTIFYING OF AC OUTPUT

As output obtained from piezoelectric material is in the AC form, it needs to be rectified. It can be done by two methods: full bridge rectifier or voltage doubler circuit [8]. On analysing both the circuits it is observed that no load voltage obtained after rectification in case of voltage doubler circuit is twice than that obtained in full bridge rectifier. The circuit diagram of both the circuits is shown in the Figure 3(a) and Figure 3(b)

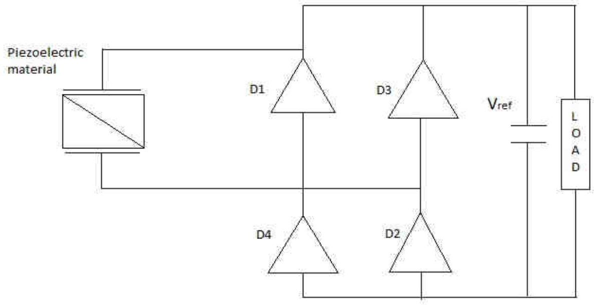


Fig. 3(a): Full Bridge Rectifier

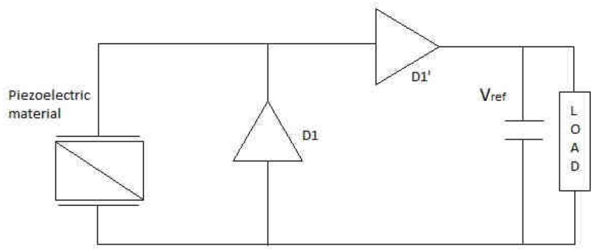


Fig. 3(b): Voltage Doubler Circuit

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication Pvt. Ltd.

Experimentally, it has been found that the maximum power extraction takes place when the output voltage after rectification (V_{bat}) is half of the output voltage of piezoelectric material (V_{pz}). Hence, in case of bridge rectifier, maximum power is extracted at $V_{bat}=V_{pz}/2$ voltage whereas in case of voltage doubler circuit, maximum power is obtained at $V_{bat}=2V_{pz}/2=V_{pz}$ voltage.

Now as we obtain maximum output at higher voltage level, current extracted is lowered in voltage doubler circuit. Due to this, the I^2R losses taking place in the diode would be significantly reduced. Also, it is evident that power dissipation in case of voltage doubler circuit is less compared to full bridge rectifier because voltage doubler uses only one diode in their filter path whereas full bridge uses two diodes at a time. Therefore, losses in full bridge rectifier is more due to more number of diodes.

VI. CASCADED CONNECTION FOR HIGH OUTPUT POWER

As discussed in the previous section, the output of the piezoelectric material is of very low range (in the range of few mW). This low output cannot be directly put into use for the appliances which are used in out day to day life. Due to this some arrangement has to be done so that the extracted energy can be put in use. Previously, amplification of the voltage was suggested, but proved out to be unfeasible as the energy consumed by the auxiliary was more than the actual energy produced by the piezoelectric material. So, the method proposed is of using more than one piezoelectric kits together, where a piezoelectric kit means a piezoelectric material connected to the voltage doubler circuit. These piezoelectric kits can be arranged on a board very close to each other such that the exposure of the every crystal to the sound wave is almost similar. This will lead to production of equal (or nearly equal) amount of energy in the piezoelectric crystals. Now these kits are either connected in series or in parallel as per the requirement. A series connection would lead to more output voltage, as shown in figure 4(a) and a parallel connection would lead to more amount of current in the output as shown in figure 4(b). Generally few kits in series and similar such rows of series crystals in parallel would be preferred as it would lead to more amount of current as well as voltage.

Now, output of such a cascaded connection would be high level DC. This can be put into small power application such as charging of Lithium ion batteries etc. But this cannot be directly done because such applications require a constant amount of source voltage. This load requirement is difficult for the piezoelectric kit to cater as it is practically not possible to make sure that the kit is continuously exposed to a sound wave of some constant dB level.

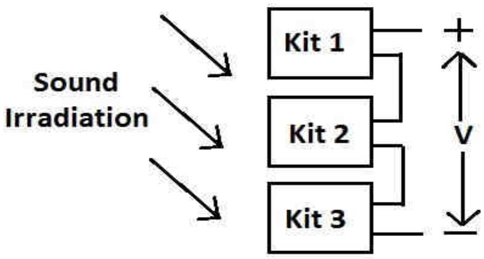


Fig. 4(a): Block diagram of series connected piezoelectric kits

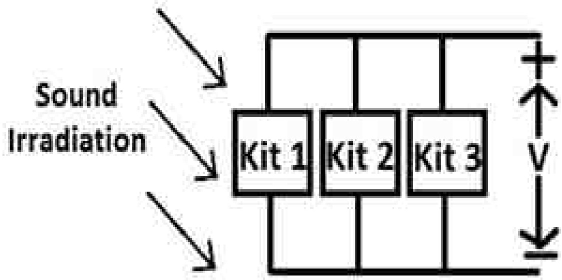


Fig. 4(b): Block diagram of parallel connected piezoelectric kits

A closed loop control can to be used so that the output across the load can be maintained constant despite the fluctuation in the output obtained from the piezoelectric material (V_{pz}) [8]. But an additional power is required for operating the control circuit which ultimately reduces the efficiency of the system. In order to mitigate such issue, the solution proposed is that the output of the kit should be stored in a capacitor. A capacitor can store the energy as and when available and also there is no constraint over the source voltage as the diodes of the voltage doubler circuit would block the flow of current from the capacitor back to kit even if the output of the piezoelectric crystal is lower than that of the capacitor voltage. Now, when the capacitor is significantly charged to the desired value, it can be used for other applications. Thus, the output of the piezoelectric material can be used in our day to day applications.

VII. CONCLUSION

This paper focusses on generation of electricity using piezoelectric material, which has emerged as a prominent alternate source of renewable energy. Various aspects of generating electricity from noise using piezoelectric material are presented here. Sources of noise having potential of generating electricity using piezoelectric material are discussed in this paper. Significance of various piezoelectric material parameters such as base material, orientation etc. for having improved efficiency are clearly stated. Series and parallel combination of piezoelectric materials help in realization of an overall system capable of generating higher power levels. Hence, piezoelectric material provide an effective solution for generating electricity from noise.

REFERENCES

1. Tanvi Dikshit, Dhawal Shrivastava, Abhijeet Gorey, Ashish Gupta, Parag Parandkar and Sumant Katiyal , “Energy Harvesting via Piezoelectricity” in BVICAM’s International Journal of Information Technology, July – December, 2010; Vol. 2 No. 2; ISSN 0973 – 5658.
2. Davion Hill, Arun Agarwal, Nellie Tong, “Assessment of Piezoelectric Materials for Roadway Energy Harvesting” for California Energy Commission, January 2014, Contract Number: 500-11-029.
3. Nathan S. Shenck and Joseph A. Paradiso, “Energy Scavenging With Shoe-Mounted Piezoelectrics” in IEEE Micro, May-June 2001, 0272-1732/01/$10.00 © 2001 IEEE.
4. M. Marzencki, S. Basrour and B. Charlot, “Design, modelling and optimization of integrated piezoelectric micro power generators” in NSTI-Nanotech 2005, www.nsti.org, Vol. 3, 2005, ISBN 0-9767985-2-2.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

5. Federal Agency Review of Selected Airport Noise Analysis Issues, Federal Interagency Committee on Noise (August 1992) and source of the information is attributed to Outdoor Noise and the Metropolitan Environment, M.C. Branch et al., Department of City Planning, City of Los Angeles, 1970.
6. E. Minazara, D. Vasic and F. Costa, “Piezoelectric Generator Harvesting Bike Vibrations Energy to Supply Portable Devices” in RE&PQJ, Vol. 1, No.6, March 2008.
7. Haris Fazilah Hassan, Syed Idris Syed Hassan and Rosemizi Abd Rahim, “Acoustic Energy Harvesting Using Piezoelectric Generator for Low Frequency Sound Waves Energy Conversion” in Haris Fazilah Hassan et.al / International Journal of Engineering and Technology (IJET), Vol 5 No 6 Dec 2013-Jan 2014, ISSN : 0975-4024.
8. Ahmadreza Tabesh, and Luc G. Fréchette, “Ultra Low Power Stand-Alone Circuitry for Harvesting Energy From A Micro-Power Piezoelectric Generator” in Proceedings of PowerMEMS 2008+ microEMS2008, Sendai, Japan, November 9-12, (2008).

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.