Review of Vibration Energy Harvesting

Mr. Kiran J. Shinde[1], Prof. Nitin V. Satpute[2], Prof. R.K. Bhagat[3]
[1] PG Student, Dept of Mechanical engineering
[2, 3] Assistant Professor, Dept of Mechanical engineering
[1, 2, 3] VIT, College, Pune-411037

Abstract- *Different forms of Energy are available in surrounding nature which otherwise will be lost. Energy harvesting is the process of converting waste or non-usable energy to useful energy. Most of the time harvested energy is stored in the form of electrical energy. This review paper mainly focused on ongoing research and study in the field of vibration energy harvesting. Conversion of vibration energy into electricity to power small sensors and electronic devices has motivated researchers a lot. This motivation resulting into number of different proof of concepts, prototypes, mathematical modeling and simulations, which is main focus here.*

Keywords- Bi-stable, Energy harvesting, resonator, wideband, Frequency Tuning.

I. INTRODUCTION

The need of power is not going to end and at the same time the sources of power supply are limited. Thus to avoid dependency over conventional power supply sources energy harvesting is needed. Now daysTo power small electronic sensors and devices batteries are used. The energy density of batteries is not increased as much as the capacity and performance of electronic devices increased in last years [1]. There are different sources of energy such as solar energy, thermal energy, vibration energy, wind energy, radio frequency which can be harvested. The energy density available is significant enough to power small electronic sensors and nodes of IOT [11].

II. ENERGY HARVESTING SOURCES

Depending on the form of energy scavenged to electrical energy or other usable form, energy harvesting classification can be organized. For example piezoelectric harvesting devices scavenge mechanical kinetic energy and convert it into electrical energy which can be stored and further supplied to devices. The different sources for energy harvesting are tidal energy, wind turbines, photovoltaic cells, and thermo-electric generators, wireless energy mainly RF and mechanical vibration devices such as piezoelectric devices, electromagnetic devices and electrostatic devices. Table 1 shows some of the harvesting energy sources with their power generation capability.

Table1: Sources of Energy Harvesting [13]

Energy	Source	Power Density
Acoustic Pressure	75 dB	0.003μW/cm^3
	100 dB	0.96μW/cm^3
Thermal	Temprature diff.	10μW/cm^3
RF	High frequencies	1 μW/cm^2
Solar	Direct sun light	10 mW/cm^2
	Office conditions	100μW/cm^2
Vibrations	Human power	4μW/cm^3
	Machines	800μW/cm^3
	Piezo	200μW/cm^2
Wind	Airflow	1μW/cm^2

As vibration energy is main focus, the vibration sources available in day-to-day life can be listed out as follow on the parameters of acceleration and frequency. From Table 2 it can be observed that the common range of frequency available is within the range of 5Hz-100Hz. The benefit with the low frequency is more will be the amplitude. Higher amplitude results into higher deflection and hence more will be power output.

Table 2: Sources of vibration [16]

Vibration source	Acceleration (m/s^2)	Frequency (Hz)
Car engine compartment	12	120
Base of 3-axis machine tool	10	70
Blender casing	6.4	80
Clothes dryer	3.5	80
Person tapping their heel	3	1
Car instrument panel	3	13
Door frame just after door closes	3	90

III. MATERIAL AND METHODOLOGY

The vibration energy harvesting is tackled by three different methods based on the principles of piezoelectric effect, electrostatic effect and electromagnetic effect. Most of the researchers have worked on the piezoelectric effect, as it is simple way to carry out electricity from vibrations. The charge separation with in the material due to strain applied causes current to flow in piezo material. This strain causes due to vibration or system made such a way that piezo material stretches converting vibrations to electricity. Electromagnetic energy harvesting works on the faradays law of electromagnetic induction

A. Piezoelectric Material

Quartz, Rochelle salt, Cane sugar, Lead titanate (PbTiO3), Barium titanate (BaTiO3), Poly vinylidene fluoride (PVDF), Lead Zirconate titanate PZT, Berlinite (AlPO4)

B. Magnet materials:

Typically, four types of magnet materials are available as follows

1) Alnico
2) Ceramic (hard ferrite)
3) Samarium cobalt (SmCo) and
4) Neodymium iron boron (NdFeB).

The properties of these materials are mentioned in Table3.

Table 3: Magnet Materials and Properties[11]

Material	$(BH)_{MAX}$ (kJ/m3)	Flux density (mT)
Ceramic	26	100
Alnico	42	130
SmCo (2:17)	208	350
NdFeB (N38H)	306	450

IV. DIFFERENT APPROACHES TOWARDS VIBRATION ENERGY HARVESTING

The energy harvesters are designed for particular one natural frequency considering the ambient source of vibration. But vibrations available are not of the same frequency always as that of natural frequency of harvester. So the effectiveness of energy harvester depends on the working range or band of frequency.

Recently the research going on the topic of non-linear bistable systems proved that these systems working under good conditions can perform better in the form of energy extracted than the linear resonator [3-4]. Non-linear bistable systems are generally found as the clamped-clamped cantilever beam with initial compression provide along the length of beam. When force applied in perpendicular direction beam shows bistable Behavior. The mechanical force applied is in the form of vibration which causes beam to snap through two bistable stages. It has been confirmed that the proposed solution, the “Double Piezo-Non Linear Harvester”, is able to supply enough energy to power small electronic devices. In particular, the energy harvester is able to convert low frequency mechanical vibrations into electrical energy. Compared to traditional linear harvesters, the bistable dynamics produces an improved device behavior in terms of an addition of the frequency band where the device is able to harvest energy from mechanical vibrations. Other main benefit of the proposed method is the wide frequency band that convinces high device effectiveness at very low charge [5].

V R challa et al. proposed the cantilever beam with two magnets and found assuring results. The device is composed of piezoelectric beam and tungsten mass at tip. Device produces electricity based on the principle of piezoelectric effect. Generally proof mass added to lower the frequency and increase the amplitude of vibration. For frequency tuning a magnetic force technique is used here. For that four permanent magnets are used. Two magnets are fixed on the tip of cantilever beam and other two at top and bottom vertically aligned. Here attractive magnetic force is used to tune with lower frequency than the resonance and repulsive force is used to tune with higher frequency than the resonance frequency. The distance between magnets kept adjustable. This technique assisted resonance tuning to ±20% of the unturned resonant frequency. A piezoelectric cantilever beam with a natural frequency of 26 Hz is used as the energy harvesting cantilever, which is effectively tuned over a frequency range of 22–32 Hz to facilitate a continuous power output 240–280 μW over the complete frequency range tested [6].

The significant sensitivity to impulse kind actions earlier exposed for bistable oscillators has motivated latest experimental and numerical studies on the power generation performance of bistable vibration energy harvesters. R.L. Harne et al. To lead to an effective and efficient predictive tool and design guide, his research develops a new analytical approach to estimate the electro-elastic response and power generation of a bistable energy harvester when excited by an impulse [7].

A different approach proposed by M. Ferrari et al. based on nonlinear converters that exploit stochastic resonance with white-noise excitation. This system is composed of piezoelectric cantilever beam with magnet at its tip. Other permanent magnet is fixed on support so that cantilever possesses two stable positions. Due to this two stable positions energy harvester is called as bi-stable energy harvester. The matlab simulation shows the under proper conditions, the system bounces between two stable states responding to random excitation. This improves energy harvesting from wide-frequency band of vibrations [9].

Triboelectric Nano generators (TENG), a novel technology for harvesting ambient mechanical energy based on triboelectric effect, have been proven to be a economical, simple and strong approach for self-powered systems. Weiqing Yang et al. revealed a rationally designed triple-cantilever based TENG for harvesting vibration energy. The device is composed of three cantilever plates: Bottom of upper plate and top of lower plate coated with poly-di-methyl siloxane (PDMS) films and both faces of middle plate coated with ZnO nanowire arrays grown by chemical approach. With the help of nanowire groupings fabricated onto the surfaces of beryllium–copper alloy foils, anew designed TENG harvests an open-circuit voltage up to 1.01 V and a short-circuit current of 55.7 μA with a peak power density of 252.3 mW/m2. The TENG was scientifically examined and confirmed as a direct power source for straightaway lighting up 40 commercial light-emitting diodes. For the first time, a TENG device has been designed for harvesting vibration energy, especially at low frequencies, opening its application as a new energy technology [8].

The approach presented by B. Ando et al. basically depends on two parallel cantilevers each one armed with magnet on its tip, both magnets will have same magnetization and poles are also same. The device is excited by the same inertial force from ambient conditions. The non-linear elastic force caused by magnetic coupling between two cantilevers. With the excitation acceleration of 5.8g the power output near to 3.5μW measured across the load of 500 k**Ω**. The result comparison indicates that new system gives results two times better [10].

V. CONCLUSION

Harvesting energy from the ambient /surrounding environment is now being considered as the possible choice. The vibration energy can be significantly harvested to power up small electronic sensors. batteries supplying power to small electronic devices and sensors can be replaced by energy harvester. This harvester will make them autonomous systems which can be used in remote areas, for operation in the absence of human, to inspect and control systems. The current limitations of vibration energy harvesters are low energy generated, narrow band of energy harvesting frequency. From review of vibration energy harvesting it is clear that frequency tuning with the help of magnets and different mechanical structures has been increased and energy Harvesting output as well.

VI. ACKNOWLEDGMENT

We would like to thank you Prof. S. R. Bahulikar HOD of mechanical Engineering Department, VIT College, Pune for continuous support and kind words through entire Project.

REFERENCES

[1] Joon Kim, K., F. Cottone, et al. (2010).“Energy scavenging for energy efficiency in networks and applications."Bell Labs Technical Journal 15(2):7-29.

[2] [Amirtharajah R. and Chandrakasan A. P, “Self-powered signal processing using vibration-based power generation,” IEEE Journal of Solid-Stage Circuits, v 33 n 5, May 1998, pp687-695.

[3] B. Ando, S. Baglio, G. L. Episcopo, C. Trigona, “Investigation on mechanically bistable MEMS devices for energy harvesting from vibrations”, IEEE Journal of Micro electromechanical Systems 21 (4) (2012) 779–790.

[4] B. Ando, S. Baglio, M. Baù, A.R. Bulsara, V. Ferrari, M. Ferrari, G. L’Episcopo, “A Nonlinear energy harvester by direct printing technology”, Procedia Engineering, 26th European Conference on Solid-State Transducers, Euro sensor vol. 47(2012) 933–936.

[5] B. Ando, S. Baglio, A.R. Bulsara, V. Marletta, “A bistable buckled beam based approach for vibrational energy harvesting”, in: Proc. of the 17thInternational Conference on Solid-State Sensors, Actuators and Microsystems, Transducers ‘2013 & Euro sensors XXVII, Barcelona, Spain, June 16–20, 2013.

[6] Challa V.R, Prasad M. G, Shi Y, Fisher F. T. “A vibration energy harvesting device with bidirectional resonance frequency tunability.” Smart Mater. Struct-17, p.1-10,2008. stacks.iop.org/SMS/17/015035.

[7] R.L. Harne, Chunlin Zhang, Bing Li, K. W. Wang, “An analytical approach for predicting the energy capture and conversion by impulsively-excited bistable vibration energy harvesters.” Journal of Sound and Vibration 373(2016)205–222. http://dx.doi.org/10.1016/j.jsv.2016.03.012

[8] Weiqing Yang, Jun Chen, Guang Zhu, Xiaonan Wen, PengBai, Yuanjie Su, Yuan Lin, Zhonglin Wang,

"Harvesting vibration energy by a triple-cantilever based triboelectric Nano-generator" Tsinghua University Press and Springer Verlag-Berlin Heidelberg 2013. DOI 10.1007/s12274-013-0364-0

[9] M. Ferrari, V. Ferrari, M. Guizzetti, B. Andò, S. Baglio, C. "Trigona, Improved energy harvesting from wideband vibrations by nonlinear piezoelectric converters" Sensors and Actuators A 162 (2010) 425–431; DOI:10.1016/j.sna.2010.05.022

[10] B. Ando, S. Baglio, L. Latorre, F. Maiorca, P. Nouet, C. Trigona, "Magnetically-Coupled Cantilevers with Anti-phase Bistable Behavior for Kinetic Energy Harvesting" Proc. Euro sensors XXVI, September 9-12, 2012, Krakow, Poland. DOI: 10.1016/j.proeng.2012.09.334.

[11] Priya S, Inman DJ. "Energy Harvesting Technologies."Springer; 2008.

[12] Blarigan L, danzl P. &Moehlis J.(2012), "A Broadband Vibrational energy harvester." Applied physics letter,100(25),253904.

[13] Cottone F, Vocca H, Gammaitoni L., "Nonlinear energy harvesting." Phys Rev Lett2009;102:080601.

[14] Anton SR, Sodano HA. A review of power harvesting using piezoelectricmaterials (2003–2006). Smart Mater Struct 2007;16(3):R1–R21.

[15] Roundy S and Zhang Y, 2005,"Toward self-tuning adaptivevibration-based micro-generators"Proc. Smart Structures,Devices, and Systems II pp 373–84.

[16] K. A. Cook-Chennault, N.Thambiand A. M. Sastry, 2008, "Powering MEMS portable devices-a review of non-regenerative and regenerative power supply systems with special emphasis on piezoelectric energy harvesting systems." Smart Materials and Structures, Smart Mater. Struct.17 (2008) 043001 (33pp)