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Energy Harvesting using Piezoelectric Transducers: A Review

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Abstract: **For managing the soaring power demand, various types of Energy Harvesting Systems (EHS) have been developed. The energy harvesting from unutilized natural renewable sources using piezoelectric transducers is one of them. Day-by-day different analytical models are being reported with different piezoelectric transducers to improve the energy efficiency and output power of the energy harvesting systems. The goal of this paper is to review the PEH (Piezo-electric Energy Harvesting) systems developed in last decade to harness energy required for small electronics. The Piezo-electric energy harvesting system works on the phenomena of direct piezo-electric effect; i.e. the transducer generates electric energy when it is exposed to mechanical stress/pressure/vibration. The suitability of piezo-electric transducer for different applications depends upon the piezo-electric materials, their shapes and configurations. In this article the different piezoelectric materials and the transducer configurations have been discussed. The performance parameters of different piezo-electric energy harvesting systems have been analyzed and the scope of improvement in the existing systems has been discussed in this manuscript.**

Index Terms: **Energy demand, Renewable, Vibration, Piezoelectric transducer, Energy harvesting.**

I. INTRODUCTION

The global demand for usable power is jumping up day-by-day. The developed countries are carrying on with consuming more and more energy, while developing countries' demand is rising gradually. As per the "International Energy Agency's 2019 World Energy Outlook", if the developed and developing countries continue to move in the present track without changing the policy, the demand of usable energy will rise by 1.3% per year till 2040 (Agency, 2019; Newel, 2020).

The solution for fulfilling the rising energy demand lies in harvesting more and more energy from the unutilized energy sources. The classification of unutilized energy sources is shown in Fig.1. The scientists are focussing on the area of energy harvesting from natural energy sources for more than a decade. Many models/devices have been developed for clean energy harvesting from different environmental sources, vehicular sources, industrial sources, human motions etc. These energy harvesting systems have been demonstrated using magneto-electric (Bo & Gardonio, 2018; Dai et al., 2011; Li et al., 2010; Annapureddy et al., 2017), thermoelectric (Park et al., 2014; Park et al., 2019), piezoelectric transducers (Zhou et al., 2014; Accouri et al., 2017; Sarkar et al., 2019; Cui et al., 2019; Argula and Lakshmi, 2020) etc. This manuscript focuses on the utilization of renewable for energy harvesting using piezoelectric transducers.

II. PIEZOELECTRIC TRANSDUCER

Piezoelectric material generates the electrical energy when it is under mechanical stress, vibration, force, pressure etc. The energy conversion property of piezoelectric transducers makes it suitable for energy harvesting applications. Different types of piezo-electric materials used in energy harvesting process are; single crystal, lead-based piezoceramics, lead-free piezoceramics, piezopolymers etc. The classification of piezoelectric material with their characteristics and examples is explained in TABLE I.

Depending on the configuration, the piezoelectric transducers are classified as: a) Cantilever beam type, b) Diaphragm type, c) Cymbal type, d) Stack type.

A. *Cantilever beam type Piezo-electric transducer*

As shown in Fig.2, the piezo-electric cantilever-beam type transducer consists of a fix-base, a cantilever beam, tip-mass and thin piezoelectric layers. The cantilever beam is fixed at one end, which helps to operate in its flexural mode (Xiong et al., 2020). Its simple geometry helps in generating high strain. The cantilever piezoelectric transducers are categorized into

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unimorph and bimorph type depending upon the number of piezo-electric layers is bounded with the cantilever-beam. The bimorph piezoelectric transducers are well-liked in piezo-electric energy harvesting (PEH) systems, as it generates almost twice the electric energy generated by uni-morphs without changing the volume of the transducer (Mishra et al., 2018).

M.Wisehke et al. developed a piezo-electric cantilever energy harvesting system (PCEHS) using cantilever piezoelectric transducer and mounted it on a rail track. More than 500 passing trains were detected and the system was monitored for 3 to 5 minutes in every one-hour interval. It was reported that around 395 µJ of energy could be generated from the vibration generated by one passing train (Wischke et al., 2011). PZT-5H stack cantilever type composite with MC nylon packaging was used to harvest roadway energy by X. Xu et al. (Xu et al., 2017).

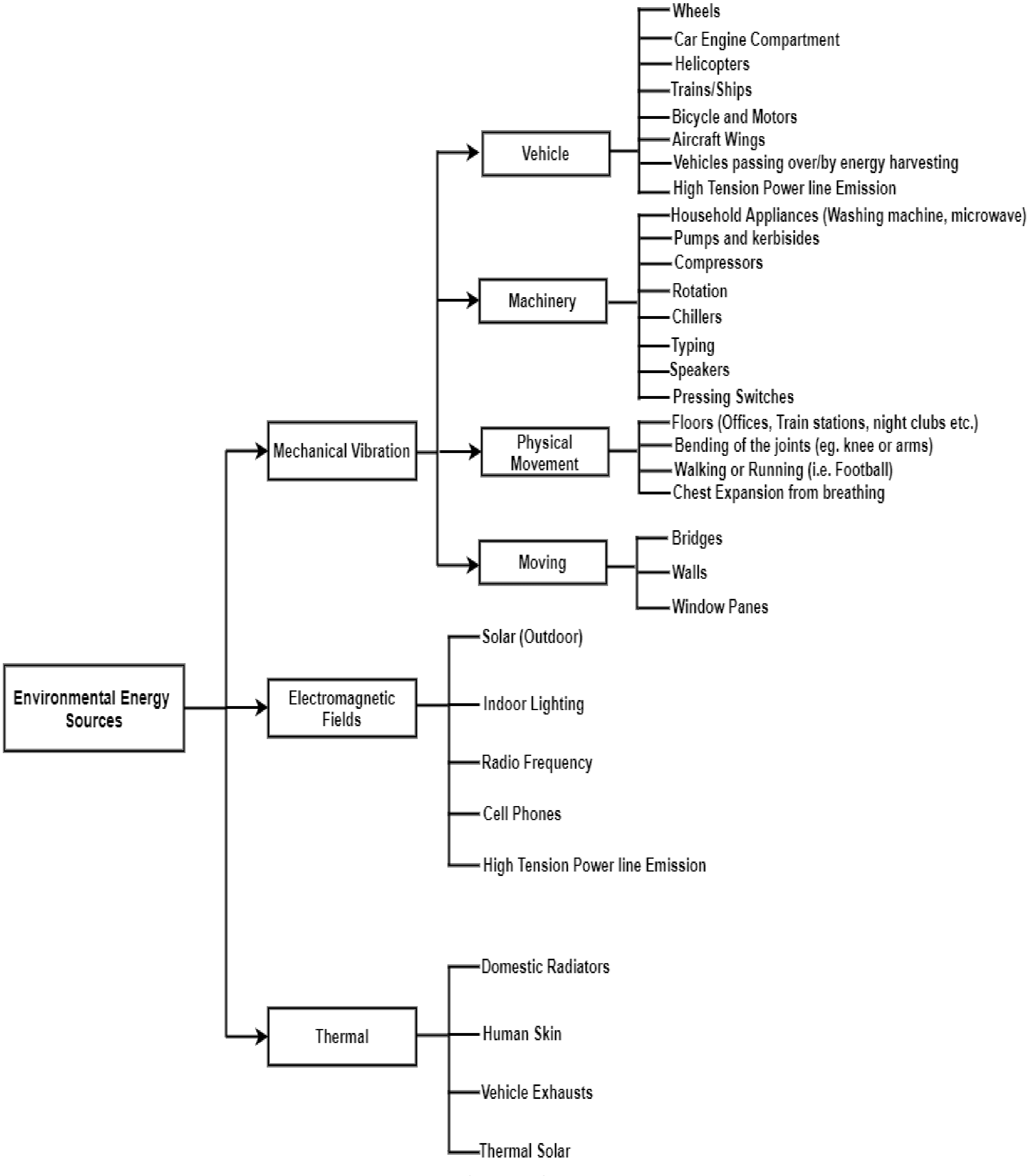

Fig 1. Classification of Energy Sources

Table I. Classification of Piezoelectric material

Class of Piezo-electric material	Descriptions & Characteristics	Examples
Single-crystal materials	➢ Bridge-man/Flux methods are used as growing techniques in singe/mono crystals. ➢ Excellent piezo-electric properties. ➢ Mainly, it has applications in the field of sensor & actuators.	Zinc Oxide (Zn O). Lead- Magnesium- Niobate (PMN)
Lead based Piezo-ceramics	➢ It is Polycrystalline in nature. ➢ It has perovskite-crystal structure. ➢ It has high piezo-electric effect. ➢ It has low dielectric loss. ➢ Simple/easy fabrication. ➢ Occurrence of lead makes it toxic.	Modified/doped PZT, for example $MgNb_2O_9Pb_3$-PZT (PMN - PZT); PZT - 5A; PZT -ZnO.
Lead- free Piezo-ceramics	➢ It is not toxic as lead is not present. ➢ Conversion efficiency is low.	Barium Titanate; $Bi_{0.5}Na_{0.5}TiO_3$; KNa (NbO_3).
Piezo-polymer	➢ Electro-active Polymer. ➢ It is Flexible. ➢ It is non-toxic and it has comparatively low weight. ➢ Low electro-mechanical Coupling. ➢ It is cost effective. ➢ Processing speed is high. ➢ It is biocompatible, biodegradable. ➢ It consumes less power as compared to other piezo-electric material.	Polyvinylidene-Fluoride (PVDS)

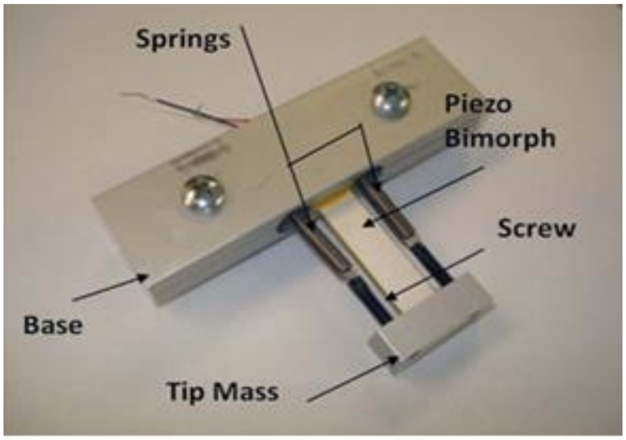

Fig 2. Cantilever beam piezoelectric transducer (Rhyme and Lajnef, 2012)

B. *Diaphragm type piezoelectric transducer:*

The diaphragm piezo-electric transducer consists of three layers. The core part or inner layer is electrode, middle layer is piezo-electric material & the outer layer is the metal shim (Fig.3). The tip mass is affixed to the core/electrode of diaphragm, to enhance the output power and its low frequency performance (Xiong et al., 2020).

E. Minazara et al. (2006) performed an experiment using piezoelectric diaphragm for vibration-energy-harvesting. They noted that a power of 0.65 milliwatt was produced at 1.71 kilohertz resonance frequency across 5.6 KΩ resistances and 80 N forces. They used a specially designed electronic circuit using “Synchronized Switch harvesting on Inductor” to improve the generated power to 1.7 milliwatt (Minazara et al., 2006).

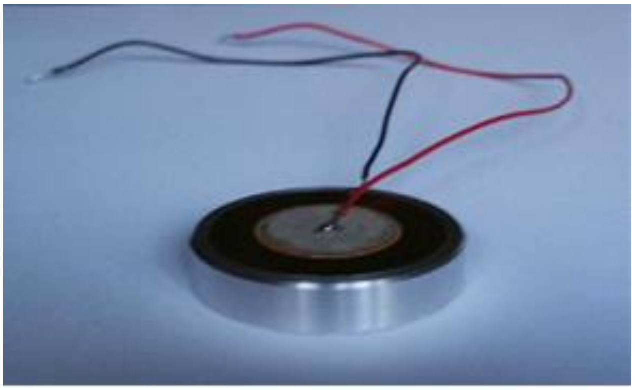

Fig. 3. Circular diaphragm piezoelectric transducer (Minazara et al., 2006)

C. *Cymbal type Piezo-electric transducer:*

The cymbal transducers comprise of a piezoelectric disc with metal capping on top and the bottom (Fig.4). The displacement of a cymbal is due to both flexure and rotational motion of the end caps. The cymbal is preferred for traffic energy harvesting systems because of its higher displacement, high stability, high contact surface and its lesser fabrication cost (Kim at al., 2004).

S. Gareh et al., from their simulation study, concluded that the piezoelectric traffic model using multiple piezoelectric cymbal transducer arrays can produce a total of 170 KW electric power for a 1-kilometre stretch considering the traffic rate as 600 vehicles/hour (Gareh at al., 2018).

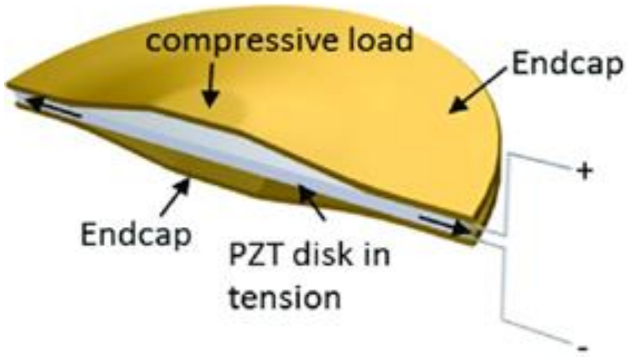

Fig 4. Half-view of Cymbal piezoelectric transducer (Yang et al., 2017)

D. *Stack type Piezo-electric transducer:*

Stacked piezoelectric transducers are the multi-layer piezoelectric transducers stacked over each-other (Fig.5). The poling direction of the layers is same as the direction of applied force. The stack type piezoelectric transducers are mostly used in high-pressure applications.

A.J. Lee et al. used a PZT-stack type piezoelectric transducer to simulate a traffic energy harvesting system on LabVIEW. They predicted that for an impulsive load of 20.8 mN the PZT-stack (SCMAP09-HI00) is capable of harvesting 0.2899 µJ energy (Lee et al., 2014).

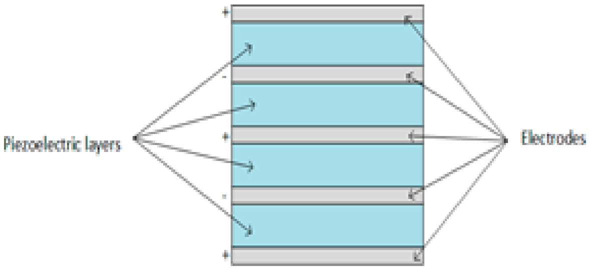

Fig 5. Stack piezoelectric transducer (Covaci and Gontean, 2020)

The merits and demerits of these four configurations of piezo-electric transducers are described in TABLE II.

Table II. Merits & Demerits of Different Types of Piezoelectric Configuration

Types of Configuration	FEATURES/Merits	Demerits
Uni-morph / Bimorph Cantilever-beam	➢ Structurally it is very simple. ➢ It has less fabrication cost. ➢ The o/p power depends proportionally upon the tip mass. ➢ It has a higher mechanical quality factor.	Not able to tolerate large impact force
Circular-diaphragm	Compatible to pressure- mode operations.	It is rigid as compared to a cantilever-beam with same size.
Cymbal	➢ Higher o/p energy. ➢ It can tolerate a large impact force.	It is not suitable to the applications which demand high magnitude vibration source.
Stacked-structures	➢ It can resist large mechanical load. ➢ Compatible to pressure- mode operations.	Highly rigid.

III. ENERGY HARVESTING FROM ENVIRONMENTAL SOURCES

As per the information provided by "Centre for Climate and Energy Solutions" (C2ES), in 2018, 26.2% of electric energy was generated globally and it is anticipated to increase to 45 % by 2040. The maximum portion of renewable energy sources are covered by solar, wind, ocean wave etc (Lee et al., 2014). Harvesting the useful energy from this unutilized renewable using piezoelectric transducer is in practice now-a-days.

An energy harvesting device has been developed using cantilever beam type piezoelectric transducer with Shape Memory Alloy (SMA). This device is capable of generating a power of 12.1 microwatt from solar energy, when the working fluid temperature is 700C and flow rate is 24 ml/second. 2.36 microwatt of power is generated at a flow rate of 4.8 ml/second with the same thermal condition. More electric energy can be generated by using more solar energy as it increases the temperature of the working fluid (Kang, 2012).

S. Wen et al. fabricated a wind energy harvester using piezoelectric cantilever beam. When the rotational speed due to wind energy is 360 rotations per minute, the device generates power of 1.38 microwatt and a voltage of 1.9 V. (Reddy et al., 2015). J. Sirohi and R. Mahadik demonstrated a wind energy harvesting device which generates a power of around 50 milliwatt when the wind flows at the rate of 11.6 m/hr (Wen et al., 2017). S.A. Oy and A.E. Ozdemir developed a piezoelectric based energy harvesting system which generates average o/p power of 519 microwatt for a wind speed range of 4.5 - 5 metre/second (Fig. 6) (Sirohi and Mahadik, 2011).

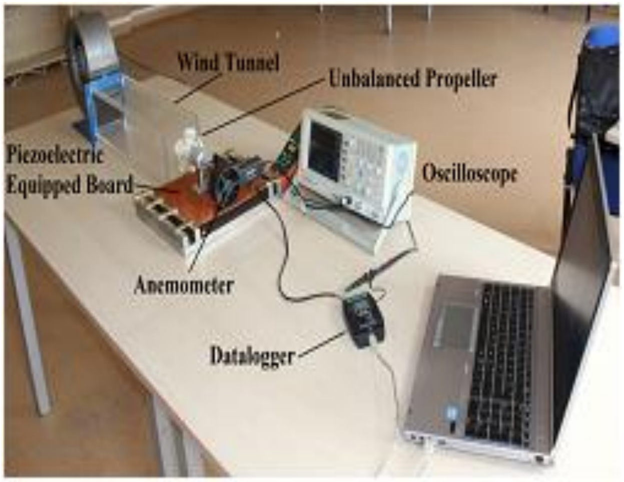

Fig 6. Wind Energy Harvester setup (Sirohi and Mahadik, 2011)

Recently, several highly efficient self-excited windmill or wind generator has been fabricated and tested using PZT (Lead Zirconate Titanate) material (Oy and Ozdemir, 2018; Zhou et al., 2019; Wanga et al., 2019; Yang et al., 2018; Wang et al., 2016; Laumanna et al., 2017; Hosseinabadi et al., 2013; Hosseinabadi et al., 2016; Zhou et al., 2016).

As per the report of United States Geological Survey released in 2020, the water covers around 71 % of the earth's surface and 96.5% of it is ocean water. Ocean wave is a great source of renewable energy. A piezo-electric coupled buoy energy harvester was developed by (Hosseinabadi et al., 2013), which generates the usable electric energy from the ocean wave. It was reported, an electrical power of 24 watt was generated using that particular system with piezoelectric cantilever of length 1 meter and the buoy length of 20 meter. The piezo-electric based ocean energy harvesting system has been studied by many researchers (Wu et al., 2015; Navabi et al., 2018; Kim et al., 2018; Viet et al., 2017; Gong et al., 2019).

The rainfalls lead to dissipation of a high amount of kinetic energy. This kinetic energy can be utilized to generate usable electric energy. Piezoelectric rain drops energy harvester setup with a spoon-full of water was demonstrated (Fig.7) (Doria et al., 2019). The performance of rain impact energy harvesters has been studied by many researchers (Ilyas and Swinger, 2017; Wong et al., 2017; Wong et al., 2014; Motter et al., 2012; Shu, 2009; Miceli et al., 2014). The efficiency of the rain drop impact energy harvesting system is very low, i.e. 0.12 % of total kinetic energy (K.E.) of the rain drops in free fall condition (Ilyas and Swinger, 2015).

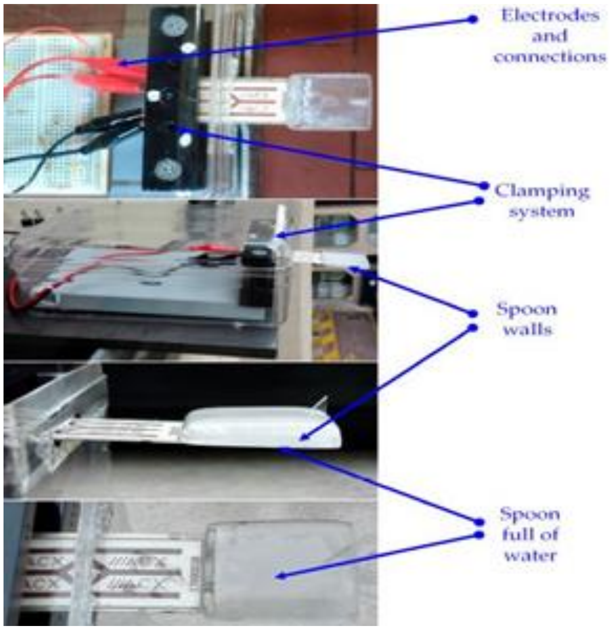

Fig 7. Raindrop Energy Harvester setup (Doria et al., 2019)

IV. ENERGY HARVESTING FROM VEHICULAR VIBRATION SOURCES

The vehicular vibration energy eventually destroys the pavement structures and it is not easy to collect that energy. The mechanical to electrical conversion property of piezoelectric transducer are used to convert the vehicular vibration energy into electrical energy. This electrical energy can be used to feed power to the road side electric appliances, such as traffic signal lights, advertising boards etc.

In 2010, Prof. H. Aramovich (CEO of Innowattech) and Associate Prof. of Technion Institute of Technology headed a project on piezoelectric energy harvesting (PEH) in roads of Israel. They observed that when the piezoelectric energy generators are installed 6 c.m. beneath the road level maintaining 30 c.m. distances from each other, the system is able to produce power of 400 kilowatt in one hour for a 1-kilometre stretch assuming the traffic of 600 vehicles/ hr (Zhang et al., 2015). Now-a-days PEH systems have been implanted in many office corridors, mostly in Japan, to lighten up LEDs when it senses the footsteps.

H. Najini and S.A. Muthukumarswamy presented a simulation-based model to advocate the idea of harvesting energy from road traffic using piezo-electric material. From this simulation work, they observed that energy of 137, 255 & 469 kwh can be yielded from a single lane road with vehicle speed of 80,100 and 120 km/hr respectively assuming the traffic of 500 vehicles per hour (Najini and Muthukumaraswamy, 2017). A. Jasim et al. have also reported numerical simulation model of PEH system for roadways applications (Jasim et al., 2018). X. Xu et al. conducted an experimental study on piezoelectric roadways energy harvesting systems. They concluded that out of PZT - 4, PZT - 8 and PZT - 5H (all at the same size), the PZT-5H posses a high voltage, high relative dielectric constant and high capacitance when load frequency is more than 5hertz. It is able to produce comparatively more power under same load. Hence, it is more suitable to be used in piezo-electric boxes for pavement energy harvesting (Xu et al., 2017). The dielectric properties of PZT-4/8/5H are listed in TABLE III (Data taken from (Xu et al., 2017)). H. Yang et al. designed a piezo-electric power generation unit using stacked array piezo-electric transducer with MC nylon as packaging material for road vibration energy harvesting. They proved the practical significance of the system by performing on-site test (Fig. 8) (Yang et al., 2017). M.V. Rodriguez et al. used PZT and lead-free PIC-700 for deigning traffic-energy-harvesting system. They concluded that the relative error in practical implementation of the theoretical model is around 3% in both the ways, by using PZT and PIC-700 (Rodriguez et al., 2019).

A number of research works have been reported on roadways energy harvesting using piezo-electric material (Li et al., 2018; Qabur and Alshammari, 2018; Wang et al., 2017; Izadgoshab et al., 2019; Jung et al., 2017; Roshani et al., 2016).

Fig 8. Piezoelectric pavement energy harvesting box (Yang et al., 2017)

Table III. Properties of PZT - 4, 8 & 5H (Xu et al., 2017)

PZT Material	ε 33	d_{33} (10^{-12} coulomb/newton)	K	Curie's Temp. (^{0}C)
PZT - 4	1300.00	250.00	0.54	300.00
PZT - 8	1020.00	220.00	0.50	310.00
PZT - 5H	2000.00	410.00	0.60	260.00

V. ENERGY HARVESTING FROM HUMAN ACTIVITIES

In a piezoelectric transducer, the usable electric-energy is generated when it is exposed to any type of stress/pressure/vibration. Vibration is found almost everywhere. Even certain human activities such as body heat, breathing, lub-dub of the heart beat and movement of various body parts while walking, jaw-movement etc. also cause vibration to certain extent. The energy harvesting from human activity is a very encouraging clean substitution to electric-energy supplied by the battery to the small transportable electric appliances.

A multi-functional shoe was designed by (Xu et al., 2017) inserting a piezoelectric transducer inside the shoe-heel and embedding the required electronic circuit on the shoe-sole for storing the electric energy. A wearable-energy-harvesting technique was developed to produce electric energy from the limb-movement by Li et al. (2018). It was reported that for one stretch-rebound limb movement cycle, the device generates a power ranging from 0.56 to 0.69 µJ for a frequency range of 0.5 to 5.0 Hz (Li et al., 2018). S.Y. Jeong et al. fabricated a tiny biomechanical energy harvesting system having dimension 4mm X 6mm X 3mm (weight=14g.) with PZT-ceramics and Light Emitting Diode switching circuit. This device is reported to produce 800 microwatts at a resistance of 400 KΩ (Jeong et al., 2019). A piezoelectric cantilever embedded shoe was designed, which provides energy of 5.6 mJ, avg. o/p power of 75 microwatt in 75 seconds of running (Fig. 9) (Al-Nabulsi et al., 2019). The podiatric sensing technique for energy harvesting has been proved to be very promising (Riemer and Shapiro, 2011; Yang et al., 2018; Khaliah et al., 2010; Howells, 2009; Cha and Seo, 2017; Rocha et al., 2010; Suripto et al., 2018; Ishida et al., 2013; Palossari et al., 2012; Meier et al., 2014; Meier et al., 2014).

Fig 9. Shoe-sole Piezoelectric Energy Harvester (Al-Nabulsi et al., 2019)

VI. ENERGY HARVESTING FROM INDUSTRIAL VIBRATION SOURCES

The industrial vibration or machinery vibration contributes a large part of total vibration energy. The mechanical parts such as motor, compressor, chillers, pump, fan, conveyor etc. causes vibration in a machine. The recent developments of PEHS generating electric energy from the vibration energy have been proved very promising.

A PEH system was developed and attached to an AC Induction motor (2 hp, two-pole, 3-phase). The horizontal-vibration was 80mG at 60 hertz. It was reported that the device was able to produce an output power of 726.2 microwatt at a target resistance of 100 KΩ in optimized condition (Fig.8) (Pathongsy et al., 2015). M. Khazaee et al. designed a self-powered / autonomous condition-monitoring-system and used that device to monitor conditions of a water pump (Fig. 10) (Khazaee et al., 2019). B. Ando et al. developed an STB (snap-through-buckling) harvester, which generates a power up to 155 µW at 5 Hz. This power is enough for running a low power electronic device or a standard WSN (Wireless Sensor Node). The avg. conversion efficiency of the system is around 15 % (Ando et al., 2017).

Fig 10. PEHS attached to an AC Induction motor (Khazaee et al., 2019)

VII. PEH SYSTEM FULFILLING ENERGY DEMAND

The low power electronic devices require power from nW to mW range for their operation. The power required to operate different devices is shown in Table IV. From the literature review, it is observed that the PEH systems developed so far generates an output power of range µW to mW (Table V & VI), which is sufficient to operate the WSNs (Wireless Sensor Nodes) and low power electronic-devices.

Table IV. Power Demand for Small Electronic Systems

Small Electronic Systems	Power Demand	Reference
32 khertz quartz oscillator.	100.0 nW	(Harrop and Das, 2011)
Electronics watch/calculating device.	1.0 µW	(Harrop and Das, 2011)
Radio frequency identification device for medicals.	10.0 µW	(Gaynor and Waterman, 2016)
Hearing aids.	100.0 µW	(Harrop and Das, 2011)
Short range (nearly 30 mm) proximity sensors	270.0 µW	(Semiconductors)
Hearing aids.	1.0 mW	(Raju and Grazier, 2015)
Auto-motive light sensors (model SFH 5711 (OSRAM)).	1.03 mW	(Semiconductors)
Sun-flower mini computation system.	1.75 mW	(Marbell and Marculesu, 2007)
Ultrawide band (UWB) transmitter.	2.0 mW	(Ryckaert et al., 2005)
Accelerometer (model ADXL 103 supplied from 5V).	3.35 mW	(Analog Devices)
Transmitter (model RFM HX 1003).	7.5 mW	(Paradiso and Feldmeier, 2001)
Potential requirement of Wireless Sensor Node working Zig-bee circuits.	10.0 mW	(Grady, 2016)
A custom designed radio (operation frequency 1.90 giga hertz)	12.0 mW	(Roundy and Wright, 2004)
Self-governing sensor modules.	20.0 mW	(Ferrari et al., 2009)
Berkeley Telos Mote.	36.0 mW	(Jiang et al., 2005)
PALM, MP3.	100.0 mW	(Harrop and Das, 2011)

Table V. Review on Performance of Piezoelectric Transducer

Piezo-electric material Used	Thickness (mm)	Application	Maximum Power generated (µW)	Frequency (Hz)	Reference
PVDF	0.41	Wind Generator	610.0	3.0	(Xianzhi, 2009)
PVDF	0.15	Self-governed Wireless	2.0	2.0	(Miso Kim, 2010)

		Sensor system			
PMN - PT	0.00084	Self-governed Cardiac Pacemaker	6.70	0.30	(Liang and Wao, 2010)
0.71Pb (Mg$_{0.33}$Nb$_{0.67}$) O$_3$ -0.29PbTiO$_3$	1.0	Piezoelectric generator	3700.0	102.0	(LeiGu, 2011)
PZT	0.8	Human limb motion- based Piezoelectric generator	47.0	1.0	(Arrieta, 2013)
PZT	20.0	Self-powered Total Knee Replacement (TKR) system	265.0	1.0	(Qiu et al., 2014)
PZT	0.30	Piezoelectric generator	2000.0	20.0	(Ming et al., 2014)
PZT & MFC (Micro Fibre Composite)	0.27	Piezoelectric generator	30000.0	50.0	(Kulkarni et al., 2014)
PMN - PZT	0.50	Piezoelectric generator	14.70	1744.0	(Sriramdas et al., 2015)
0.4Pb (Mg$_{0.33}$Nb$_{0.67}$) O$_3$ -0.6Pb (Zr$_{0.38}$Ti$_{0.62}$) O$_3$	0.20	Propeller based under water PEH System	17000.0	24.50	(Zhiran et al., 2017)
PZT – 5H	5	Shoe-integrated Piezoelectric generator	1430.0 (walk of person weighing 90 kg.)	1.0	(He and Jiang, 2017)
PZT-5H	1	Vibration Energy Harvester	1055	51	(Hua et al., 2018)
PZT-5A	0.275	Vibration Energy Harvester	530	109.5	(Kaur et al., 2019)
PZT-5A	0.5	Piezoelectric generator	2500	42	(Li et al., 2011)
PZT-5A	0.5 (2 piezo plates used)	MEMS Harvester	1080	20.1	(Bischur and Schwesinger, 2013)
PZT	0.25 (2 piezo plates used)	Broadband vibration Energy Harvester	7070	20	(Hwang et al., 2014)
PZT	1	Powering WSN	390	38	(Xu et al., 2012)
PZT-5H	3	Piezoelectric generator	3.18	93	(Renaud et al., 2009)
PZT-5A	0.5 (4 piezo plates used)	Shear mode energy harvester	570	620	(Platt et al., 2005)
PVDF	-	Multistep PEH System	8.59	30.8	(Yuan et al., 2008)
PZT	3	MEMS Harvester	979	77.2	(Henry and Sodano, 2003)
PZT-4	0.2	Multimode Energy Harvester	2350	66.7	(Erturk et al., 2008)
PZT	-	Footstep PEH System	6130	2.3 (6.2 km/hr)	(Kim et al., 2020)
PZT	0.3	Wind Generator	43.12	12	(Turkmen and Celik, 2018)

Table VI. Review on Performance of PEH System

PEH System	**Maximum Power generated/ Power density**	**Frequency (Hz)**	**Load Resistance**	**Reference**
Self-governed temperature monitoring system.	43.0 W/m^2	15.0	0.50 kΩ	(Hwang et al., 2019)
PEH System for bi-cycle.	3.40 mW	2 - 30	200.0 kΩ	(Vasic et al., 2014)
Self-governed WSN.	3560.0 µW/cm^3	1368.0	-	(Marzencki et al., 2007)
MEMS(Micro-electromechanical-system) based Piezo-electric generator.	10846.0 µW/cm^3	608.0	21.40 kΩ	(Fang et al., 2006)
Multidirectional Wind generator.	1.73 mW	15.70	15.0 kΩ	(Zhao et al., 2015)
Wind energy harvester.	10.0 µW	11.0	1.0 MΩ	(Hobbs and Hu, 2012)
Piezo-electric generator	40.0 W/m^2	2.0	6.0 kΩ	(Barrero-Gil et al., 2010)
Piezo-electric generator	300 - 400 µW	200 - 250	-	(Wright, 2006)
Piezo-electric Cantilever Vibration Energy Harvester	416.0 µW/cm^3	183.80	16.0 kΩ	(Shen et al., 2009)

Piezo-electric Vibration Energy Harvester in water vortex	1.10 Mw/ m^2	-	-	(Shan et al., 2015)

CONCLUSIONS

The transition of small electronic devices from battery-powered to self-powered or self-governed systems has been achieved by using the energy harvesting systems. The piezo-electric transducers are extensively used in energy harvesting applications due to its simple fabrication process and cost effectiveness. It possesses a high energy/power density, still there are certain disadvantages which limit the broader application range of these devices. These systems generate low output energy and need utmost power extraction, rectification, high voltage regulation and optimization of the integrated system. These drawbacks must be overcome to enhance the efficiency of PEH systems.

Out of all vibration sources, the traffic generated vibration has been proved to be very promising for the PEH applications. The roadway energy harvesting needs to be given more attention, especially in the highly populated countries, to fulfil the post pandemic energy demand.

FUTURE SCOPE

In the current scenario the focus should be given to the microminiaturization and the power-conversion efficiency of the system. The conventional half bridge and full bridge rectification techniques are not applicable for micro-mini systems. Therefore, different active rectification techniques need to be explored for co-integration with the system to fulfil both the requirements. To improve the performance of the system more focus should be given to optimization of parameters; such as mass-ratio, damping-constant, frequency, load-resistance, electro-mechanical coupling factor etc.

This work is relevant for the researchers to choose the best method of energy harvesting and invest more time and effort for enhancing the efficiency and performance of that particular method.

Conflicts of interest: We are not involved in any kind of conflict of interest.

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