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Review

Analysis on piezoelectric energy harvesting small scale device – a review

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ABSTRACT

Due to advancement of auto regulated powered wireless sensors systems; piezoelectric pulsation energy harvesters (PVEHs) have received a significant attention. Though, a popular of these devices has very low input frequencies. This paper seeks to analyze the current method to harness energy from vibration using piezoelectric setup in the low range of frequency zone and demonstrate an experiment model to validate the results from the setup. Many reviewers have given different modelling approach to optimize the performance parameter such as mass ratio, damping constant, frequency, load resistance, electromechanical coupling constant and capacitance etc. Finally, it has been found from experimentally and simulation that the maximum power harvested from the piezoelectric vibration setup depends upon the maximum deflection of the beam subjected to many dynamic constraint parameters such as inertia of the beam, maximum lift force due to wind, and lift drag characteristics curve etc.

Contents

1. Introduction

Due to the problem of global warming in the whole world, many researchers had focused their area towards eco friendly energy harvesting technique such as solar, wind, hydra and biomass etc. Now days the principle of energy harvesting from aero elastic vibration had become a key issue to supply power for small scale electronic device in remote sensing area. Many of the researchers have worked on the low power consumption electronic device such as actuator, MEMS (Zhang and Wang, 2016; Muralt, 2000; Zhou et al., 2005), the monitoring devices (Roundy and Wright, 2004; Inman and Grisso, 2006) for health checkup and the high costly battery replacement device (Capel et al., 2003) etc. Zhang and Wang (2016) obtained the maximum power harvested from Piezoelectric device at a reduced velocity $U^* = 5$ and Resonating frequency at f = 26.37 Hz, while Bischur and Schwesinger (2013) harvested the maximum power from Piezoelectric device at the thickness t = 0.15 mm and Resonating frequency at f = 2 Hz. Shukla et al. (2010) extended the work in the field of piezoelectric energy harvesting and got the Maximum power harvested from Piezoelectric device at the thickness t = 0.0.005 mm and Resonating frequency at f = 2 Hz. Li et al. (2011) harvested the Maximum power from Piezoelectric device at the thickness t = 0.41 mm and Resonating frequency at f = 3 Hz (Renaud et al., 2009) harvested the Maximum power from Piezoelectric device at the thickness t = 0.8 mm and Resonating frequency at f = 1 Hz (Platt et al., 2005) harvested the Maximum

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power from Piezoelectric device at the thickness t = 2 cm and Resonating frequency at f = 1 Hz (Yuan et al., 2008) harvested the Maximum power from Piezoelectric device at the thickness t = 0.3 mm and Resonating frequency at f = 20 Hz (Dhakar et al., 2013) harvested the Maximum power from Piezoelectric device at the thickness t = 0.51 mm and Resonating frequency at f = 36 Hz (Sodano et al., 2003) harvested the Maximum power from Piezoelectric device at the thickness t = 0.27 mm and Resonating frequency at f = 50 Hz (Erturk et al., 2008) harvested the Maximum power from Piezoelectric device at the thickness t = 0.5 mm and Resonating frequency at f = 1744 Hz (Xu et al., 2012) harvested the Maximum power from Piezoelectric device at the thickness t = 1 mm and Resonating frequency at f = 102 Hz (Hwang et al., 2014) harvested the Maximum power from Piezoelectric device at the thickness t = 0.00084 mm and Resonating frequency at f = 0.3 Hz. Meninger et al. suggested a technique to harness mechanical vibration into electrical energy and obtained the power density around 3.8 $\mu W/cm^3$ Roundy et al. constructed a MEMS device to harness electrostatic energy and obtained the power density around 1160 $\mu W/cm^3$ at 120 Hz. Williams's et al. fabricated a micro generator with dimension $5 \times 5 \times 1\ mm^3$ based on the electromagnetic induction principle by assuming of the deflection of the structure is 50 μm.

El-hami et al. constructed an energy harvesting device from vibration and produce the electricity of 4167 $\mu W/cm^3$ and 320 Hz. Ching et al. modeled a spring based on laser micro machined technique to harness vibrating energy into electrical one and obtained the power output around 830 $\mu W/cm^3$ and 60–100 frequency at 1 KΩ resistance. Xiaobiao Shan et al. harvested power from MFC (macro fiber composite) at the water velocity of 0.5 m/s Leland and Wright developed a prototype based on simple supported bimorph vibration energy harvesting method and obtained the power output around 300–400 μW at 200–250 Hz.

2. Brief review on piezoelectric energy harvesting set up

As the performance of the figuring has risen progressively, batteries have given a sharp growth over the past period. Priya (2007) and Roundy et al. (2003) had obtained the resulted power density around 15000 $\mu W/cm^3$ from direct sunlight of solar cells compare to other sources. Roundy et al. (2003) acquired the power density 150 $\mu W/cm^3$on cloudy days. Thus, the solar cell is impractical to install specifically in the embedded applications due to unavailability of absence of light and obstruction from the particles (Beeby et al., 2006; Venkatasubramanian et al., 2001; Riffat and Ma, 2003) used a thermoelectric generator based on the See beck effect to convert the thermal energy to electrical energy. A thermoelectric device generates a voltage due to temp. Huidong et al. (2014) worked on different piezoelectric configurations with digitized electrodes to optimize power output as shown in Fig. 1. While Kim (2012) extended his work in {3–1} and {3–3} as shown in Figs. 2 and 3 mode of Difference on it and vice versa known as Peltier effect (Ching et al., 2002). A review work was carried out on the power obtained from the human activities such as human blood pressure, motion of the arm, heat of the body and typing (Starner, 1996, 2004). Joseph et al. (2005) suggested that the power of amount 7 W can be harvested from the single foot of human of weight 154 pound. Cook-Chennault et al. (2008), Beeby et al. (2006), Joseph et al. (2005), Kymissis et al. (1998), and Sodano et al. (2004) had used the piezoelectric material beneath a running sneaker's to harness the energy. Reviews have been done by Cook-Chennault et al. (2008), Beeby et al. (2006) and Sodano et al. (2004) on the issue regarding energy harvesting from piezoelectric form human walking. This concept of energy harvesting has been further extended, planned and applied in the ocean energy from flexible piezoelectric membranes. Sarkar et al. (2014) had worked on extreme wind climate modeling in Indian region while Sarkar et al. (2017) studied different models on Weibull methods in different region in India. Now a day's Macro (Schmidt, 1992; Myers et al., 2007) and micro wind turbines (Cook-Chennault et al., 2008) are available to harness wind energy. Priya (2007) compared the different sources of power in sensor's network circuit. The reviews on small scale power supplies for MEMS devices can be extracted in Cook-Chennault et al. (2008). It is the property of piezoelectric material the electric charge or voltage can be produced when the mechanical force is applied on it.

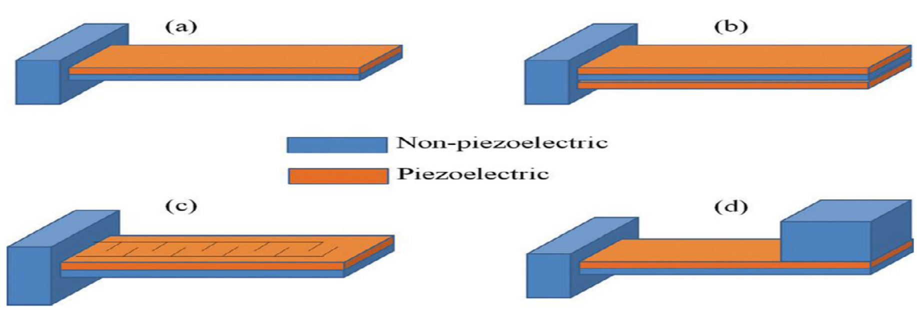

Fig. 1. Various arrangements of piezoelectric cantilevers beams: (a) unimorph; (b) bimorph; (c) a piezoelectric cantilever with inter digitised electrodes; (d) a piezoelectric cantilever with proof mass at its free end (Huidong et al., 2014).

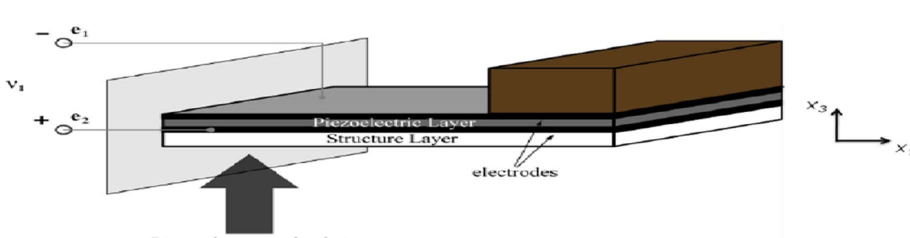

Fig. 2. Unimorph cantilevered piezoelectric energy harvester device in {3–1} mode of operation with standard electrode configuration. Note asymmetric layers and the need for a "structural" layer (Kim, 2012).

Max. Power obtained from vortex vibration is 40 W/m^2 at 10 m/s at an optimum value of and $\varepsilon^* = 0.1$ and the corresponding frequency is 2 Hz Max. Power obtained from vortex vibration is 10 μW, at R = 100 Ω and v = 1.8 to 4.3 m/s at an optimum value of $m^* = 30$ and $\varepsilon^* = 0.072$ f = 11 Hz. Max. Power obtained from vortex vibration at 5.20 to 6.67 m/s. The frequency of the vibrating vortex system is found to be 15.70 Hz Marzencki et al. suggested a technique to harness mechanical vibration into electrical energy and obtained the power density around 10 $\mu W/cm^3$ at 204 Hz. Jeon et al. suggested a technique to harness mechanical vibration into electrical energy and obtained the power density around 37037 $\mu W/cm^3$ 13.9 k Hz. Fang et al. suggested a technique to harness mechanical vibration into electrical energy and obtained the power density around 10846 $\mu W/cm^3$ 608 Hz Marzencki et al. suggested a technique to harness mechanical vibration into electrical energy and obtained the power density around 3560 $\mu W/cm^3$ 1368 Hz

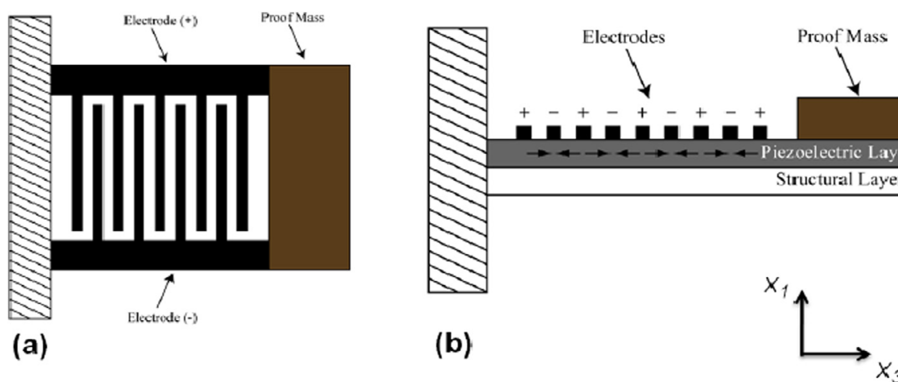

Fig. 3. Inter digitized electrode (IDTE) configuration in cantilevered piezoelectric energy harvesting {3–3} mode devices: (a) top-view and (b) side-view (Kim, 2012).

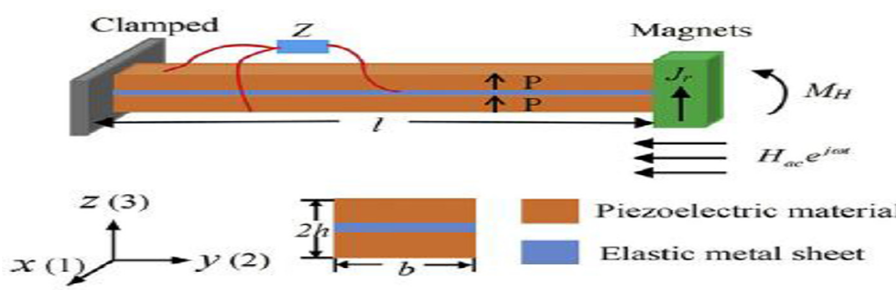

Fig. 4. A schematic diagram of single cantilever piezoelectric model.

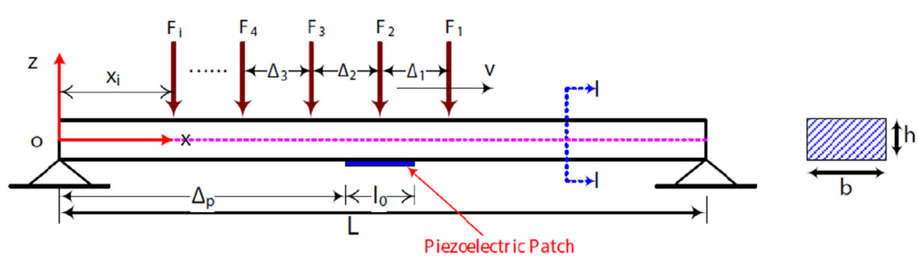

Fig. 5. Unimorph piezoelectric model with multi loads (Amini et al., 2017).

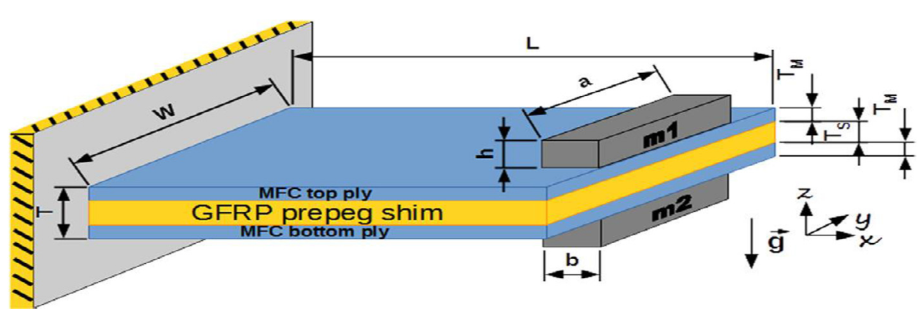

Fig. 6. A piezoelectric cantilever model (De Giuseppe et al., 2017).

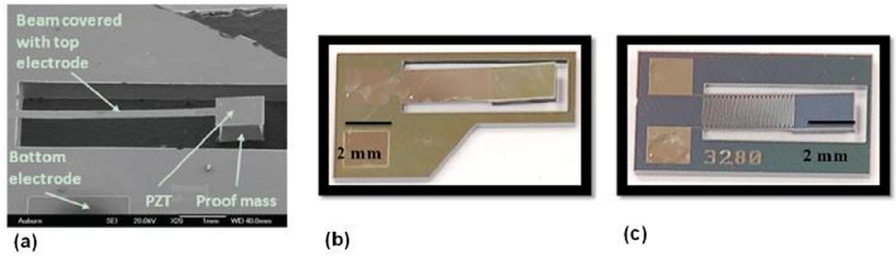

Fig. 7. Fabricated, unimorph, MEMS-scale PVEH: (a) SEM image and (b) optical image of a MEMS-scale PZT cantilever in {3–1} mode with a proof mass, (c) optical image of a MEMS-scale PZT cantilever with a proof mass in {3–3} mode with IDTEs (De Giuseppe et al., 2017).

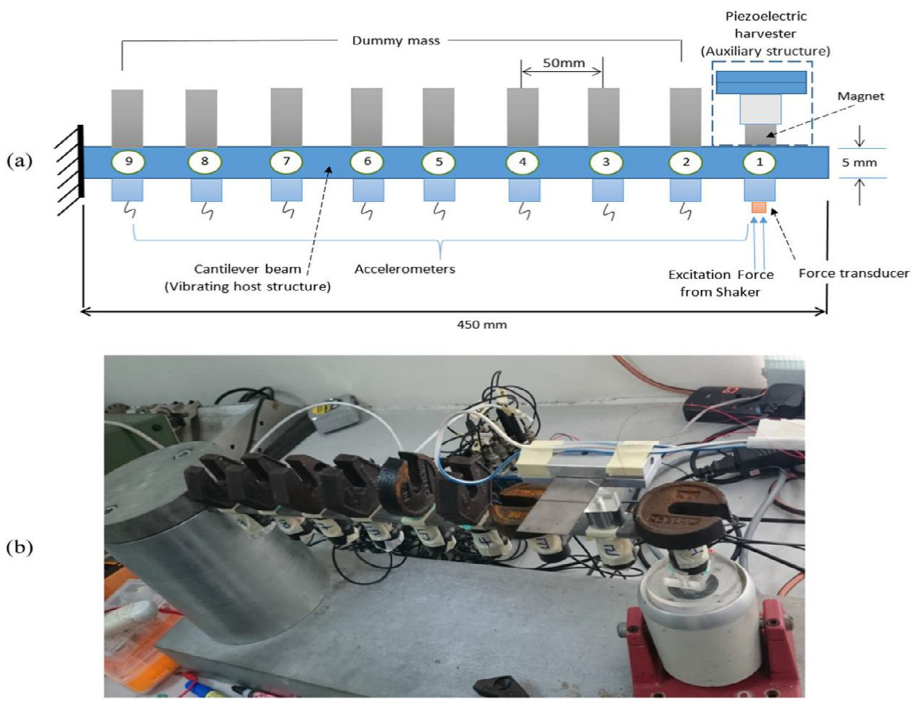

Fig. 8. a) Schematic drawing and (b) actual experimental setup of dual coupled cantilever based PVEH system (Shan, 2015).

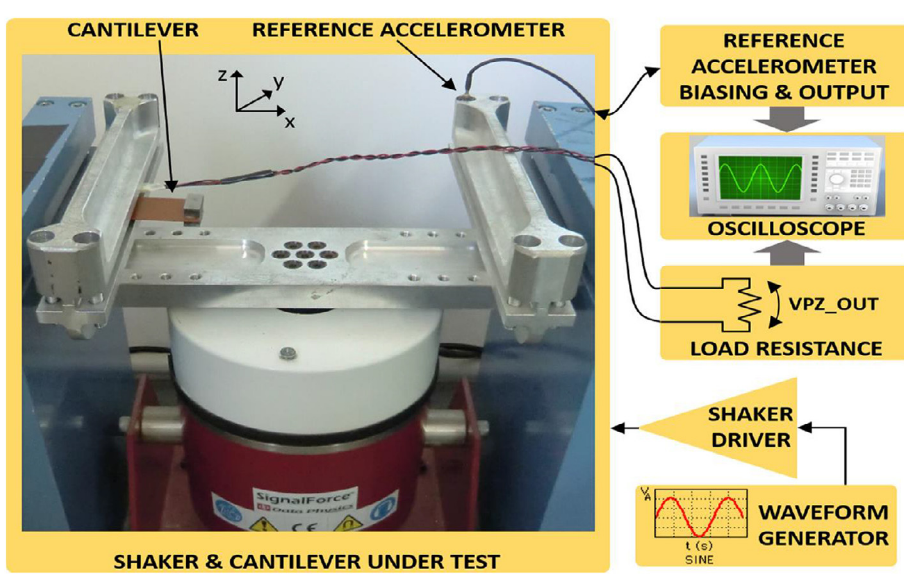

Fig. 9. Experimental set up by De Giuseppe et al. (2017) for a cantilever beam.

Renaud et al. (Fig. 4) Suggested a technique to harness mechanical vibration into electrical energy and obtained the power density around 21680 μW/cm^3 1.8 k Hz. Goushcha et al. (2015) conducted an experiment in a Wind Tunnel on the different configurations of the beam with specified piezoelectric material. The output voltage of the beam was measured at different locations from the wall at zero pitch and roll angles. Mannini et al. (2016) had done an experiment to understand the interaction with the two excitation and four regimes of VIV galloping and found the high value of mass damping for decoupling the excitation of vortex induced vibration.

Amini et al. (2017) prepared a multi load piezo electric beam setup of a rectangular section as shown in Fig. 5 and De Giuseppe et al. (2017) with a proof mass at the end shown in Figs. 6 and 7 respectively. Fig. 8 shows the actual set up of dual coupled cantilever based PVEH system (Shan, 2015) while in Fig. 9 for a single cantilever beam (De Giuseppe et al., 2017).

3. Modeling and experiment of piezoelectric vibrating energy harvesting system with or without proof mass

The lattice structure and phase diagram of Lead Zirconate Titanate has been shown in Figs. 10 and 11. The equations for an unbounded piezoelectric material are Muralt (2000)

$$s_{ij} = s^{e}_{ijkl} t_{kl} + d_{kij} e_k \quad (1)$$

$$d_i = e^{t}_{ik} e_k + d_{kil} t_{kl} \quad (2)$$

$$s_{ij} = s^{d}_{ijkl} t_{kl} + g_{kij} d_k \quad (3)$$

$$e_i = \beta^{t}_{ik} d_k - g_{ikl} t_{kl} \quad (4)$$

where i, j, k,l stands for 1,2,3, S stand for strain component, t is the constant stress, d is piezoelectric constant (C/N), E is the electric field (V/m). ε is the dielectric constant (F/m) and β is the impermittivity components (m/F). Lead zirconate titanate (Pb[Zr(x)Ti(1−x)] O3) or PZT is widely used by the researchers to harness energy. PZT crystal unit consist of tetravalent metal divalent ion when fired. At normal conditions the large divalent metal ion lead has a tetragonal or rhombohedra structure. It is the property of piezoelectric material generates electricity due to deformations of the piezo material.

Soderkvist (1991) had used two method of solving the problem of piezoelectric for a cantilever beam one is based on energy and the other is force equilibrium. Hagood et al. (1990) developed a formulation for actuators and duToit and Wardle (2007) for energy. As per the law of conservation of energy if the kinetic energy (T_k), potential energy (U), electrical energy (W_e) and W is the external work done. Then

$$\int_{t_1}^{t_2} (\partial(T_k - U + W_e) + \partial W)dt = 0 \quad (5)$$

All the terms are explained as

$$T_k = \frac{1}{2}\int_0^{V_s} \rho_s \dot{u}^t \dot{u} dV_s + \frac{1}{2}\int_0^{V_p} \rho_p \dot{u}^t \dot{u} dV_p \quad (6)$$

$$U = \int_0^{V_s} S^t T dV_s + \int_0^{V_p} S^t T dV_p \quad (7)$$

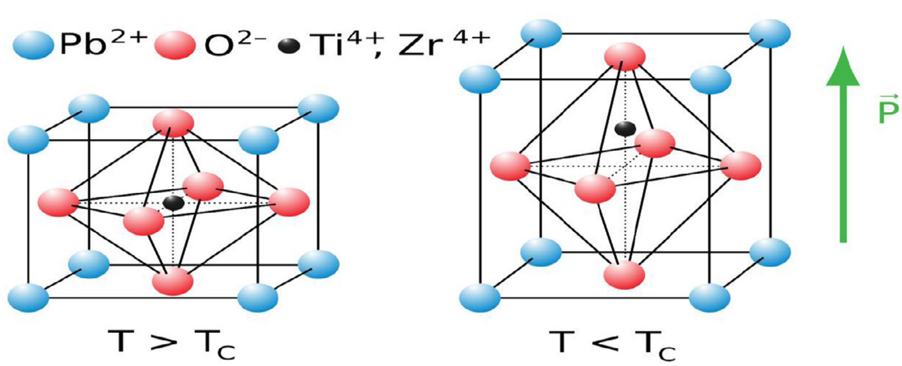

Fig. 10. Lead Zirkonate Tiatnate (https://en.wikipedia.org/wiki/Lead_zirconate_titanate#/media/File:Perovskite.svg).

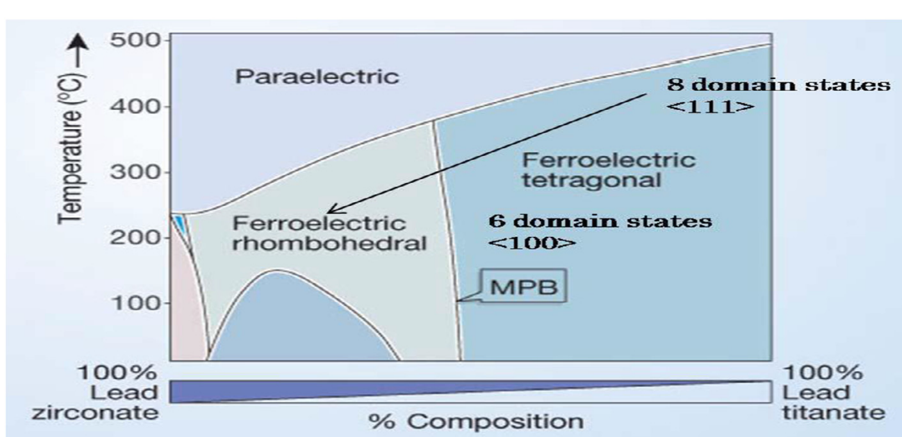

Fig. 11. Phase Diagram OF PZT (https://en.wikipedia.org/wiki/Lead_zirconate_titanate#/media/File:Perovskite.svg).

Table 1
A review of the performance parameter of the piezoelectric device.

References	Frequency in Hz	Power output (Max.)	Thickness of the piezoelectric material in mm	Year	Conclusion
Zhang and Wang (2016)	26	0.0007 μW	0.2 mm	2016	Maximum power harvested from Piezoelectric device at a reduced velocity U* = 5 and Resonating frequency at f = 26.37 Hz
Bischur and Schwesinger (2013)	2	2 μW	0.15 cm	2010	Maximum power harvested from Piezoelectric device at the thickness t = 0.15 mm and Resonating frequency at f = 2 Hz
Shukla et al. (2010)	2	0.005 μW	0.0005 mm	2010	Maximum power harvested from Piezoelectric device at the thickness t = 0.0.005 mm and Resonating frequency at f = 2 Hz
Li et al. (2011)	3	610 μW	0.41 mm	2011	Maximum power harvested from Piezoelectric device at the thickness t = 0.41 mm and Resonating frequency at f = 3 Hz
Renaud et al. (2009)	1	47 μW	0.8 mm	2009	Maximum power harvested from Piezoelectric device at the thickness t = 0.8 mm and Resonating frequency at f = 1 Hz
Platt et al. (2005)	1	265 μW	2 cm	2005	Maximum power harvested from Piezoelectric device at the thickness t = 2 cmand Resonating frequency at f = 1 Hz
Yuan et al. (2008)	20	2000 μW	0.3 mm	2008	Maximum power harvested from Piezoelectric device at the thickness t = 0.3 mm and Resonating frequency at f = 20 Hz
Dhakar et al. (2013)	36	10 μW	0.51 mm	2013	Maximum power harvested from Piezoelectric device at the thickness t = 0.51 mm and Resonating frequency at f = 36 Hz
Sodano et al. (2003)	50	30000 μW	0.27 mm	2003	Maximum power harvested from Piezoelectric device at the thickness t = 0.27 mm and Resonating frequency at f = 50 Hz
Erturk et al. (2008)	1744	14.7 μW	0.5 mm	2008	Maximum power harvested from Piezoelectric device at the thickness t = 0.5 mm and Resonating frequency at f = 1744 Hz
Xu et al. (2012)	102	3700 μW	1 mm	2012	Maximum power harvested from Piezoelectric device at the thickness t = 1 mm and Resonating frequency at f = 102 Hz
Hwang et al. (2014)	0.3	6.7 μW	0.00084 mm	2014	Maximum power harvested from Piezoelectric device at the thickness t = 0.00084 mm and Resonating frequency at f = 0.3 Hz

* Comments: Table 1 shows the variation of power output with the thickness of the piezo layer.

Table 2
A brief reviews on piezoelectric energy harvesting technique.

References	Year	Power output	Frequency in Hz	Conclusion remarks
Meninger et al. (2001)	2001	3.8 μW/cm^3	–	Meninger et al. suggested a technique to harness mechanical vibration into electrical energy and obtained the power density around 3.8 μW/cm^3
Roundy et al. (2002)	2002	1160 μW/cm^3	120	Roundy et al. constructed a MEMS device to harness electrostatic energy and obtained the power density around 1160 μW/cm^3 at 120 Hz.
Williams and Yates (1995)	1995	40 μW/cm^3 4000 μW/cm^3	70 330	Williams's et al. fabricated a micro generator with dimension 5 × 5 × 1 mm^3 based on the electromagnetic induction principle by assuming of the deflection of the structure is 50 μm.
El-hami et al. (2001)	2001	4167 μW/cm^3	320	El-hami et al. constructed an energy harvesting device from vibration and produce the electricity of 4167 μW/cm^3 and 320 Hz.
Ching et al. (2002)	2002	830 μW/cm^3	60–100	Ching et al. modeled a spring based on laser micro machined technique to harness vibrating energy into electrical one and obtained the power output around 830 μW/cm^3 and 60–100 frequency at 1 kilo ohm resistance.
Shan et al. (2015)	2015	1.1 mW/m^2	–	Xiaobiao Shan et al. harvested power from MFC (macro fiber composite) at the water velocity of 0.5 m/s
Shen et al. (2009) and Dongna et al. (2008)	2009	416 μW/cm^3	183.8	Shen et al. designed a low frequency multilayer PZT energy harvesting model and obtained the power density 416 μW/cm^3 at 183.8 resonating frequency.
Eli and Paul (2006)	2006	300–400 μW	200–250	Leland and Wright developed a prototype based on simple supported bimorph vibration energy harv ε^* esting method and obtained the power output 300–400 μW at 200–250 Hz.
Barrero-Gil (2010)	2010	40 w/m^2	2	Max. Power obtained from vortex vibration is 40 W/m^2 at 10 m/s at an optimum value of and = 0.1 and the corresponding frequency is 2 Hz.
Hobbs and Hu (2012)	2012	10 μW	11	Max. power obtained from vortex vibration is 10 μW, at R = 100 Ω and v = 1.8 to 4.3 m/s at an optimum value of m* = 30 and = 0.072 f = 11 Hz
Zhao et al. (2015)	2015	1.73 mW	15.70	Max. Power obtained from vortex vibration at 5.20 to 6.67 m/s. The frequency of the vibrating vortex system is found to be 15.70 Hz.
Marzencki et al. (2005)	2005	10 μW/cm^3	204	Marzencki et al. suggested a technique to harness mechanical vibration into electrical energy and obtained the power density around 10 μW/cm^3 at 204 Hz.
Jeon and Sood (2005)	2005	37037 μW/cm^3	13.9 k	Jeon et al. suggested a technique to harness mechanical vibration into electrical energy and obtained the power density around 37037 μW/cm^3 13.9 kHz.
Fang et al. (2006)	2006	10846 μW/cm^3	608	Fang et al. suggested a technique to harness mechanical vibration into electrical energy and obtained the power density around 10846 μW/cm^3 608 Hz
Marzencki et al. (2007)	2007	3560 μW/cm^3	1368	Marzecki et al. suggested a technique to harness mechanical vibration into electrical energy and obtained the power density around 3560 μW/cm^3 1368 Hz
Renaud et al. (2007)	2007	21680 μW/cm^3	1.8 k	Renaud et al. suggested a technique to harness mechanical vibration into electrical energy and obtained the power density around 21680 μW/cm^3 1.8 kHz

*Comments: Table 2 shows the variation of power output with the frequency of the vibrating system.

Table 3
A reviews on piezoelectric energy harvesting set up.

References	Method	Size of the device	Load in Ω	Fluid velocity	Type of fluid	Conclusion
Shan (2015)	Experimental and Numerical	30 mm	0.56 M Ω	0.35 m/s	Water	Max. power obtained from vortex vibration is 0.9 μW at R = 0.56 M Ω
Ding et al. (2016)	Experimental and Numerical	0.0889 m		2.75 to 11.92 m/s	Water	Max. power obtained from vortex vibration is 0 to 22 W at water velocity in the range of 2.75 to 11.92 m/s
Huajie (2015)	Experimental	10 mm	3 K Ω	159 m/s	Air	Max. power obtained from vortex vibration is 85 mW at R = 3K Ω
Zhang (2017)	Experimental and Numerical	32 mm	–	0.1 to 0.43 m/s	Water	Maximum efficiency from the vortex vibration obtained at 0.1 to 0.43 m/s of water
Rujun (2015)	Experimental and Numerical	20 mm	100 to 150 K Ω	2.028m/s	Water	Max. power obtained from vortex vibration is 84.49 μW at R = 100 to 150 K Ω, V = 2.028m/s
Barrero-Gil (2010)	Analytical	0.2 m	–	10 m/s	Air	Max. power obtained from vortex vibration is 40 W/ m^2 at 10 m/s
Nishi (2014)	Experimental	0.025 m	–	6 m/s	Water	Max. power harnessed from vortex vibration at water velocity at 6 m/s
Tao et al. (2017)	Numerical			7.2 m/s	Air	Max. power obtained from vortex vibration is 150 W at 7.2 m/s
Zhang (2016)	Experimental and Numerical	0.06 m	–	7.88 m/s	Water	Max. power obtained from vortex vibration at 7.88 m/ s velocity of water
Narendran (2016)	Experimental	110 mm	20 to 80 Ω	6.80 m/s	Water	Max. power obtained from vortex vibration is 3.2950 Mw/km^3 at R = 20 to 80 Ω, V = 6.80 m/s
Chen et al. (2013)	Experimental and Numerical	1.25 cm	100 Ω	1.8 to 4.3 m/s	Air	Max. power obtained from vortex vibration is 10 μW, at R = 100 Ω and v = 1.8 to 4.3 m/s
Vicente-Ludlam (2017)	Experimental	0.2 m	–	5.20 to 6.67 m/s	Air	Max. power obtained from vortex vibration at 5.20 to 6.67 m/s
Soti et al. (2017)	Numerical	40 mm	–	5.8 to 6.8 m/s	Air	Max. power obtained from vortex vibration at 5.8 to 6.8 m/s
Goushcha et al. (2015)	Experimental and Numerical	–	–	5.8 m/s	Air	Max. power obtained from vortex vibration is 0.8 W at 5.8 m/s

*Comments: shows the variation of the power output with the size of the device, load and flow velocity.

Table 4
Comparison of different grades of piezoelectric material properties

Data	PVDF	Lead Titanate	Lead Zirconate Titanate				
		SP-2	SP-4	SP-8	SP-5A	SP-5J	SP-5H
Piezoelectric Coupling Co-efficient	–						
K_p		0.01	0.01	0.01	0.01	0.01	0.01
K_{33}		0.52	0.52	0.52	0.52	0.52	0.52
Piezoelectric charge constant ($\times 10^{-12}$ C/N)							
d_{33}	30 pC/N	68	320	215	450	550	650
d_{31}	−18 pC/N	3	−122	−97	−195	−220	−3
Piezoelectric volatge constant ($\times 10^{-3}$ Vm/N)							
g_{33}		39	27	24	26	22	20
g_{31}	340 (mV/N)	−1.7	−11	−11	−11	−9	−9
Relative Dielectric constant, K_3^t (low signal, @ 1 kHz		195	1325	1000	1750	2450	3250
Dissipation factor, tan (Low field)	0.05	0.010	0.004	0.004	0.004	0.020	0.020
Density ρ kg/m^3	1800	6900	7600	7600	7700	7500	7500
Frequency Constants (Hz-m)							
N_p (planer mode disk)			2200	2270	1950	2000	1950
N_t (thickness mode disk)			1905	2030	1800	1950	2000
N_c (circumference mode cylinder)			990	1060	860	870	860
N_{31} (length mode cylinder)			1580	1700	1330	1295	1386
N_{sp} (radial mode sphere)			1675	1810	1480	1430	1520
Ageing rate, % change per time decade	–						
K_3^t		−0.3	−2.5	−4.6	−0.8	−2.0	−2.2
K_p		-	−1.6	−2.0	−0.6	−1.5	−0.9
N_p		+0.2	+1.0	+0.2	+0.2	+0.3	+0.2
Electrical field dependenceMax Positive Field (V/mm)	–						
Max Negative Field		–	700	800	600	450	400
(V/mm)		–	350	400	300	225	200
Max AC fields, ems @ 25 deg C (V/mm)		80	350	400	80	80	80
Curie Temp, T_c (Deg C)	–	200	325	330	340	260	190
Mechanical Quality Factor Q_m	–	2400	150	110	65	150	67

*Comments: Comparative analysis of different piezoelectric materials properties.

Table 5
Shortcomings of piezoelectric harvesting device from others renewable energy sources such as Solar, Wind and Biomass.

Elements	Wind	Solar	Biomass	Small Scale Energy harvesting device
Power Output	Can be obtained in KW and MW	Compare to less than Wind	Less than Wind and Solar	Very Small power in micro to milli watts.
Application	Electricity can be fetched to grid or high voltage storage	Electricity can be fetched to grid or high voltage storage	Not available commercially but still larger than piezo.	Used for small scale remote sensing places
Sources	Wind	Sun	Availability of constant fuel sources	Mechanical elements problems with wear & tear degraded with time.
Operational duration	Full time	Depending on the sun light	Reliability on biological components	Limited time span
Cost	Very high	Less in compare to wind	Less in compare to wind and solar	Cost increases much more with the size of piezoelectric materials for a higher power output
Dependence of material properties on the power output	Less sensitive to material structural properties	Less sensitive to material structural properties	Less compare to piezo devices	Very much sensitive to structural properties even a small change in crystal can change in power output

$$W_e = \frac{1}{2}\int_0^{V_p} E^t D dV_p \quad (8)$$

$$\partial W = \sum_{k=1}^{nf} \partial u_k f_k(t) + \sum_{j=1}^{nq} \partial \varnothing_j q_j \quad (9)$$

where V_p is the volume of piezoelectric material, V_s if for beam, ρ_s is the of strutural beam, ρ_p is the density of piezomaterial.

4. Conclusion

In this paper a comprehensive review has been presented on the mechanical energy to electrical energy conversion including theory, different methods of design and application. Several energy harvesting had discussed with the corresponding energy harvesting configurations with different materials and types. The amount of energy harvesting from piezoelectric set up depends upon several extrinsic and intrinsic factor which are tabulated in the above tables (Tables 1–5).

For the piezoelectric harvesting device, the main advantages are the ease of application due to its simplified structure. Moreover, these materials are not affected by internal electromagnetic waves. The researchers have explored many piezoelectric materials like Polymer composites, piezoelectric ceramics, polymers etc. in several energy harvesting configurations to adjust the use of this technique in many applications. It has been found both experimentally and analytically that polymer piezo material behaves well of harvesting energy due to its soft nature. Though, the power output from the piezo material is in the range of microwatt and mill watt, yet PZT type of ceramic found to be good in boosting the intrinsic properties of the material. In this review throughout, the researchers have concentrated their attention to develop the electromechanically couple model to verify the performance of piezoelectric material in different configurations.

On the other hand, there are some disadvantage of piezoelectric energy harvesting set up such as depolarization, sudden breaking of piezo layer due to high brittleness and poor coupling coefficient. PVDF material has poor adhesive properties which causes difficulties in device fabrication. In compare to PVDF materials the PZT materials have a lower electromagnetic coupling coefficient due to which they are required strained directly.

As per the result from the different articles suggest that the maximum efficiency can be achieved for an optimum value of the product of mass and damping ratio. The new kind of experimental work had been developed with the help of scotch yoke mechanism to generate power from the rotating blades of the wind turbine. It is found to be the strong dependence with the inlet velocity of the vortex induced vibration device in compare to other energy converting device. Some reviewers had assumed the approximate analytical solutions for the output voltage, pitch angle, plunge deflection and results are compared with the numerical solution of integration equation.

The production of energy harvesting has been optimized and compared by changing the geometry, increasing the no of cylinders, by changing the boundary condition, coupling the cylinder with the wind turbine and by changing the piezoelectric material. Based on the previous history on the VIVACE, a mathematical model has been formulated in order to find out relationship among the experimental parameters and the response of the system. Due to random characteristics of free vibration, new development in design of efficiency of energy harvesting is a great challenge such as creation of new energy harvesting design by innovating design methods and also by exploring non linear benefits. Moreover, portable compact size design with the integrate functions are also hot areas of research in the field.

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