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PIEZOELECTRIC USING VIBRATION ENERGY HARVESTING USED AS SUPPLY POWER TO ELECTRONIC DEVICES

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ABSTRACT

Energy harvesting is the method of changing ambient energy like vibration into electrical energy that can give power several of applications. Energy harvesting is key requirement of today's life as there is a decay of conventional energy sources day by day due to use of advanced technology increase. Today's it is necessary for us to find new, not costly, and feasible and ecofriendly sources of energy. Nonconventional energy sources like Solar, wind, tidal, vibration need to harvest all these energies to use it properly for our demand to remove dependence on conventional energy sources. Vibration energy is referred as by-product of everyday life. This paper features to usevibration as the vital source of energy. Harvesting of Piezoelectric energy is increased and used in portable devices and wireless sensors nodes in which battery power supply are undesirable. In various applications dynamic stress is used to produce energy while there is a use of static stress in this case. This paper indicates the response of piezoelectric generator. A specific piezoelectric bender Brass reinforced PSI-5A4E material bimorph PZT material is suggested which have fixed dimension that is available on Piezo Systems Inc. having proof mass consist of steel with weight of 0.0019625 kg and excited at 2.5ms-2 is modeled as equivalent electrical circuit and simulated on matlab to give its behavior of variable frequency on resistive load which is fixed and variable resistance load at fixed frequency. Observation indicates that maximum voltage is obtained at vibration frequency close to 65Hz. Result also indicated that variation of output power with load varying at fixed frequency and fixed load with variable frequency.

***Keywords**: PZT, piezoelectric, reinforced, harvest, dynamic stress*

I. INTRODUCTION

Energy harvesting is a method of energy derived from ambient sources, captured, and reserve for various applications like small wireless autonomous devices. However conventional energy sources are day by day decaying due to use of advanced technology is increasing. Today's it is necessary for us to find new, not costly, feasible and ecofriendly energy sources. Nonconventional energy sources like solar, wind, tidal, vibrational need to harvest these energies to use it for our requirements to remove dependency on conventional energy sources. An increase inpiezo electric energy harvesting is used in portable devises and wireless sensors node where undesirable is battery power supply. In most of the applications dynamic stress is used to produce energy while in this case static stress is used. Depend on vibration energy harvesting for generating the low power electricity is deeply researched over the last few decades. The encouragement in this research field is because of requirement of reduced power small electronic component like wireless sensor node which is used in applications of passive and active monitoring. The ultimate objective is to enable self-dependent wireless electronic system for the waste vibration energy recovery that is available in proximity due to which the requirement of maintenance for replacement of battery and conventional batteries chemical waste can be reduced. From the basic transduction mechanism used for conversion of vibration to electricity like. electromechanical, piezoelectric, electrostatic and magnetostrictive conversion techniques as well as electro active polymers use creates piezoelectric transduction to receive great attraction for generation of low power electricity because of high power density and ease of piezoelectric materials applications.

Mathematical descriptions

Depend on wireless sensor node typical size the output potential power from a piezoelectric bender has a direct relation to size. Size constraints play a vital role in selection of a configuration of power converter. Due to this reason it is important to mention the general size at the outset. The model developed holds for any size if generates a magnitude of order of larger or smaller were desired a various design configuration may be referred according to the need

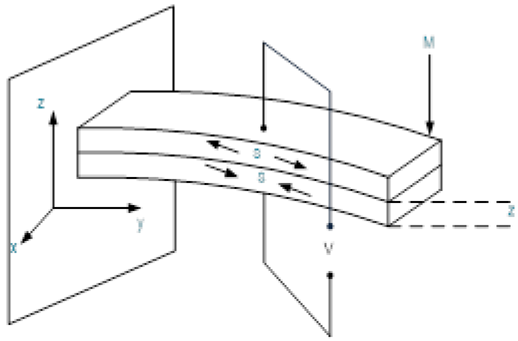

Fig 1. Piezoelectric bender

In the figure above:
S is known as strain,
V is referred voltage
M is known as mass
Z known as vertical displacement.

A cantilever element is selected for producing voltage rather than stack due to low resonance frequencies and higher strain is attained. This elementcan mount in various ways to be worked as a generator. A two layer bimorph mounted as a binder beam with mass working on a free end as given in figure has been selected for two particular reasons:-
1) The cantilever Iis in highest average strain for a given input and the output power is nearly approaches to the average strain.
2) The mounting cantilever provides the low resonance frequency for a given size that is necessary since the frequency range of input vibration is in 60-200Hz.

When developed the model a beam of uniform width is assumed by which mathematics more manageable and validation of model is easy due to uniform width bender availability. A simple cantilever improvement which have uniform width made by width of beam which is varying. Width is varying so that strain remains constant and due to this average strain becomes higher there is a no loss in generality of this model due to uniform width assumption. If a beam that is of non-uniform width is used the necessary relationships for design that produce from the analytical model holds well equally. To analysis possible power amount from a vibration source given an analytical model of generator is vital and also to make simple and understanding relationship that provides hints to the designer so that how the designer can rectify the performance of system. By remembering these objectives in mind a piezoelectric generator analytical in figure is generated

Equations 1 and 2 for a linear piezoelectric material in a form of reduce-matrix are as follows:

$$[S]=[s^E][T]+[d]^t[E] \quad (1)$$

$$[D]=[\varepsilon^T][E]+[d][T] \quad (2)$$

Where:-
[S]is known as six dimensional strain vector
[T] is known as stress vector
[D] is known as three dimensional electric displacement vector
[E] is known as electric field vector
[S^E] is referred as 6x 6 compliance matrix evaluated at constant electric field
[d]is known as 3 x 6 piezoelectric strain coefficient matrix and
ε is 3 x 3 dielectric constant matrix evaluated at constant

In this convention shows stress due to mixed mechanical and electrical efforts and assumethe stress generated only by mechanical efforts. Concluding above figure 1 that have two layer bending element, material is poled along axis 1(x), voltage is calculated from above and below surfaces that is perpendicular to axis 3(z). Assume that vibrations are active on axis 3(z)only, under these conditions the piezoelectric material evaluates one dimensional state of stress along axis that is 1(x). Above equations (1) and (2) can be written as follows:

$$S_1 = s_{11}^E T_1 + d_{31} E_3 \quad (3)$$

$$D_3 = \varepsilon_3^T E_3 + d_{31} T_1 \quad (4)$$

Now S_1, T_1, D3,E_3, s_{11}^E and will be written as S, T, D, E, s and ε respectively, for the sake of simplicity. Also the elastic constant c =s^{-1} willbe used instead of compliance

Piezoelectric as a power generator

Modeling of piezoelectric elements like equations of systemcan be easily generated containing both the portion of mechanical and electrical the piezoelectric system taken as circuit elements in its model. The electromechanical coupling is modeled as a transformer. An equivalent circuit of the bender is given in figure below.

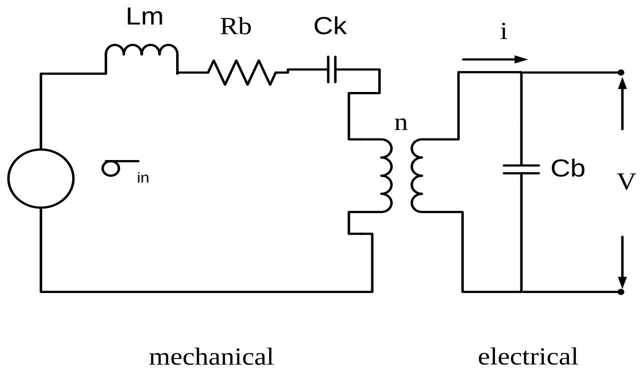

Fig .2: Circuit representation of the piezoelectric generator

In this figure:
L_m shows inertia of of generator
R_b shows mechanical damping
C_k shows mechanical stiffness
σ_{in} shows equivalent stress generator due to input vibrations.
C_b shows capacitance of piezoelectric bender
V is known as generated voltage

The 'across' variable that is on the mechanical side of the circuit is referred as stress, σ (equivalent to voltage), and 'through' variable is referred as strain rate, $\dot{S}$ (analogous to current). Using the technique of modeling, the mechanical side of the circuit is assumed as an uncoupled mechanical system. Hence the stress variable used is σ not T and the stress strain relationship is given by $S = s\sigma$ or $\sigma = cS$ .The transformer shows the piezoelectric coupling. Transformers are analyzing with a turns ratio that is related to voltage on one side to the voltage on the other side. And thereafterstress that is on the mechanical side is related to voltage on the electrical side.

This circuit also used KVL and KCL. KVL on mechanical side is shown in equation (5)

$$\sigma_{in} = L_M \ddot{S} + R_b \dot{S} + \frac{S}{C_k} + nV \quad (5)$$

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And the KCL on electrical side is shown in equation (6)

$$i = C_b \dot{V} \quad (6)$$

The figures shown below gives schematic diagram converter and composite beam that shows geometric variable i. e. length, width and thickness

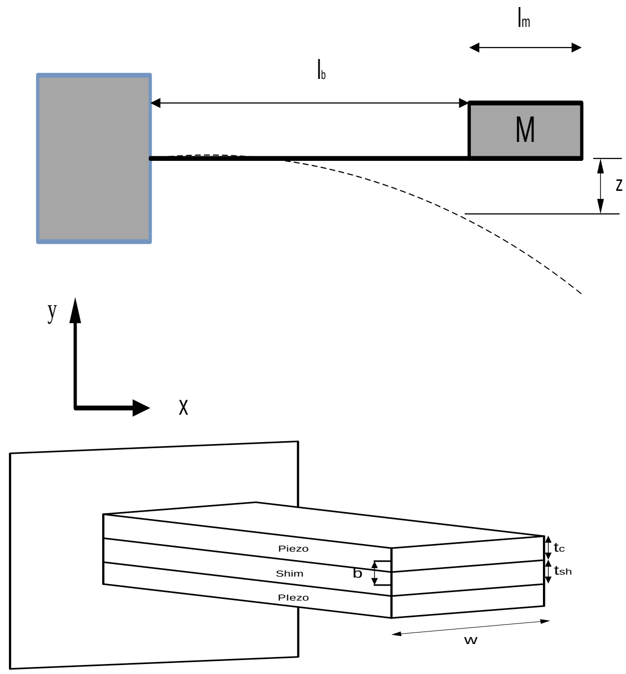

Fig3. Schematic diagram of the composite beam

Table 1. Brass reinforced PSI-5A4E material bimorph PZT piezoelectric Dimensions for energy harvesting.

Name	Symbol	Value
length	L_b	0.0635 m
width	w	0.0318 m
thickness	t_c	0.00051 m

Table 2. Brass layer thickness is also taken as 0.51 mm.

Name	Symbol	Value
Length	l_b	0.0635 m
Width	w	0.0318 m
Thickness	t_c	0.00051 m
Relative Dielectric constant	ε_r	1800
Piezoelectric “d” coefficients	d_{31} d_{33}	$-190 x 10^{-12}$ m/v $390 x 10^{-12}$
Coupling coefficients	k_{31} k_{33}	0.35 0.72

Density	ρ	7800 kg/m3
Elastic Modulus	c_p	$6.6\text{x}10^{10}$ N/m^2
Brass elastic modulus	c_{sh}	$10.5\text{x}10^{10}$ N/m^2
Mechanical damping ratio	b_m	0,015

Table 3. Proof Mass Dimensions is (Made of Steel)

Length	l_m	0.010 m
Width	w_m	0.005 m
Height	h_m	0.005 m
Mass	m	0.0019625 kg
Density	d	7850 kg/m3

Important constraints of equivalent circuit that are R_b, L_m, C_k and C_b these constraints need to be calculated to used to simulate the model.

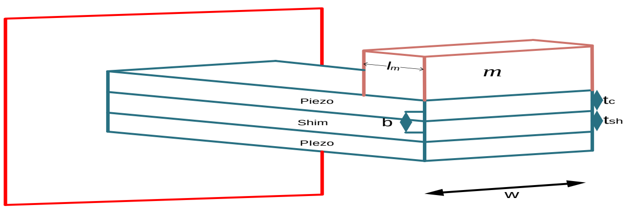

Fig 4. Bimorph piezoelectric cantilever

From equations (7), (8), (9), (10), (11), (12), (13), (14)

$$I = 2\left[\frac{wt_c^3}{12} + wt_c b^2\right] + \frac{\eta_s w t_{sh}^3}{12} \quad (7)$$

$$I = 9.81\times10^{-12} \quad (8)$$

Modified value of k1 from figure of previous chapter:

$$k_1 = b\left(\frac{4l_b + 3l_m}{4I}\right) \quad (9)$$

$$k_1 = 3.171253823\times10^6 \quad (10)$$

$$\sigma_{in} = k_1 m\ddot{y} \quad (11)$$

With the acceleration 2.5 msec-2 and 120Hz (assumed)

$$\sigma_{in} = 15558.96407 \quad (12)$$

Modified k2 , from the equation (13)

$$k_2 = \frac{l_b(l_b + l_c)}{3b} \quad (13)$$

$$k_2 = 2.220424837 \quad (14)$$

$$L_m = k_1 k_2 m \quad (15)$$

$$L_m = 1.3819\times10^4 \quad (16)$$

$$R_b = k_1 k_2 b_m \quad (17)$$

$$R_b = 1.05622961 \times 10^5 \quad (18)$$

$$n = \frac{-ad_{31}c_p}{2t_c} \quad (19)$$

$$n = 12294.11765 \quad (20)$$

$$C_b = \frac{a^2 \varepsilon w l_e}{2t_c} \quad (21)$$

$$C_b = 2.6582876 \times 10^{-8} \quad (22)$$

$$C_k = c_p^{-1} \quad (23)$$

$$C_k = 0.15151515 \times 10^{-10} \quad (24)$$

These values of R_b, Lm, Ck, C_b and n can be used in equivalent circuit which is representation Of piezoelectric bender, all these monitor the performance of piezoelectric generator.

II. SIMULATION AND RESULTS

Simulation result after getting this equivalent circuit by using PSpice, the figure shown below is a model of PSpice equivalent circuit having parameter evaluated above

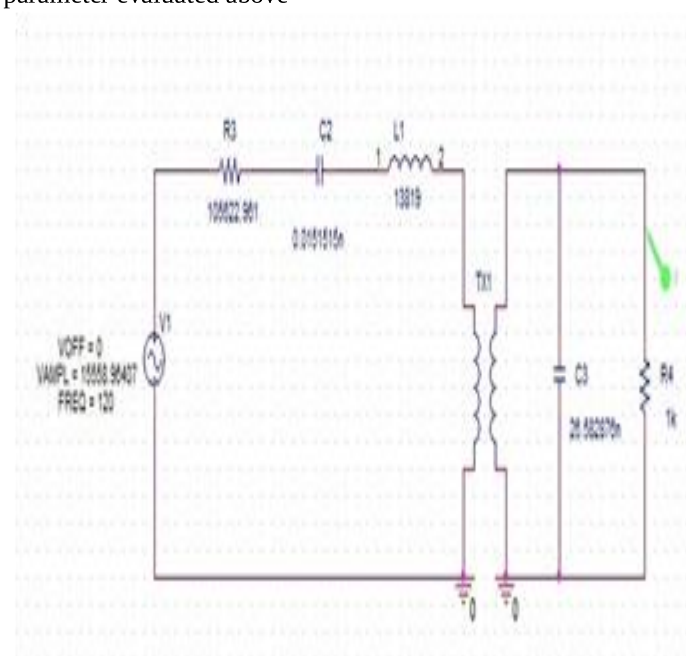

Fig 5. P Spice Model of equivalent Circuit

The simulation results of its are on next page. Results indicates that signal is sinusoidal but not with constant magnitude

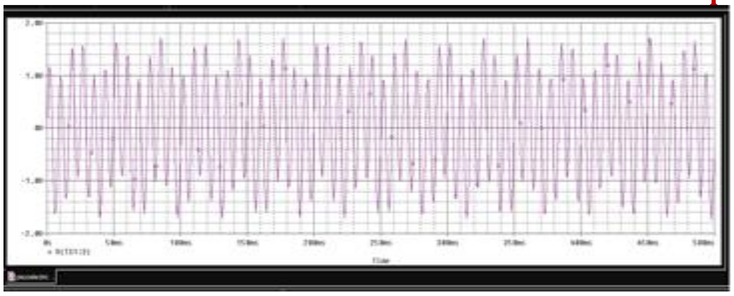

Fig 6.Simulation Result of equivalent electrical circuit

When referred to the transformer secondary side above equivalent circuit will be rectified as given below having source that is divided by turns ratio and passive elements that is divided by turns ratio square.

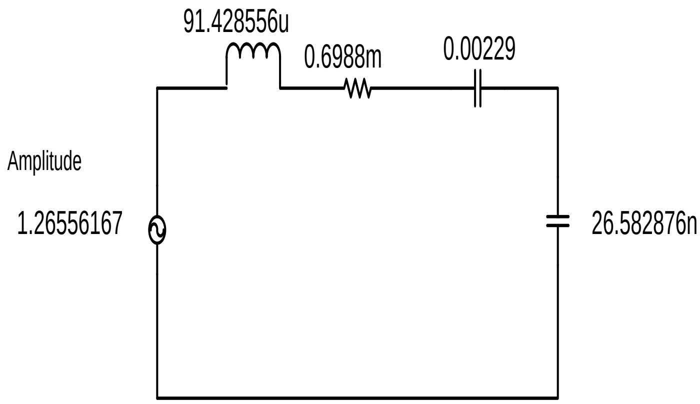

Fig 7.Equivalent circuit refer to secondary side

Entire system for the use of energy harvesting is given below and full model is simulated with the help of matlab with resistive load. The figure shown on next page describes a block diagram of entire energy harvesting system.

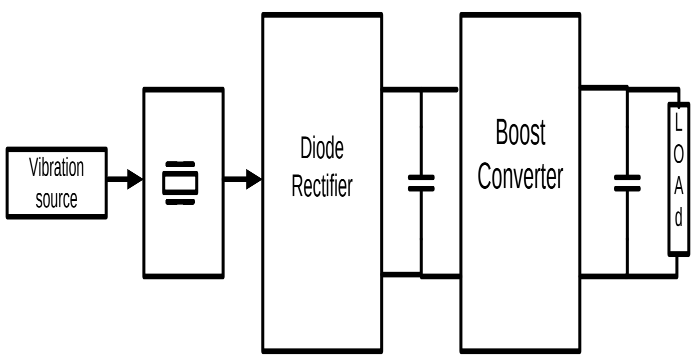

Fig 8.whole system model

And its Matlab based model is given below:-

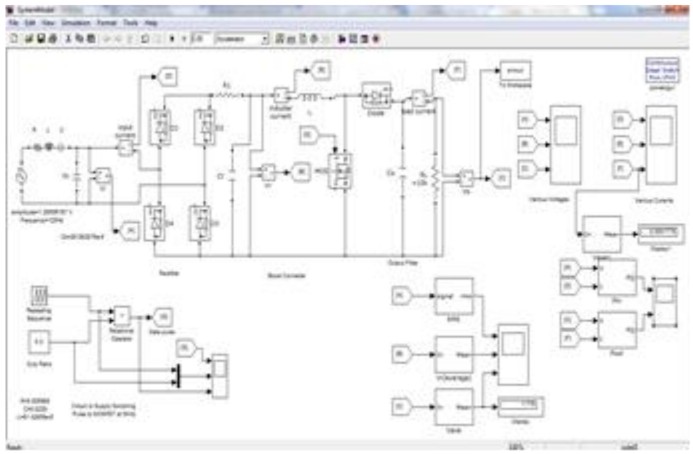

Fig 9. Matlab model of System

The simulation output when vibration frequency is 120Hz and boost converter switching frequency is nearly5 kHz is attained is shown on next page.The next page figure shows upper signal which is input voltage waveform to the rectifier middle one is preferred output voltage after passing of upper signal through rectifier and capacitor filter and lower one is known as final output voltage which we get from energy harvesting circuit.

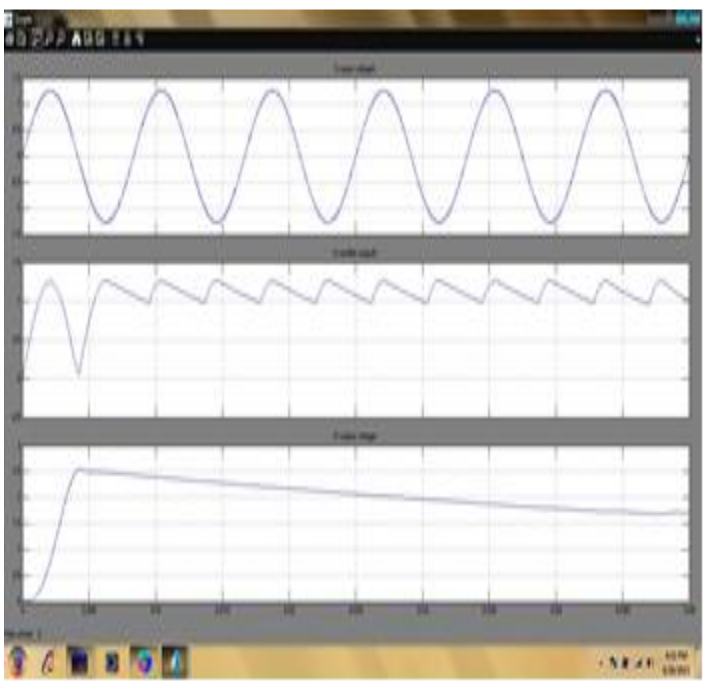

Fig 10.Various voltage waveforms

Multiple current waveforms are given below. In this figure upper one is referred as input current, middle one is referred as inductor current, and lower one referred as output current or load current.

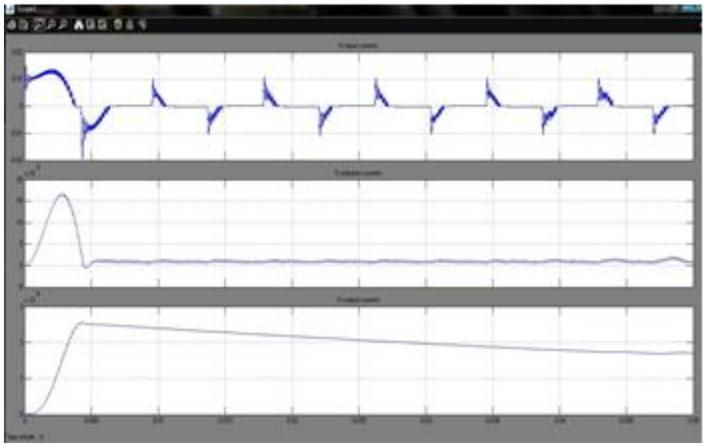

Fig 11.various current waveforms

The figure shown below gives change in output voltage while with variation in vibration frequency it is not varied linearly but maximum voltage is attained at frequency of 65Hz with this specified piezoelectric bender. After frequency of 150Hz voltage is increasing as a function of linealy approximately.

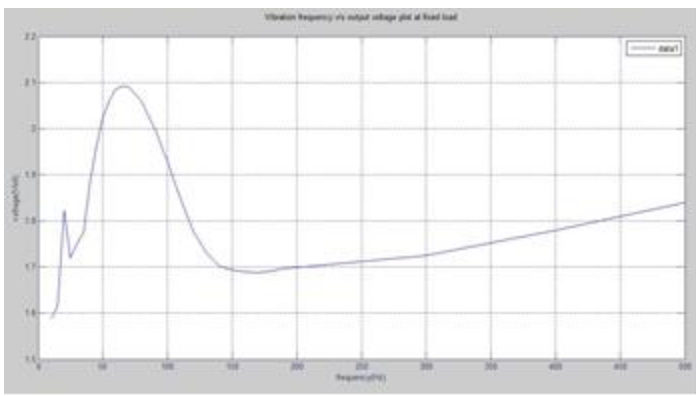

Fig 12.vibration frequency vslaod voltage plot

Load power varying when variation of frequency is given below. Maximum power is obtained at frequency 65Hz. After frequency of 150Hz power is increasing as a linear function.

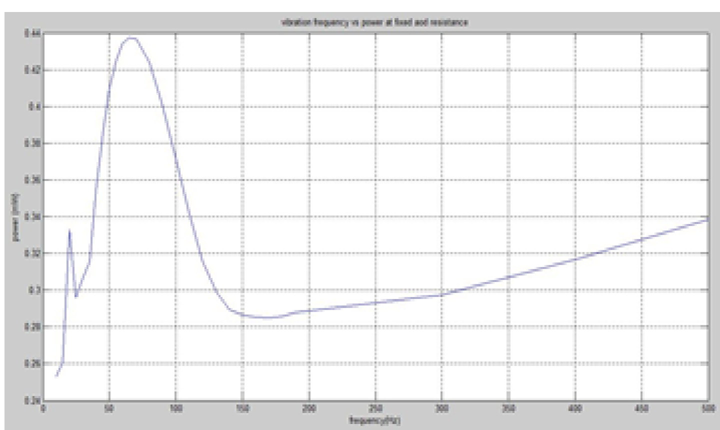

Fig 13.vibration frequency vs power

By varying load resistance with vibration frequency 60Hz, load voltage variation is given below.It is in increasing mode but not as a linear function of load resistance. If load resistance increases output voltage increases at vibration frequency.

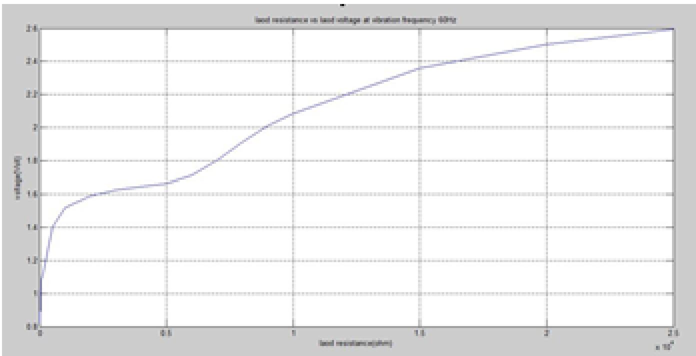

Fig 14.Load resistance vs output voltage at vibration frequency 60Hz.

Load power variation is given below with resistance load is shown below. Follows the formula in which V is known as load voltage and R is referred as Load resistance.

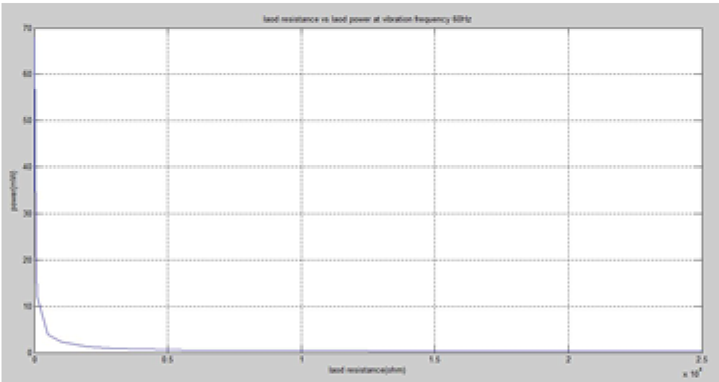

Fig 15.load power vs load resistance at 60Hz.

The figure shown below gives only after change of vibration frequency up to 120Hz. All other things remains same these figure indicates that there not too much change in variation of voltage and power with load resistance.

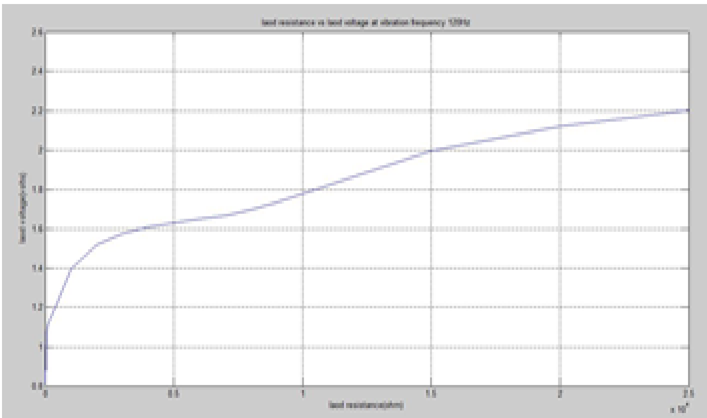

Fig 16.Load resistance vs output voltage at vibration frequency 120Hz.

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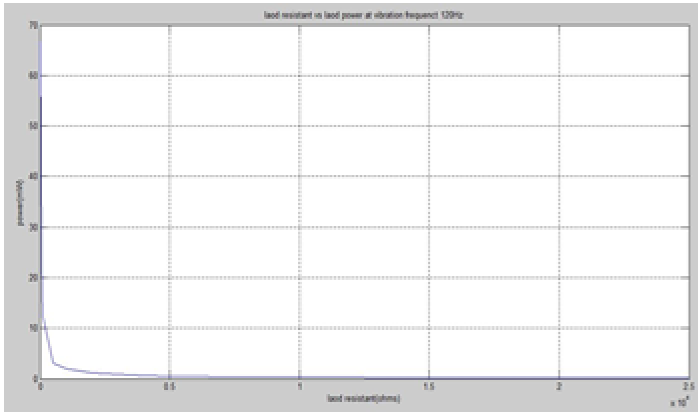

Fig 17.Load power vs load resistance at 120Hz.

III. CONCLUSION

This paper features a study of harvesting of piezoelectric energy from vibrations energy by using a cantilevered bimorph piezoelectric stack. To know and analysis the PSI-5A4E, PZT materials in a cantilever beam structure having a circuit of power conversion modeling methods are implemented with the help of mathematical approach of PZT bender. An electrical circuit that is equivalent is derived and its constraints are evaluated and a constant acceleration is preferred 2.5 ms-2 with frequency varying. DC-DC converter is used which is boost converter. According to literature survey three different models is used for an actuation mode or a bimorph bender have been suggested for a potential application on the bimorph bender with various layers as a power generator. The models performed on the Matlab/Simulink/Simpower are simulated and performance of bender with respect to time is performed out that indicates the behavior of output voltage. The model depend on the coupled field describes the best compared to others to show the performance of a piezoelectric element in this particular environment of application. The model depend on an equivalent electrical circuit equivalent component is not comfort to indicates the dynamics present in the vibration of the PZT. However the other model that depends on the energy conversion is not able to indicate the effects of load on damping behavior. The experimental results indicate that the system implemented supplies a maximum power that is 6.8 mW at 10Ω resistive load when the PZT bender excited with a vibration and amplitude of 2.5 ms-2 at frequency of 65 Hz. Curves of Frequency vs output power and load resistance vs power are drawn.

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