Study on the Induced Voltage in Piezoelectric Smart Material (PZT) Using ANSYS Electric & Fuzzy Logic

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Study on the Induced Voltage in Piezoelectric Smart Material (PZT) Using ANSYS Electric & Fuzzy Logic

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ABSTRACT: *The objective of this study is to do simulation for the prospective of energy harvesting analysis of piezo-electrical smart materials through ANSYS Electric and MATLAB Fuzzy logic. It is to be determined that how much potential this PZT system has for the induced potential difference which is then further transformed into energy by voltage converter system. The voltage obtained from PZT system through both simulation 0.0050 V (ANSYS) and 0.00556 V (Fuzzy) is very much enough for charging any type of battery through piezoelectricity. These outcomes are again confirmed by Mamdani's method (0.00550 V). ANSYS and Fuzzy logic has proved their importance in every scientific system for complete voltage analysis.*

Keywords: PZT, ANSYS, Fuzzy Logic, MATLAB.

1. INTRODUCTION

In current years, the energy harvesting has been proven as the habitual objective for researchers [1, 2]. Scientists always tried to provide the independent way out for operating the small electrical devices with minimal harvesting of energy [3]. Amongst all methods, the favorite is vibrational energy harvesting due to its mechanical vibrations. This method has demonstrated by connecting it to the piezo-electrical energy harvesting from mechanical vibrations [4]. Lead Zirconate Titanate (PZT) is considered as the best piezo material. PZT can produce piezo-electrical effect. This material is used to sense variations in stress, acceleration, heat, pressure, and energy by transforming them to electric energy [5]. A piezo-electrical crystal circuit of PZT as shown in Fig. 1.

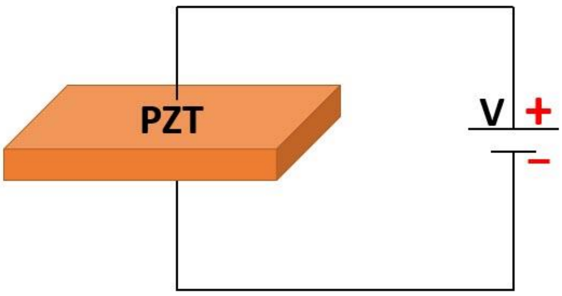


Fig.1. PZT crystal and circuit.

In this piezo-electrical crystal of PZT the atoms of the unit cell are organized in symmetry as shown in Fig. 2(a). Therefore, it is electronically neutral because of the perfect balance of charges as shown in Fig. 2(b). If this material is stressed by applying a force then due to the deformation of the structure and misbalancing of positive and negative charges in the material, the charges are induced as shown in Fig. 2(c). This process spread over the material and causing the net positive and negative charges on the opposite faces of the PZT crystal as shown in Fig. 2(d). Reverse can also be done by applying voltages externally.

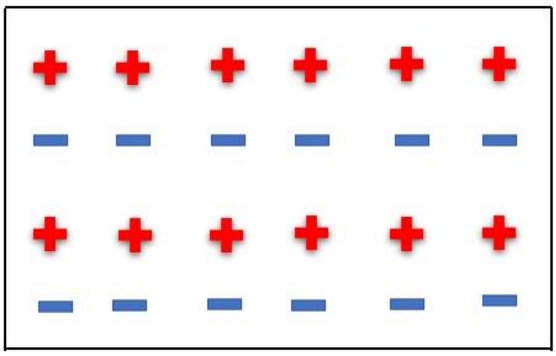
This effect is the capability of certain materials to produce an electric field in response to subjected external stress. This PZT material is positioned between two metals. Mechanical stress is then subjected on PZT by these metallic plates, which compels the balance of all produced electrical charges into misbalance. Potential difference is developed according to the equation (1).

$$\Delta V = \frac{\Delta W}{\Delta Q} - - - - - - - - (1)$$

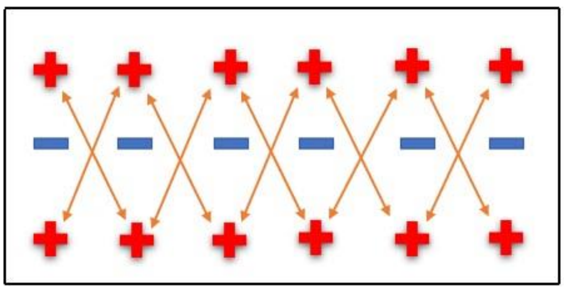
Consequently, electrical energy is harvested due to mechanical vibrations which is shown in Fig. 1. Depending on their construction and size of PZT, a piezo-electrical PZT material can produce voltages up to 100 V and the maximum current can vary from nano ampere to micro ampere [2-4]. There is a need to construct an amplifier to amplify the output to the desired level and then process the value further. The minimum force applied on the material is from 6mN to max 10 mN using a pressure head by clamping the sample on both terminals.

As the simulation is an important tool in research before fabrication a device, many researchers have been used different simulation techniques (Fuzzy, ANSYS, MATLAB, COMSOL and ABAQUS) for simulations of different materials [5-14]. Kunz et al. (2001) worked on PZT thin films for charge sensitivity [15]. Cappelleri et al. (2002) simulated PZT bimorph actuator with ABAQUS by meta-model based technique [16]. Lin and Chen (2003) simulated PZT actuator for micropumps with ANSYS [17]. Ajitsaria et al. (2007) bimorph piezo-electrical PZT beam for the generation of voltage with the help of MATLAB [16]. Roscow et al. (2017)

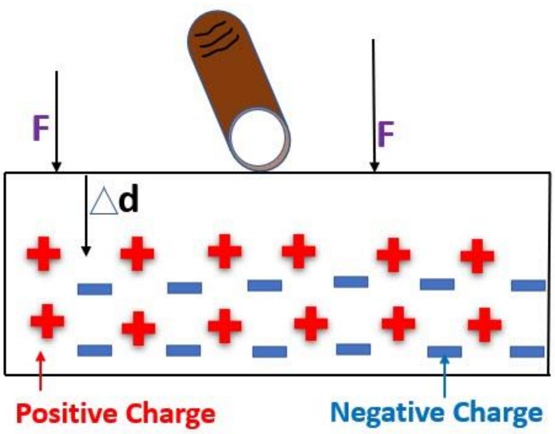
simulated PZT-5H structures with ANSYS APDL [18]. AL-Athel et al. (2017) simulated PZT material as stationary blades to investigate the thermal induced vibrations with ANSYS [19]. Shanker and Duggal simulated for incipient damages of PZT patches with ANSYS [20]. Xu et al. (2018) simulated the mesoscale structure of concrete core with multiscale simulation technique [21]. Tierno et al. (2018) simulated BPZT and ZnO thin films using ANSYS HFSS 17 [16]. Shin et al. (2018) simulated NDR-FinFET and exhibit its operating principle with MATLAB [22]. Wart et al. (2018) simulated PZT by using MATLAB with usual and artificial radiation [23]. Afzal et al. (2018) analyzed charging of smart phone by Fuzzy Logic method [24]. In this study, two different simulation methods (ANSYS Electric and MATLAB Fuzzy logic) are applied on the PZT material and their obtained results are compared and discussed for the fabrication the PZT-based energy harvesting device.



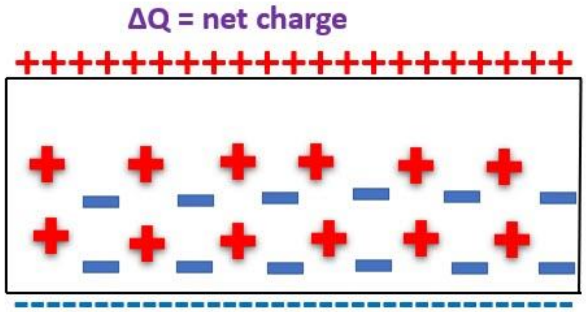
(a)



(b)



(c)

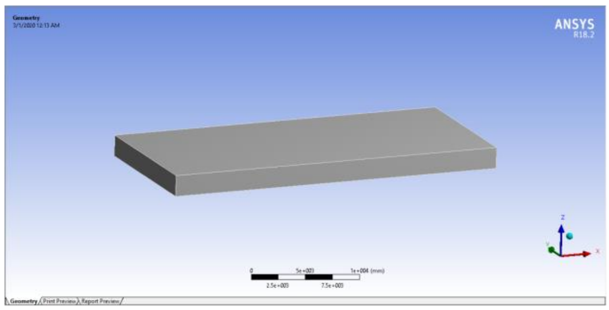


(d)

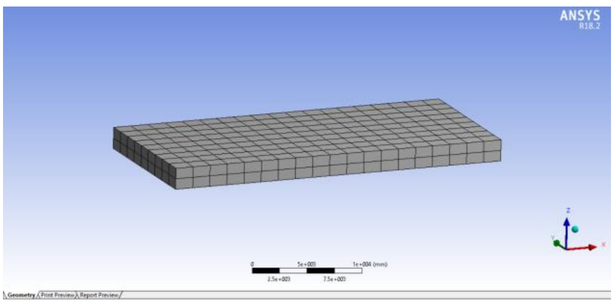
Fig. 2(a, b, c, d). Conversion of mechanical movement into electrical energy in PZT material.

2. ANSYS ELECTRIC SIMULATION

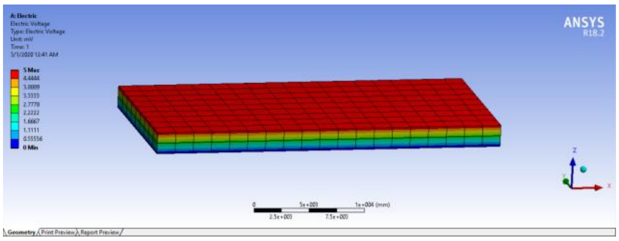
ANSYS Electric 18.2 was used to simulate the piezoelectric material and determined the voltage on a sheet of PZT material. For ANSYS simulation, parameters like relevance centre is fixed at 0, element size is fixed by default (built in), element order is linear, size function is adaptive, transition is set at fast, bounding box diagonal is fixed at 35431 mm, minimum edge length is fixed at 2000.00 mm, target quality is fixed at 0.050000, smoothing is set on medium, inflation transition is set at smooth transition, transition ratio is set at 0.272 and growth rate is fixed at 1.2. After meshing (2110 nodes and 342 elements), value of voltage is determined, maximum voltage = 5 mV. The results are shown in Fig. 3.



(a) Geometry of PZT



(b) Mesh analysis of PZT

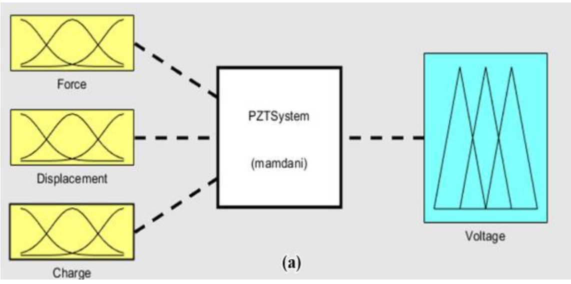


3(c) Voltage analysis

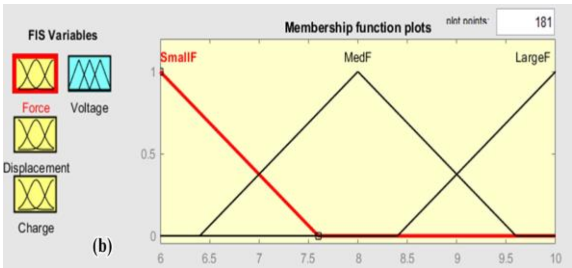
Fig. 3. Results of ANSYS electric simulation.

3. SIMULATION OF FUZZY LOGIC

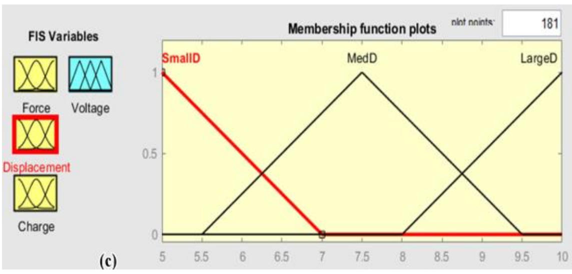
In this study we have considered MATLAB Fuzzy Logic technique because still no one has used this simulation method for PZT material. In this simulation we have considered three inputs (force, displacement and charge) and one out-put (potential difference) for the fuzzy-logic controller with three membership functions (Mfs) of each variable. Their ranges are considered as 6 mN to 10 mN for force, 5mm to 10mm for displacement, 100 mC to 1000 mC for charge and 1 milli volts to 100 mili volts for potential difference. The Fuzzy rules 27 = 3^3 are prepared with the help of IF and then statement. The Fuzzy system (4a), membership functions 4(b, c, d, e) and rules (4f) are presented below in Fig. 4(a, b, c, d, e, f).



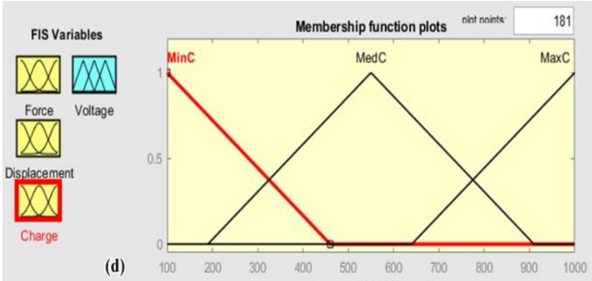
(a) PZT System



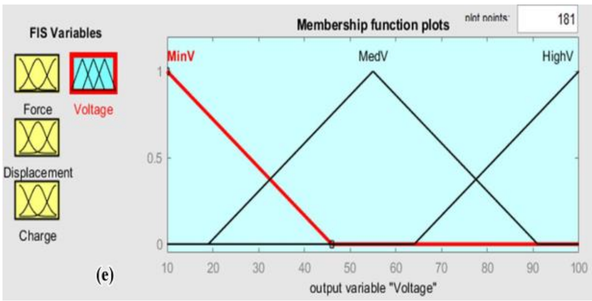
(b) Membership function of force



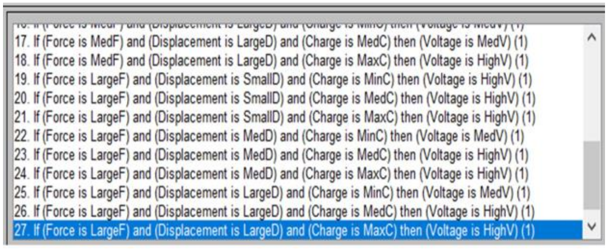
(c) Membership function of displacement



(d) Membership function of charge



(e) Membership function of voltage



(f) Rules of Fuzzy Logic

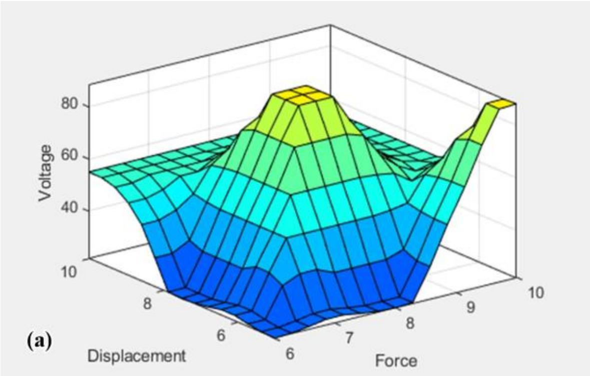
Fig. 4. (a) PZT system in Fuzzy Logic, (b, c, d, e) membership functions and (f) Rules of Fuzzy Logic

4. RESULTS

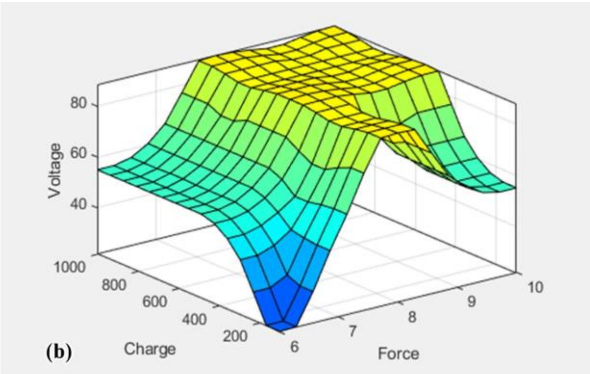
With the help of this simulation the force was retained at 9.04 N, the displacement was retained 6.35 mm, the charge was retained at 284 mC. The potential difference was attained at 5.56 mV as displayed in Fig 5, MATLAB viewer of rules.

Fig. 5. View of rules in MATLAB

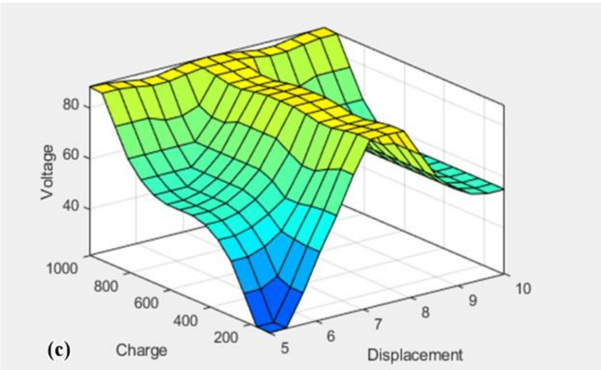
The 3-dimensional and 2-dimensional displays between force, displacement, and charge with potential difference are exposed below in Fig. 6 (a, b, c, d, e, f).



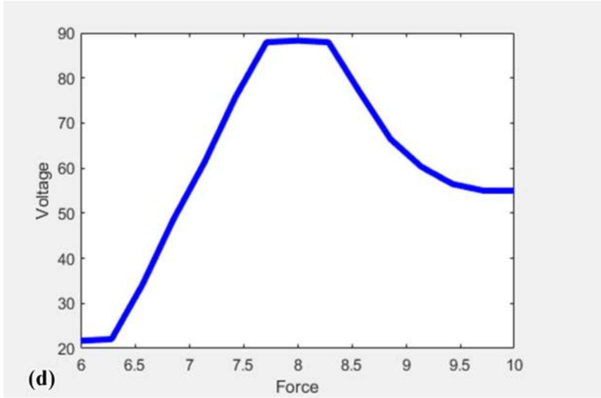
(a) 3D Graph between displacement and force with voltage as output



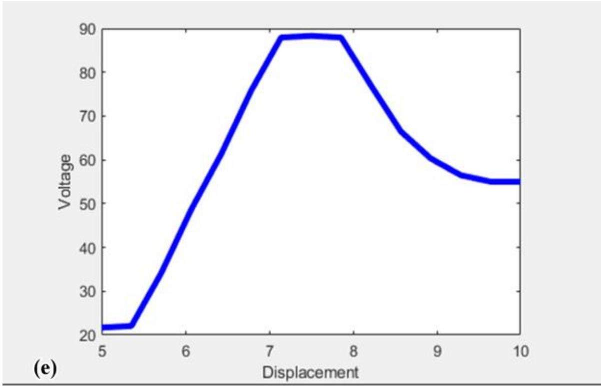
(b) 3D Graph between charge and force with voltage as output



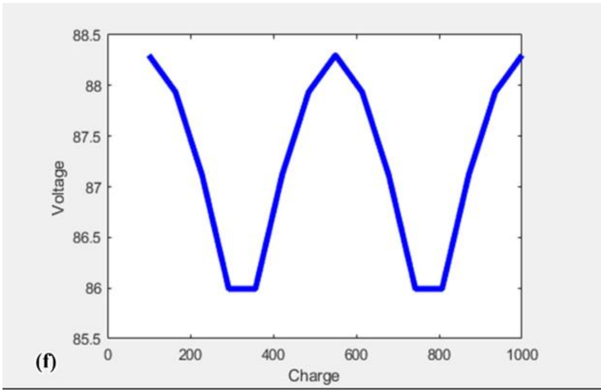
(C) 3D Graph between displacement and charge with voltage as output



(d) 2D Graph between force and voltage



(e) 2D Graph between displacement and voltage



(f) 2D Graph between charge and voltage

Fig. 6. (a, b, c, d, e, f) Graphs between force, displacement, charge, and potential difference.

The threesome graphical results present that energy harvesting from PZT material induced potential difference ranging from 1 to 100 mili volts successfully. The following Fig. 7(a, b, c) presents the portions in order to find the values of C1, C2, C3, C4, C5 and C6 for Mamdani's calculation.

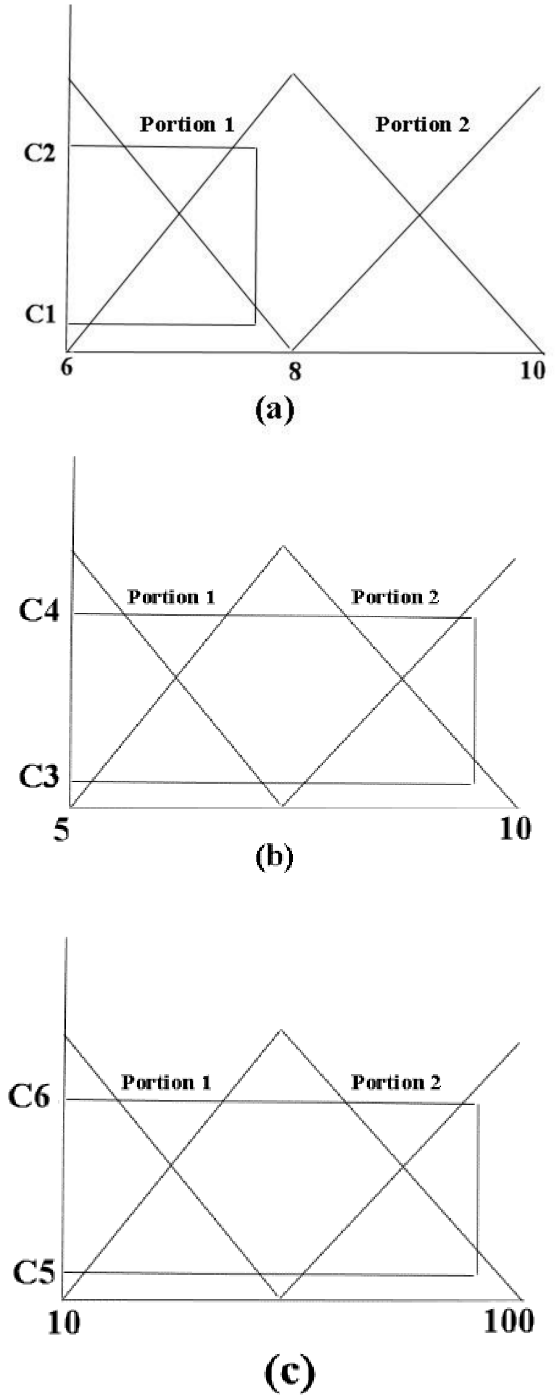


Fig. 7. (a) Force C1 and C2. (b) Displacement C3 and C4. (c) Charge C5 and C6.

The values of C1 and C2 have been calculated as,

C1 = (10 - 7.8) / 10 = 0.22
C2 = 1 - C1 = 0.78

The values of C3 and C4 have been calculated as,

C3 = (10 - 9.8) / 10 = 0.02
= 0.02 / 100 =0.0002
C4 = 1 – C3 = 0.0098

The values of C5 and C6 have been calculated as,

C5 = (100 - 90) / 100 = 0.1
= 0.01 / 100 =0.0001
C6 = 1 – C5 = 0.009

Table 1. Membership functions for Si and Ri

No	Force	Displacement	Charge	Voltage	Mfs Value
1	Small F	MedD	MedC	MedV	C1 C3 C5
2	Small F	MedD	LargeC	MedV	C1 C3 C6
3	Small F	LargeD	MedC	MedV	C1 C4 C5
4	Small F	LargeD	LargeC	MedV	C1 C4 C6
5	MedF	MedD	MedC	MedV	C2 C3 C5
6	MedF	MedD	LargeC	MinV	C2 C3 C6
7	MedF	LargeD	MedC	HighV	C2 C4 C5
8	MedF	LargeD	LargeC	MedV	C2 C4 C6

With the help of Table 1, simulated result is verified with Mamdani's relation ([Σ(Ri × Si) / ΣRi] *100 = 5.50 mV). The difference between the two values is 0.01 with 0.01 % inaccuracy.

5. CONCLUSIONS

The progressive study is continuing with simulation of ANSYS Electric and Fuzzy logic. These simulation schemes can be functional to control complex structures, like PZT material (actuator). Simulation with both software is an alternative method to find the decent results. There are countless values in Fuzzy Logic and ANSYS is a very powerful software for simulation. In this research we have found alternative techniques to discover the value of induced potential difference. The variance is just 0.005 V between two simulations techniques and there is no difference between Fuzzy and Mamdani values. Piezoelectric materials can generate voltages in the range of 0.001 to 0.1 V [25]. Consequently, it is confirmed that this PZT system has the tendency to induce the potential difference in certain range. By using these simulation techniques, the researchers can have a very good idea that how much the system has the working potential. Maximum and minimum output of any system can be measured by these simulation techniques successfully. The results comparison is given below in Table 2.

Table 2. Comparison of results

Voltage	Value
ANSYS	0.00500
FUZZY	0.00556
Mamdani's model	0.00550

The simulated values are very close to each other. Therefore, results are verified. The output current that is produced from a PZT system is very low, therefore, charging time of the battery is increased. It can be utilized to charge a battery. The voltage obtained through both simulation 0.00500 V (ANSYS) and 0.00556 V (Fuzzy) and 0.00550 V by using Mamdani's principle is very much enough for charging any type of battery through piezoelectricity. This PZT system has the potential to develop voltages in the range of 1 milli volts to 100 mili volts. These PZT systems are needed for the sensors and actuators that can be enhance the charging process. The obtained simulation results of this paper will be helpful to fabricate the efficient energy harvesting PZT system.

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