Modelling and Investigating Electricity Generation Using Smart Piezoelectric-materials

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Abstract

This is a study of mechanical energy harvesting using Smart Piezoelectric materials, in the module of the speed bump, that transforms the mechanical stresses into electrical potential, also modelling and simulation this materials using COMSOL software, with results compare of many materials, and experience of several load states and others, for producing clean electricity by exploiting wasted sources such as walking, sound, pressure and traffic moving. This will help to decrease energy consumption and environmental impact even further, also reparating some power coming from the main grid, for instance, in street lighting, signboards or other. Another objective of this study, utilizing smart materials to design renewable energy systems in Libya.

Keywords: Smart Materials, Piezoelectric Materials, Energy Harvesting.

1. Introduction

This term "**Piezoelectricity**" used to describe the ability of certain materials to develop an electric charge that is directly proportional to an applied mechanical stress, and these also showing the converse effect. This term has involved two sections: (Piezo) is from the Greek word "piezein", which means "to press tightly or squeeze", and (Electricity). The uniform meaning is "**squeeze electricity**" (Bohidar, Kumar, Mishra, & Sharma, 2015). The Piezoelectric effect was initially observed by the French physicists *Jacques & Pierre Curie* in 1880, they discovered a connection between the macroscopic piezoelectric phenomena and the Crystallographic structure in crystals of sugar, quartz and Rochelle salt, where that an electrical output was produced when imposed a mechanical strain on those materials. They demonstrated this coupling by measuring the charge induced across electrodes placed on the material, when it underwent an imposed deformation. The converse effect was first mathematically deduced from fundamental thermodynamic principles by *Lippmann* in 1881, later the *Curie* brothers demonstrated it. The property was interesting, but The electromechanical coupling is not very useful, because the amount of electrical signal was "small" and not exist precise instrumentation for measuring output (Leo, 2007) (Varadan, Vinoy, & Gopalakrishnan, 2006). Due to World War I, interest in piezoelectricity increased. In 1917 *Paul Langevin* developed an underwater device, a transducer that utilized a piezoelectric crystal to produce a mechanical signal and measure its electrical response as a means of locating submarines, this work was the basis of Sonar and became one of the first engineering applications for the piezoelectricity. Also World War II stimulated even more advance in the piezoelectric materials and devices, *Frederick Lack* developed a crystal that operated through a wide range of temperatures, this development allowed the use of aviation radio and engage mass attacks. In Japan, a temperature stable crystal was developed by *Issac Koga*, major developments included new designs of ceramic filters. In addition to improvements in sonar, developments in electronics began as electronic oscillators, filters, buzzers, and audio transducers (Leo, 2007) (Varadan, Vinoy, & Gopalakrishnan, 2006). Barium-Titanate **($BaTiO_3$)** was an early synthetic piezoelectric material that had piezoelectric and thermal properties that made it superior to quartz crystals, and the polymeric materials such as Poly vinylidene fluoride **(PVDF)**, have also been shown to exhibit similar characteristics. Intense research is still going on to produce useful and reasonably priced actuators, which are low in power consumption and high in reliability and environmental ruggedness (Varadan, Vinoy, & Gopalakrishnan, 2006).

2. Problem Statement

Because of the constant demand for energy, with high cost and depletion of the natural resources, Must look for alternative sources of energy production. In line with the environment, economy and various applications. One of these applications is harvest energy, in several ways including the harvesting by use

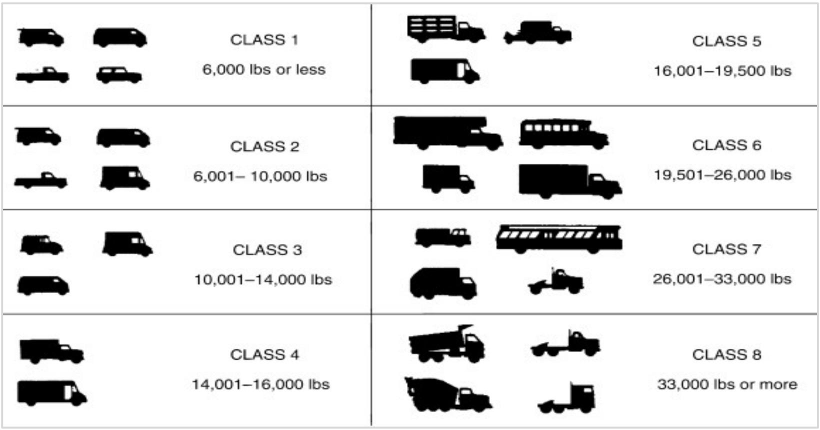

Figure 1: Classification of trucks by (GVW).

the piezoelectric materials. Harvest vibration or motion energy from humans walking, machinery vibrating, or cars moving on a roadway is an area of great interest, because this energy is otherwise untapped, and since movement is everywhere, the ability to capture this energy cheaply would be a significant advancement toward greater efficiency and cleaner energy production. Consequently, a speed bump as a system generating and Harvesting the energy has been designed in this project by using Piezoelectric Smart materials, as well as many materials experimented, load states and formats, then testing feasibility of this application. For exploiting the wasted mechanical energy, for instance; in lighting.

3. Methodology

3.1 Estimating External Force: In American Classification Of Trucks according to "GVWR" (Committee on Review of DOE's Office of Heavy Vehicle Technologies, 2000) and assuming that the road is designated for the transit the Light and Medium duty trucks, to calculate the Arithmetic Mean of the mass:

- **Mean of mass:** $\frac{6000+10000+14000+16000+19500+2600}{6} = 15250\ Pounds.$
- **External force:** 67789.379= 70 KiloNewton approximately. This is affecting a speed bump, specifically on the Moving substrate, above springs.

3.2 Smart Module Designing: One of the models were designed is model A. Where the descending segment by effect of external force, causes Impact Load on Edge of the piezo beam (yellow parts), causing an Edge load or Boundary load. In this model, the dimensions of **Piezoelectric segment** are **(Width 0.5 _**

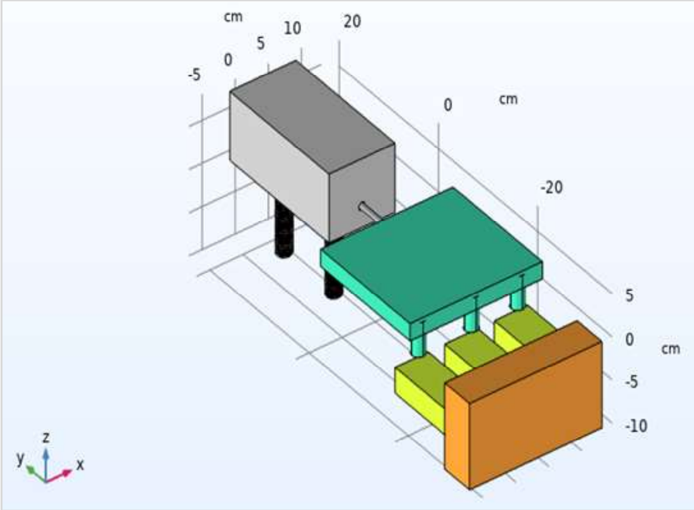

Figure 2: Speed Bump Model A.

Depth 0.15 _ Height 0.15 m). Also this segment is subject to 4 Different Load States.

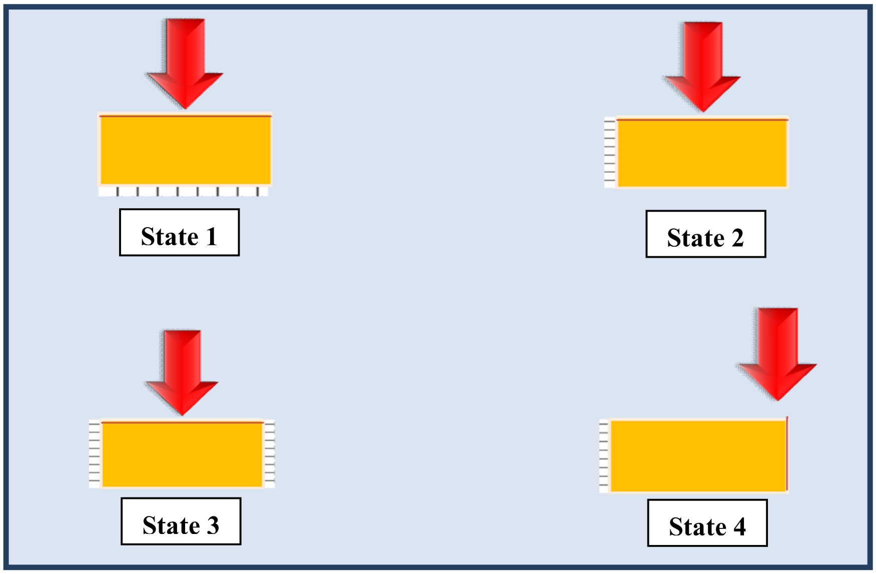

Figure 3: States of loads.

State1: segment is fixed from bottom, load is uniform on surface boundary. **State2:** segment is fixed from one edge, load is uniform on surface boundary. **State3:** segment is fixed from two edges, load is uniform on surface boundary. **State4:** segment is fixed from one edge, load is localized on the other edge.

3.3 Drawing and Simulation Using COMSOL5.5: COMSOL Multiphysics® is a general-purpose simulation software for modeling designs, devices, and processes in all fields of engineering, manufacturing, and scientific research. And that encompasses all the steps, from defining geometries, material properties, and the physics that describe specific phenomena to solving and postprocessing models for producing accurate and trustworthy results. Also turn models into simulation applications and digital twins for use by other design teams, manufacturing departments, test labs, customers, and more. The platform product can be used on its own or expanded with functionality from any combination of add-on modules for simulating electromagnetics, structural mechanics, acoustics, fluid flow, heat transfer, and chemical engineering.

4. Results

4.1 Results of Load States:

Description of the Study Case: Geometry (W 0.5_ D 0.15 _ H 0.15 m), Material (PZT-4D), External Load (-1000 N *k*), Electric Potential (0 V), Normal Mesh.

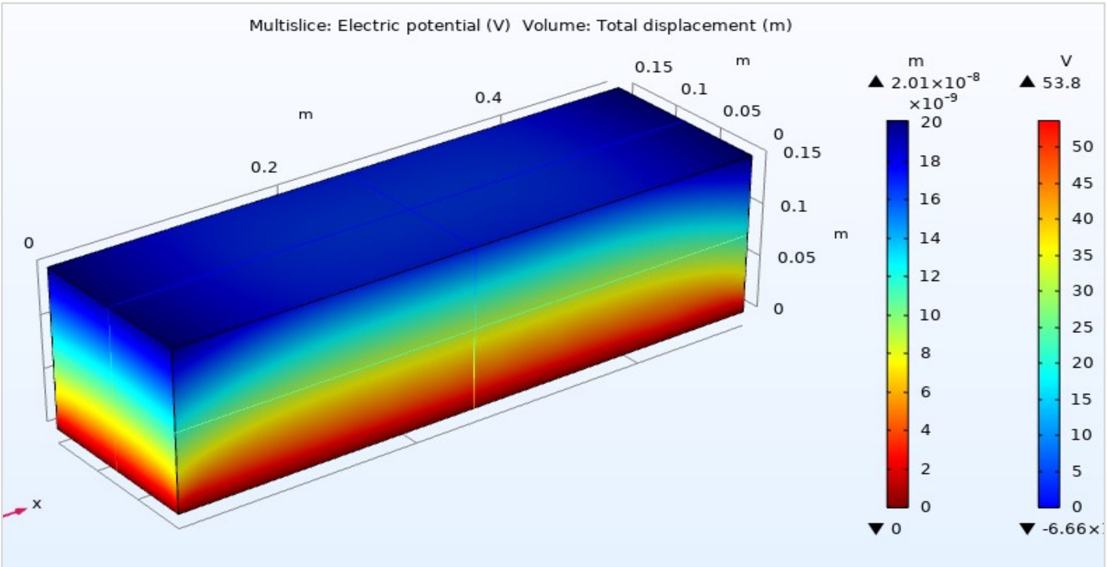

Figure 4: Electric Potential and Total Displacement in state 1.

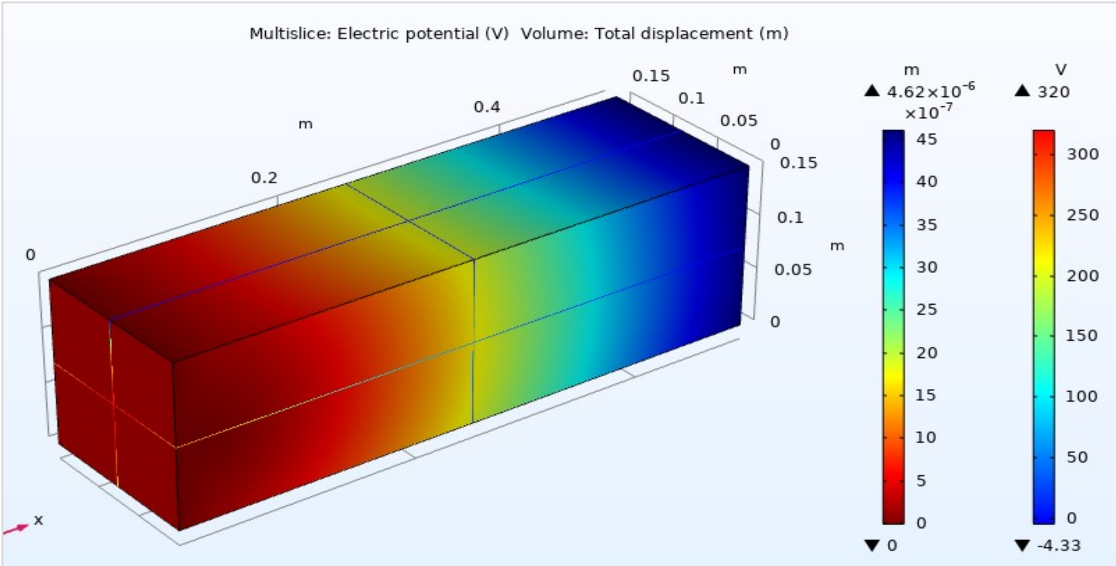

Figure 5: Electric Potential and Total Displacement in state 2.

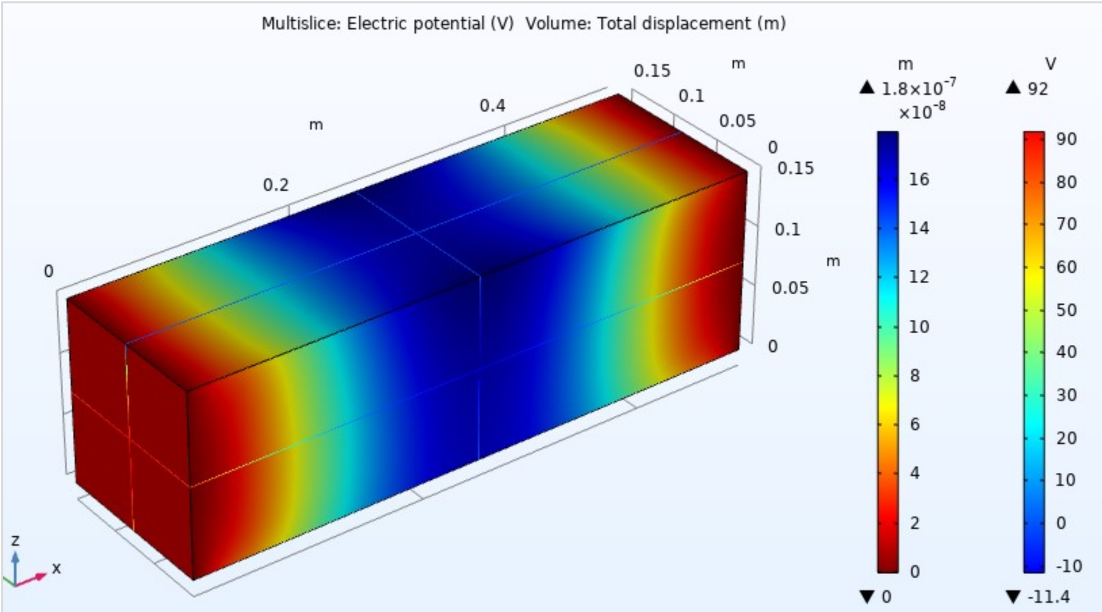

Figure 6: Electric Potential and Total Displacement in state 3.

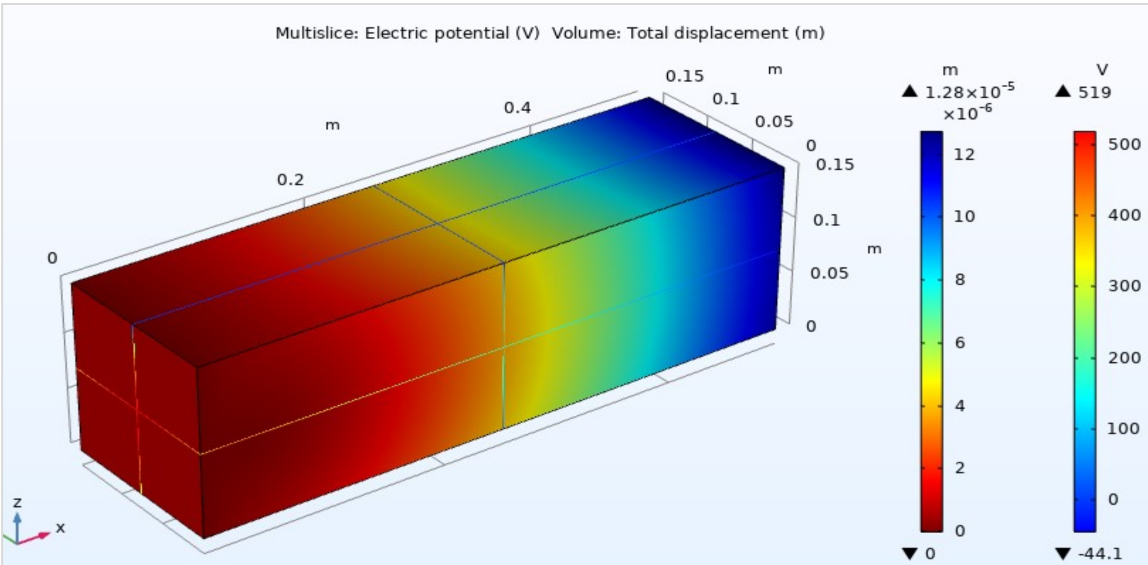

Figure 7: Electric Potential and Total Displacement in state 4.

4.2 Results of Piezoelectric Materials:

Ceramic vs. polymeric Piezoelectric material. Description of the Study Case:

- Geometry (W 0.5_ D 0.15 _ H 0.15 m)
- External Load (-1000 N *k*)
- Electric Potential (0 V)
- Load Type (State 4)
- Finer Mesh

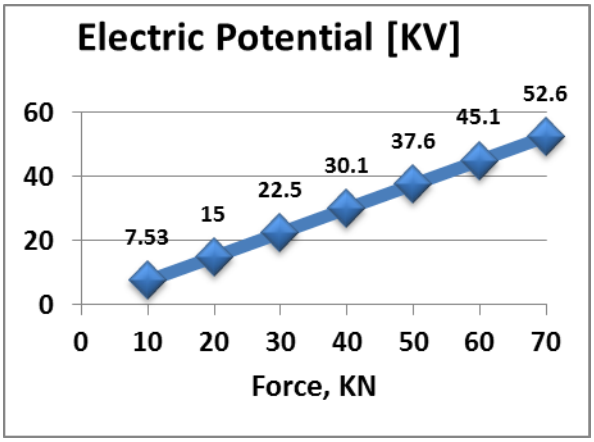

Figure 8: Electric potential result of PZT-2.

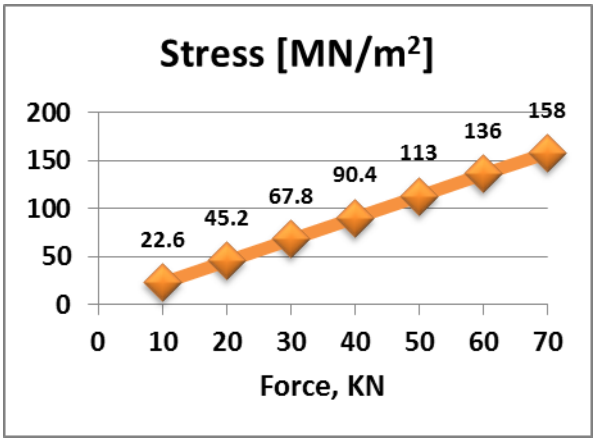

Figure 9: Stress result of PZT-2.

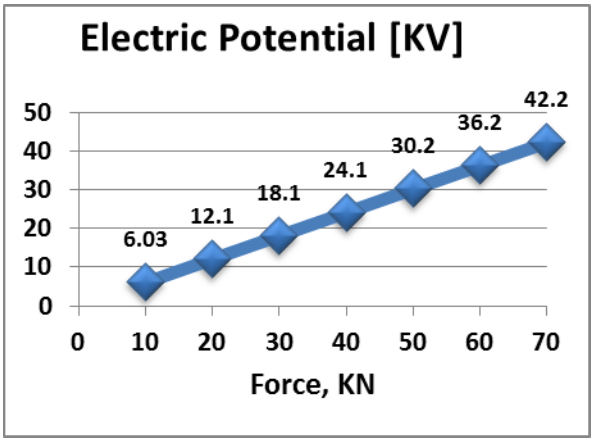

Figure 10: Electric potential result of PVDF.

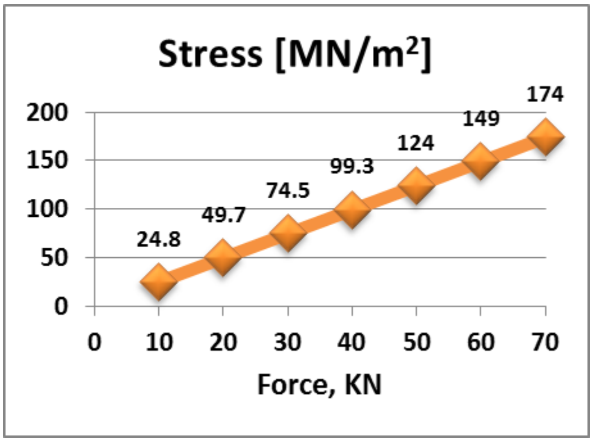

Figure 11: Stress result of PVDF.

5. Discussion

- **Load states:** Based on the results, State 4 has the best result.
  State4: was the best because the load was localized, not distributed, and fixing from one-sided gives more flexibility, for produce more E. potential, Max. V [**519 V**].
  State2: Was good result, one-sided fixation conferred good E. potential, because it is flexible, Max. V. [**320 V**].
  State3: In this case, a curvature occurred, not a deflection. Acceptable but not satisfactory result., Max V. [**92 V**].
  State1: Bad result, less flexibility, less stress, less voltage. It is the lowest of the four cases, with the same substance and other conditions. Max. V. [**53.8 V**].

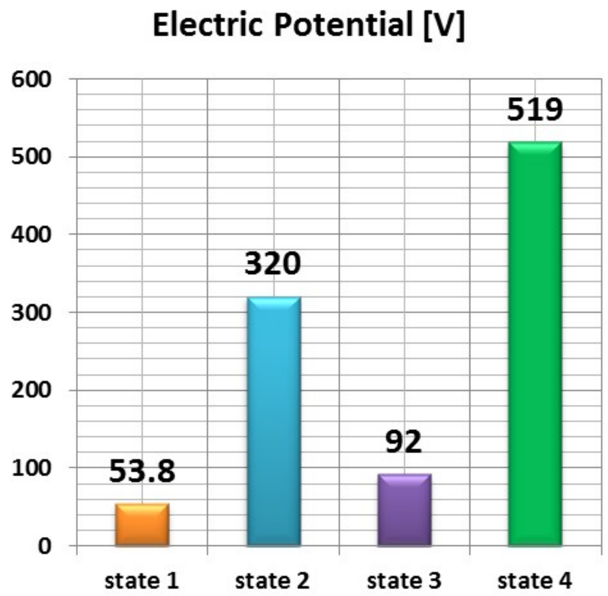

Figure 12: Compare Electric Potential between Load states.

- **Piezoelectric Materials:** Best Maximum Electric Potential, was from **$LiNbO_3$** (**54.8**), **PZT-2**(**52.6**), **PZT-7A**(**52.6**), **$BaTiO_3$** (**48.3**), **PVDF**(**42.2**). In general (**PZT**) Better in properties, more reliability, more usability and application compatibility. Another thing has been noticed: The difference between **($BaTiO_3$)** regular material and **($BaTiO_3$)** Poled material, as **($BaTiO_3$-Poled)** is better than **($BaTiO_3$)** when all boundaries had a default electric potential (**0 V**) while the opposite was when it upper boundary (4) only had a default electric potential (**0 V**).

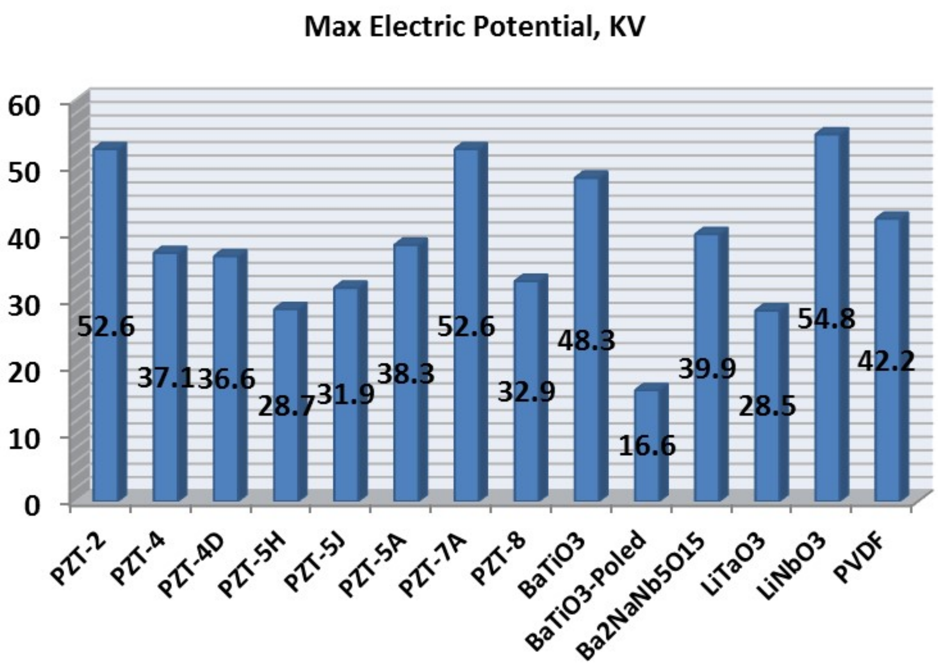

Figure 13: Compare of Electric Potential.

6. Conclusions

In this study, COMSOL software was used to drawing, modelling, and simulation of piezoelectric materials. These materials involve in speed bump module, as the energy harvester, to harvest the wasted mechanical energy, and reduce the work on the main network, by providing secondary sources of lighting for instance. 14 materials were exterminated, the maximum value of electric potential (+54.8 KV) for one piezoelectric segment (Subject to increase). Also concluded from this study that:

- PZT, $LiNbO_3$, $BaTiO_3$, and PVDF are the best materials.
- Beam deflection is better than bending it.
- Better fixing of the segment on one side than from the bottom.
- Localized force is better than uniform force.
- The less restrictive the material, the more produced.
- The more flexibility the material, the more produced.
- Load state, segment shape, area under stress and dimensions greatly affect the results.

7. Recommendations

- Attention to all mechanical calculations and choosing realistic spring designs.
- Ensure the choices of materials involved in designing the speed bump model (moving parts).

- Ensure that the speed bump dimensions comply with local and standard specifications.
- Design of electrical circuits required to collect and store this energy.
- Create a study similar to this, to collect energy at airports or footpaths.
- Expanding the field of research in piezoelectric materials and thermoelectric materials.
- Study of piezoelectric composite materials (ceramic - polymeric).
- Attempt to search for piezoelectric polymeric-composites from which to make a tire of vehicles.
- Application of such a study to piezoelectric nano-materials.

8. References

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