Generation and Capture of Electric Energy Using Piezoelectric Materials: A Review

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Abstract. Piezoelectricity comes as a principle of transformation of mechanical energy into electrical energy, it is limited in terms of investment, time and research, due to this fact, the need arises to be able to innovate with data collection on the most used models to collect and generate electrical energy. In this research, the literature regarding the generation and collection of electrical energy using piezoelectric materials was analyzed, from this analysis, fifty innovative articles were determined in the last three years, which were reflected in a data matrix, in which it presents the generation and collection element, the applications, and shows the performance in terms of power or voltage that the prototypes supply. With the results of the table, a condensed panorama of current data is obtained, about the most used and outstanding of this form of little-used energy, but which is a competent and efficient alternative for the generation of electricity.

1. Introduction

Electric energy is currently used in order to develop any service in daily life, which ends up being more environmentally friendly, profitable when using energy in any work field and a priority for the development of many technologies in history [1][2][3].

The point is that, when wanting to generate electrical energy, there are not many energy devices that make the most of their configuration, or generation processes that are not polluting with the environment. Piezoelectricity, as the principle of producing electrical energy under a force that is applied in a certain area, is an innovative option for the generation of renewable energy, since it has a wide range of materials, such as piezoelectric transducers, for various availabilities, offering a good potential differential when used [4][5].
[6]. For this reason, it is necessary to carry out this research, to expose through research in the literature regarding the generation and collection of electrical energy, various sustainable models that, using piezoelectric materials, can provide efficient solutions for this form of energy, little used, clean and renewable. Also, it is very important to contribute this study to subsequent projects in the same framework, so that they have current antecedents of what was done, and thus further improve the efficiency obtained in the model that is being sought [7][8][9][10].

The objective of this article is to base research on the literature regarding the generation and collection of electrical energy using piezoelectric materials, and then make a selection of the fifty most outstanding technical-scientific articles in the last three years. The authors of the different sections focus mainly on selecting a difficulty in some field, when wanting to supply electrical energy to a process or equipment that needs it, but always prioritizing the use of piezoelectrics for this service. Some highlight the use of piezoelectric materials, such as Lead Zirconate Titanate (PZT) and Polyvinylidene Fluoride (PVDF), since due to their properties they are truly efficient in producing electrical power; Other authors emphasize that the use of these elements are polluting with the environment, since they contain Lead, deducing that it is necessary to carry out tests on other materials that allow obtaining an efficiency equal to or greater than those commonly used [11][12][13][14][15].

This review presents a methodological process that consists of the creation of a data matrix focused on the technological models already investigated, in order to summarize and visualize the analysis made. The table will show the most prominent devices or prototypes by the authors of the inquiries, highlighting the piezoelectric material used in each of them. Also, the application in which the prototype takes place and in which service it will be developed will be defined, in order to later determine how much each model fulfilled in the generation of this clean energy, making known the active voltage or power output that was reached to provide. Finally, an analysis of the results will be carried out with the creation of graphs to extract the information from the previous table, and thus be able to visualize the investigated models more easily [16][17][18].

2. Work development

2.1 Data matrix

To detail the investigation of the fifty technical-scientific articles, the elements, applications and performance of the investigated models within the framework of generation and collection of electrical energy are illustrated through a data matrix, using piezoelectric materials as a solution for transform mechanical energy into electrical energy through vibrations, in order to power a selected device or process. Next, it is presented in Table 1, of the aforementioned.
Piezoelectric element generator and power

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Table 1. Data matrix on the technical-scientific articles investigated.

| Articles                                                                 | Piezoelectric element generator and energy collector | Application                                                                                     | Performance                                                                 |
|-------------------------------------------------------------------------|-----------------------------------------------------|---------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| [16][17][4][5]                                                          | Energy harvesting devices based on Lead Zirconate (PZT) piezoelectric ceramic transducers, such as cantilever beam, springs or patches, are presented. Also, the PZT-5X, which is made up of hardened steel and ceramic, is used in two prototypes. A device is manufactured with the use of PZT-5A material, excellent in fields where the temperature is high and variable. | Installations are found in offshore buoys, asphalt pavements, tank pipes, buildings, broadband environments, in tanks that obtain chemical reactions and the human body. This at the rate of powering implantable medical electronic elements, LED lights and portable devices such as low-power wireless sensors. | Innovative piezoelectric energy collector designs are presented, reaching between 4.91 μW and 2.09 kW / day, as output power. Also, in terms of potential differential, between 400 mV and 20 V/s can be discovered. |
| [7][8][10][45][46][47][48][49][50][51][52]                             | The prototypes present in these eleven articles consist of piezoelectric material in Polyvinylidene Fluoride (PVDF), either in folded sheets, as a cantilever, in the form of patches or more commonly used as a nanogenerator. | There are installations of the prototypes on local roads, bridges for vehicles or trains, tires for automobiles or bicycles, pipes with constant fluid flow and also, in replacement of batteries. This to supply the power supply of wireless sensors, LED diodes and microelectronic systems. | Optimum energy harvesting performance is obtained in the different designs, finding electrical powers between 1.2 μW and 16.5 W. Also, in terms of voltage, there are values between 29 mV and 7 V. |
| [11][13][14]                                                            | The authors of these three articles expose prototypes composed of piezoelectric macro fiber material (MFC), which is made up of rectangular PZT 5A fibers and are embedded with copper electrodes, in order to generate the necessary electrical energy. They are visualized in the form of a cantilever or as patches. | Installations of energy harvesting devices in wind generators, air flow pipes and in the human body are exposed. To achieve constant power to wireless sensors and portable mobile electronic devices. | Optimal electrical power generation is achieved using piezoelectric transducers with an output power between 700 μW and 13.6 mW. |
| [53]                                                                    | A high performance piezoelectric elastic nanogenerator is manufactured, composed of piezoelectric nanowires (NW) with Zinc Oxide (ZnO). It also consists of an AC / DC converter and a DC/DC converter, for rectification of the transformed signal from environmental vibrations. | It is installed in the human body so that when exerting a movement, it generates electrical energy to provide self-powered touch sensors. | It features excellent performance with a maximum output power of 55 μW. |
| [54]                                                                    | Device in the form of a tile, with sheets of substrates. Mainly, it is composed of a flexible, thin film, chemically stable and biocompatible piezoelectric material of Group III Nitride (III-N). | Implementation in tiles to power light-emitting diodes, and to charge commercial capacitors and batteries that operate optical pulse sensors. | It complies with the transformation of mechanical energy into electrical energy, collecting an active output power of up to 167 μW. |
| [55]                                                                    | The prototype is based on the use of piezoelectric materials of Perovskite Oxide in sheet form; Also, it consists of a rechargeable battery and a rectifier. Everything named is located superficially on the heart to transform the heart rhythm into electrical energy. | It is established in portable electronic devices or implantable biomedical devices for a continuous feeding of the same. | It show excellent electrical properties, exhibiting good flexibility in generating electrical power up to 0.3V. |
| [56]                                                                    | Power generator prototype located on the model; Composed of flexible piezoelectric material with thin films of Poly (Vinylidene Fluoride/Trifluoroethylene) (P(VDF-TrFE)) ferroelectric polymer. | Device implanted in the heart, such as pacemakers, to obtain self-powered sensors implantable in the human body. | Power generation is obtained but with minimum voltages of 3V, recommending optimizing the capacity of the piezoelectric. |

Source: Authors.
In the matrix produced, the most relevant research and applications of the fifty technical-scientific articles are condensed. The piezoelectric material, PZT, is used in 64% of the investigated sections, emphasizing its excellent piezoelectric properties and its efficiency in applications, reaching up to 2.09 kW/day in incrustations within roads. Also, 22% of the authors of technological articles present prototypes that mainly contain PVDF material, emphasizing its flexibility and effectiveness, reaching up to 16.5 W, in local road installations.

At the end, other types of piezoelectric materials that have fewer applications in recent years are presented, but this does not make them less important, since the authors of the sections work to eradicate the use of Lead, being a highly polluting chemical element environmentally friendly, but still widely used in piezoelectricity applications over time.

It is important to expose through research in the literature regarding the generation and collection of electrical energy, various sustainable models using piezoelectric materials, in order to provide efficient solutions for this form of energy, little used, clean and renewable, which is and will be a competent alternative for electricity production.

2.2 Analysis of results
For the generation and collection of electrical energy, it is very important to identify the piezoelectric element used, since it helps the transformation of mechanical energy by exerting a force into electrical energy through vibrations.

![Piezoelectric elements highlighted in the investigated technical-scientific literature. a) Identification of piezoelectricity and elements used in recent years; b) Change in the number of investigated articles depending on piezoelectric materials.](image)

In Figure 1, the different piezoelectric materials used in the investigated sections can be observed, it is identified that Lead Zirconate Titanate is the most used at a rate of thirty-two articles, highlighting its flexibility and efficiency in applications. Polyvinylidene Fluoride (PVDF) was used in eleven articles, which although it did not produce power as in the PZT road application, it manages to generate 16.9 W in this same adaptation, complying with the collection of electrical energy. Finally, the MFC elements can be observed with three articles that use it and the piezoelectric nano cables (NW) with Zinc Oxide (ZnO), Group III Nitride (III-N), Perovskite Oxide and [P (VDF/TrFE)], which only have one application, but it
does not make them less important, since they provide elements without Lead, this being very polluting with the environment.

The most prominent places for the installation of piezoelectric generators are illustrated below, which were found in the fifty articles investigated.

Figure 2. Installation of piezoelectric generators featured in the technical-scientific literature investigated. a) Identification of piezoelectricity and facilities used in recent years; b) Change in the number of articles investigated depending on the instances.

Source: Authors.

In Figure 2, the different installations of piezoelectric generators in the last three years are observed. The technological development has been quite extensive, identifying 18% of the articles investigated from installations on local roads, 12% in high-flow pipes and the same, to achieve the replacement of conventional batteries. It is illustrated, the incursion of piezoelectricity into the human body in 10%, also, 4% in level buoys that use the waves of the sea as their main force and the same percentage for their placement on automobile or bicycle tires. Likewise, they are obtained from a single item in installations in buildings, broadband, tanks and electric generators. Finally, with 32%, there is the arrangement of piezoelectric generators in fields where it is required to produce energy to power a low-power device, thus taking advantage of any mechanical energy that is had.

It is illustrated below, the outstanding devices of the investigation in the articles, which will be fed by the electrical energy produced from the use of piezoelectric materials which first take some external force to transform it into the required energy.
Figure 3. Applications of piezoelectric generators featured in the investigated technical-scientific literature. a) Identification of piezoelectricity and applications used in recent years; b) Change in the number of articles investigated depending on the applications.

Source: The authors.

In Figure 3, four types of applications found in all the investigated sections are identified, obtaining that twenty of them used the electrical energy generated to power low-power portable electrical devices, nineteen of them were applied to promote the sustainable and durable self-powering of wireless sensors. With eight articles, applications in LED street lamps are discovered, and with three the innovative application of devices implanted in the human body is detected, for the replacement of batteries, opening a wide panorama, in subsequent investigations within the same field.

3. Conclusions

It was presented the feasibility of carrying out a technical-scientific evaluation of applications in the framework of generating and collecting electrical energy using piezoelectric materials, obtaining as a result a matrix with a wide panorama of data on the most used and outstanding of this little-used form of energy, but that it is a competent and efficient alternative for generating electricity.

From a table of data on the research in the fifty models destined to generate and collect electrical energy, it is obtained that the main device to carry out the investigations were prototypes made by the authors of the same, since the few suppliers of piezoelectric devices Existing elements make these elements very expensive and a good economic viability of the service of this kind of technology is not obtained.

In the applications of the service to be supplied, their use in low-power electronic devices is appreciated in all the technical-scientific models, seeking their self-supply in implantations of the human body, wireless sensors or portable devices in a specific field.

Finally, it can be clarified that all the models fully meet their objectives, although some generate more than what is established in the sections and others lack very little to fulfill their purpose. From this, it can be inferred that it is very important to contribute this research to subsequent projects in the same framework, so that they have current antecedents of what was done, and thus, further improve the efficiency obtained in the model that is being sought.

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