Piezoeletricity as an Alternative Source of Electric Power Generation in an Education Institution in the Amazon

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Abstract

The development of technologies for the generation of clean and sustainable energy has brought significant changes to the energy sector in Brazil and worldwide. The newest technology is piezoelectricity, which although it has been studied for years, has not yet gained its proper space in the national and international electrical matrices. With this in mind, the present work aims to describe the process of installing a prototype carpet using piezoelectric ceramics that, through a force applied by any individual, is capable of generating enough energy for the operation of a turnstile in a HEI from Manaus-AM. The application was tested by modeling applying mathematical equations in the working of the prototype developed by APC International. Different answers were obtained considering the different dimensions for the piezoelectric parts. However, it is understood that this energy production model, treated as a new technology, presents economic viability in its implementation. One of the results demonstrates that the smaller the ceramic piece, the greater the energy production and can be adapted over time to respond to large productions. Thus, it is concluded from the calculations made that piezoelectric ceramics is an excellent alternative for the production of clean energy on a small scale, in a short time, and in the long term can reach large scale.

Keywords: piezoelectric; sustainable energy, electric energy;

1. Introduction

In Brazil, investment in renewable energy took strength after the oil crisis in the 1970s. Since then, the country has undergone a series of changes and adaptations, so that there was cooperation due to the increase of these sources in the national energy matrix where, From this perspective, the concern from this perspective has been generating a technological advance so that new sources of alternative energy develop.

Renewable energy comes from the use of natural resources for clean energy generation, such as harnessing wind potential, solar irradiation, water potential, among others. The use of these resources as an alternative source for power generation has grown exponentially in recent years and the search for new sources seeks to develop and provide a more efficient generation, which in fact is intensifying.

In 2016, the world's energy matrix was 86% non-renewable energy (IEA, 2018). In Brazil, in 2017, its energy matrix was composed of 56.5% of non-renewable energy (EPE, 2018), showing a decrease in energies that cause more environmental losses and resource degradation.

Even though more than half of its energy production comes from non-renewable sources, Brazil has one of the world's most renewable energy matrices, being supported by energy production from water sources (EPE, 2018).

The electricity sector accounted for 17.5% of the energy consumption produced in the country, being the Brazilian electricity matrix composed by 80.5% by renewable sources (EPE, 2018), while the world electricity matrix is composed by 24.5%. % by renewable sources (IEA, 2018).

Even though solar power generation is still underrepresented in Brazil and around the world, it has cooperated for a change in both power generation scenarios to drive sustainable power generation.

In Brazil, electricity generation occurred in a different way due to the emergence of distributed generation and the creation of Normative Resolution No. 482, promulgated by the National Electric Energy Agency (ANEEL), on April 17, 2012 [3].

Distributed generation (GD) is characterized by the production of electricity through small generating plants that use renewable sources of electricity and that connect to the distribution network of the concessionaires through the facilities of the consumer units (ANEEL, 2016).

Studies focused on the development of new sources of clean energy allowed the discovery of piezoelectric as an alternative energy source, emerging from the knowledge of French physicists Pierre and Jacques Currie who demonstrated that, by compressing piezoelectric crystals, it was possible to generate a difference of potential, where from this observation numerous studies were obtained until we reach piezoelectricity.

Piezoelectrics are crystals that react to compressions by appearing a pulse from the created electric field, which can be captured as electrical voltage. One of the basic characteristics of piezoelectric crystals is that these crystals do not have a symmetry center, since in each direction a different behavior will occur when an external stimulus is applied to these materials (JESUS et al. 2014).

According to Wang et al. (2018), piezoelectric materials are classified into crystalline materials (Quartz); piezoceramics; piezoelectric semiconductors; polymers; piezoelectric composites; and glass ceramics, and each material has its own piezoelectric and mechanical characteristics, the polymers being more flexible and generating less energy while the ceramics are more rigid and capable of generating more energy.

Piezoelectricity is the conversion of mechanical energy generated by a compression into electrical energy. Although the technology is little known for large power generation, piezoelectrics are found in microphones, toys, electronic scales, alarms, among others. The compressions exerted on this equipment are converted into electricity to ensure their functionality (CIGOGNINI et al. 2016).

The use of piezoelectric plates for the production of electricity has a growing tendency and there is a great effort to improve this technology since, one must analyze the type of piezoelectric element to be used, one must also consider the quality of the material and the carrying capacity limits without causing damage to the material used (SILVA, 2018).

In addition, it is important to analyze the feasibility of implementing this power source in order not only to reduce environmental impacts and losses in energy transport, but also to reduce energy generation and consumption costs.

Thus, the present study aims to analyze the generation of electricity through piezoelectric crystals by simulating a generator prototype in a turnstile of a private college in the city of Manaus seeking to describe the installation process to be performed.

2. Materials and Method

Based on the study by LIMA (2013), a prototype was designed using a piezoelectric mat that should generate enough energy for the operation of the turnstile in a HEI in Manaus, AM.

The operating principle of the generator is based on the passage of people through the turnstile, where when an individual of a given mass applies a force on the piezoelectric mat an electric field will be generated in the sensors that will produce sufficient voltage to ensure the turnstile works.

In order for the generator to be sufficient to feed the ratchet, the system is composed, in addition to piezoelectric ceramics, of other materials to keep the ratchet on for 16h for 5 days a week.

To control the current, which will be sent to the ratchet and the battery, the LS3024EU charge controller will be used. This controller has a PWM system that ensures the least amount of voltage losses to the system and also controls the charge and discharge levels of the batteries and compensates for operating temperatures while preserving their useful life. This device also allows the battery type and output charge to be set through its panel.

For storage of surplus energy a 48 Ah stationary battery with a nominal voltage of 12 V and a reserve capacity of 65 minutes will be used. This battery has an emergency light and alarm that act when the battery charge levels are below indicated. The battery will guarantee a system autonomy of 16h, that is, if there is not enough power generation the battery will meet the ratchet need well, the battery capacity is expressed:

$$t\,(h) = \frac{C\,(Ah)}{Consumo\,(A)} \quad \text{(Eq. 1)}$$

Where t is the autonomy time the system should have in hours; C is the energy capacity of the battery in ampere-hours; and consumption is the current the battery must have in order for the system to be powered to function.

The piezoelectric ceramics used for this simulation was APC 850, which is made of lead zirconate titanate (PZT) and has high sensitivity to deformations in its structure. 1).

Table 1 - Characteristics of piezoelectric ceramics

E (Gpa)	v	ρ (Kg/m³)	Piezoelectric Constants (10-12m/V)			ε_{33}	G (10-³Vm/N)	
			d_{31}	d_{32}	d_{33}		g_{31}	g_{33}
63	0,3	7600	-175	400	590	1950	-10,2	24,8
d: piezoelectric constant; g: piezoelectric voltage constant; ε: relative dielectric constant; ρ: density; E: Young's module; v: Poisson's ratio								

Source: APC International (2019).

The calculations performed considered four different dimensions for the ceramic pieces, so that it was possible to analyze what would be the best option for the prototype elaboration (Table 2).

Table 2 - Dimensions of Piezoelectric Ceramic Parts

DIMENSIONS (MM)	HEIGHT	LENGTH	THICKNESS
POTTERY 1	10	10	0,5
POTTERY 2	30,1	30,1	1
POTTERY 3	32	32	0,9
POTTERY 4	32,1	32,1	1,5

Source: APC International (2019).

Sensors made of piezoelectric ceramics can operate in different ways. However, for this simulation will be considered only the operation of the sensor in compression mode which submits the sensor to a mechanical stress applied in parallel to its polarization and, as a result, a thickness deformation and an electrical output potential are generated (LIMA, 2013).

APC International has developed a calculator that allows you to calculate the physical and electrical properties of the piezoelectric materials sold by them, demonstrating the voltage generated as a function of the force (N) applied to the piezoelectric sensor.

$$V = \frac{(g33 \; x \; F \; x \; h)}{(l \; x \; w)} \qquad \text{(Eq. 2)}$$

Where: V is the generated voltage; g33 is the piezoelectric constant; F is the force applied to Newton; h is the thickness of the sensor; l is the length of the sensor; w is the width of the sensor.

The sensors are connected in series and positioned at the ends of two overlapping aluminum plates so that the applied force directly on the mat is distributed, thus generating a mechanical force that will create deformations in the sensors and consequently producing an electric field. To isolate the contact sensors with the plates, we use fiberglass mesh that has high tensile strength; In addition to being an excellent electrical insulator, it is a material composed of thin non-rigid and flexible glass filaments joined to plastic materials.

In order to be able to turn on the turnstile, we need to understand how it works. The ratchet has a power supply (Figure 1) that has the ability to adapt to voltages ranging from 100 to 240 V and at its output has a charge controller that allows only 12 V, with a 5% variation, up or down to the controller board, which performs its unlocking actions. The voltage source also has protection against short circuit and overheating.

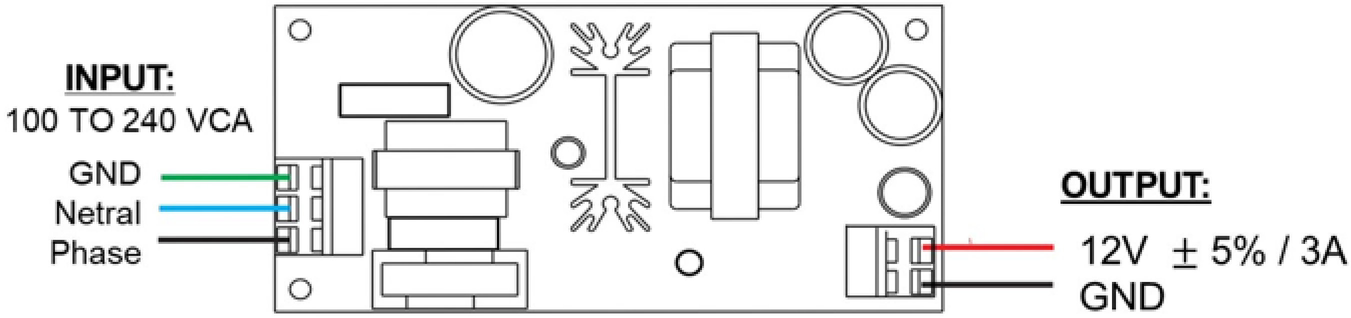

Figure 1 - Ratchet Power Supply
Source: Catrax Master, 2019 Product Manual

3. Results and Discussion

Applying the equations elaborated by APC International, it was possible to analyze what would be the ideal dimension for the piezoelectric ceramic piece to be used to generate enough energy for the operation of the ratchet. It was observed that the smaller the ceramic piece, the greater the tension generated (Table 3), due to the fact that the applied force is more centered on smaller pieces.

Table 3 - Voltage Generated as a function of Applied Force

Mass (Kg)	Applied Force (N)	Generated Voltage (V)			
		Ceramic Dimension (mm)			
		10 x 10 x 0,5	30,1 x 30,1 x 1	32 x 32 x 0,9	32,1 x 32,1 x 1,5
50	490	60,7600	13,4127	10,6805	17,6900
55	539	66,8360	14,7539	11,7485	19,4591
58	568,4	70,4816	15,5587	12,3893	20,5205
60	588	72,9120	16,0952	12,8166	21,2281
65	637	78,9880	17,4365	13,8846	22,9971
70	686	85,0640	18,7777	14,9527	24,7661
73	715,4	88,7096	19,5825	15,5935	25,8275
78	764,4	94,7856	20,9237	16,6615	27,5965
80	784	97,2160	21,4602	17,0888	28,3041
85	833	103,2920	22,8015	18,1568	30,0731
88	862,4	106,9376	23,6063	18,7976	31,1345
92	901,6	111,7984	24,6793	19,6521	32,5497

Source: Own authorship (2019).

CIGOGNINI ET AL. (2016) mention that in many cities have already tested this technology, where the first city to test this technology was Toulouse, France, where local authorities installed eight piezo plates on the sidewalks to produce about 480 W of electricity. Innowattech also tested in Israel, where it installed road signs, train tracks, airport runways and subway stations, and according to the results obtained, it was possible to generate 200 kWh with the compression of 20 cars / min. highway.

The piezoelectric ceramic that presented the best results was ceramic 1, which generated the largest amount of voltage possible. Therefore, the ideal dimension to use for the prototype is 10 x 10 x 0.5 mm.

According to SILVA (2018) there is a growing trend in the use of piezoelectricity, considering the responsiveness and analyzing an individual with average mass of 71.16 kg it is possible to apply a force of 697.44 N, so the generated voltage will be 21.266 V using only one piezoelectric ceramic piece. Considering an ideal condition, where the applied force is equally distributed over the five piezoelectric ceramic pieces, no energy losses will occur. Therefore, it can be assumed that the total voltage generated will be 86.4826 V. Since the ratchet needs only 12 V to operate, it can be assumed that the energy generated will be sufficient to maintain the operation of the equipment for 7 hours. h, with only one individual going through the turnstile.

Thus, the generated voltage is proportional to the applied force on the piezoelectric ceramic, ie, the higher the applied force the greater the generated voltage (Figure 2).

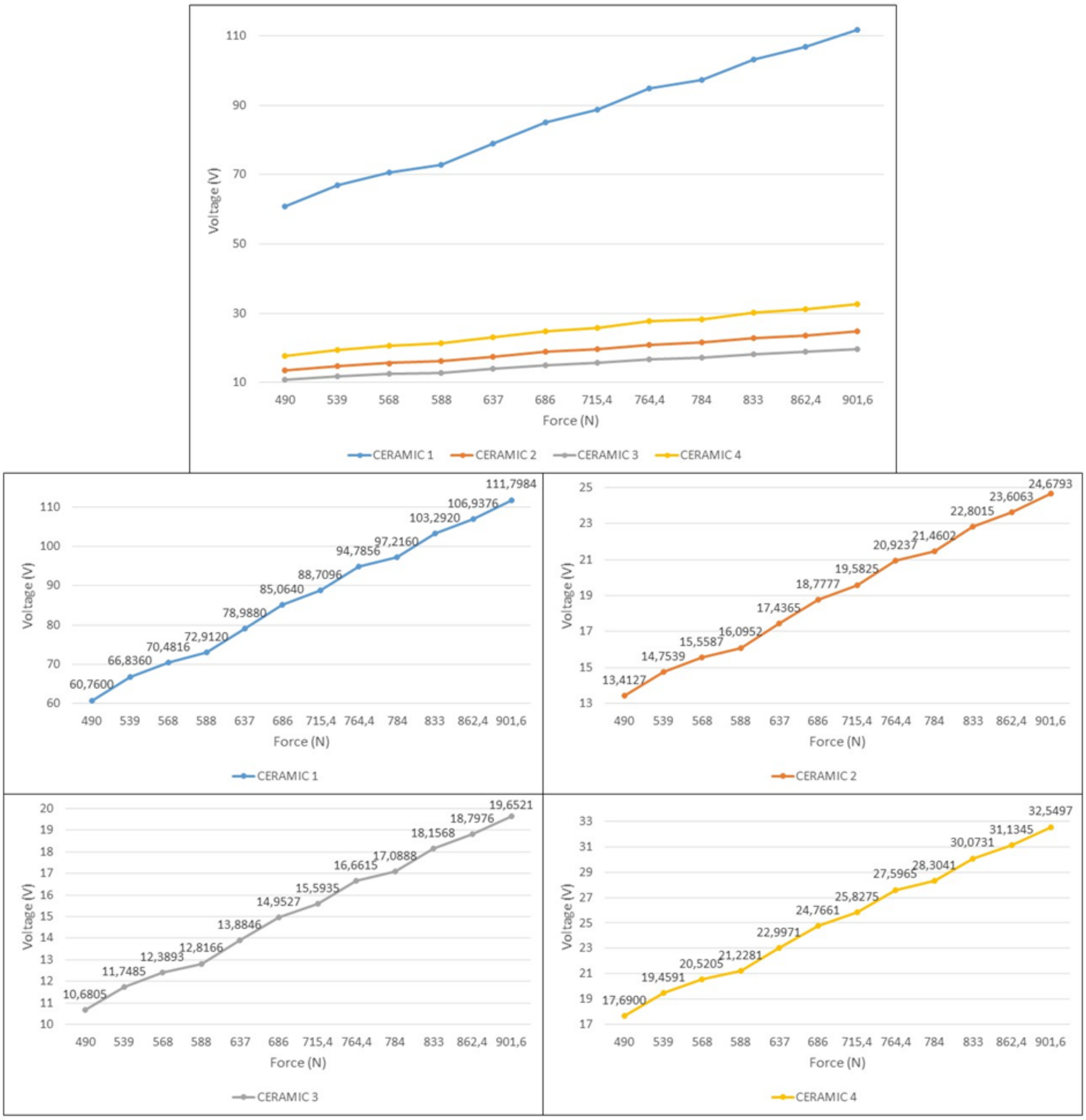

Figure 2 - Voltage Generated as a function of Applied Force
Source: Own (2019).

The investment to be made for the elaboration of the carpet prototype using piezoelectric ceramics is negligible in relation to the expenditure with electricity consumed by the evaluated turnstile (Table 4).

Table 4 - Prototype Budget

	Qnt.	Unit Price (R $)	Total price (R$)
APC Piezoelectric Ceramics 850	5	15,57	77,85
Stationary Battery 48 Ah 12 V	1	259,00	259,00
Aluminum Sheets 250x250x1 mm	1	11,59	11,59
Fiberglass Mesh	1 m	12,19	12,19
Wire # 2.5 mm²	5 m	0,88	4,40
Fiberglass Glue	1	24,90	24,90
Total			389,93

Through the calculations made it was possible to realize that piezoelectric ceramics is an excellent alternative for the production of clean energy in small and large scale, having a project with little investment and with considerable answers.

4. Conclusion

The use of piezoelectricity in only one IES turnstile will generate a reduction in energy consumption of 4,800 kWh / month, a saving of R $ 2,592.00 considering the off-peak tariff applied to the institution. Considering the use of this technology for all turnstiles of only one unit of the institution, the investment would be around R $ 2,339.58 and the return on investment would occur in less than 1 month.

Piezoelectric materials are quite diverse, the prototype can be adapted for use with any other piezoelectric material, such as piezoelectric inserts, which are easier to find on the market, and are much cheaper than other piezoelectric materials. However, as a polymer, the tablets are not rigid enough to undergo large deformations and thus generate an electric field for a considerable amount of energy. On the other hand, piezoelectric ceramics, given this rigidity, adapted to the model, conditions the creation of a larger electric field, thus generating a high potential difference when compared to that generated by the inserts.

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