



# FOOT STEP POWER GENERATION USING PIEZOELECTRIC METHOD

<sup>1</sup>Alao P.O, <sup>2</sup>Okandeji, A. A, <sup>3</sup>Olajide M. B, <sup>4</sup>Olasunkanmi G, <sup>5</sup>Jagun Z.O.O, <sup>6</sup>Kuponiyi, D. S

<sup>1,3,4</sup>Department of Electrical and Electronic Engineering, Olabisi Onabanjo University, Ago-Iwoye, Nigeria

<sup>2</sup> Department of Electrical and Electronic Engineering, University of Lagos, Akoka, Nigeria.

<sup>5</sup>Department of Computer Engineering, Olabisi Onabanjo University, Ago-Iwoye,

<sup>6</sup>Department of Electrical/Electronic Engineering, Gateway (ICT) Polytechnic, Saapade, Nigeria

\*Corresponding E-mail: aokandeji@unilag.edu.ng

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## ABSTRACT

The demand for energy and power on a daily basis is on the increase due to the fact that the major requirement for modernity and general world development is the availability of energy. Accordingly, an alternative solution to deal with the non-availability of power is to implement the renewable source of electricity. Electricity generation using piezoelectric method is an example of a renewable source of power. Specifically, footstep power generation incorporated with piezoelectric technology whereby an applied force on walkways causes the rotation of a wheel which in turn rotates a motor and creates electric charge enough to power appliances with the help of an inverter. This device can be installed on walkways, in areas where there is a large concentration of people such as marketplaces, religious centers where activities in such places help to generate electricity because of the constant movement on the piezo-electric platform.

**Keywords:** *footstep power generation, piezoelectric technology, inverter.*

**INTRODUCTION**

Electricity is an integral utility in modern day society with links to everything from a human’s subconscious fear of the dark to the practical need for working illumination in an industrialized world. The entire world essentially runs on electricity in one form or the other. Proposal for the utilization of waste energy of power with human locomotion is very much relevant and important for highly populated countries like Nigeria where marketplaces, churches etc. are overcrowded around the clock (Umeda, Nakamura, and Ueha, 1997). When the flooring is engineered with piezoelectric technology, electrical energy is produced by the pressure captured by floor sensors and converted to an electrical charge by piezo transducers. Human-powered transport has been in existence since time immemorial in the form of walking, running and swimming. However, modern technology has led to machines being used to enhance the use of human-power in more efficient manner. In this context, continuous human motion e.g. pedal power is a suitable source of energy and has been used since the nineteenth-century making use of the most powerful set of muscles in the human body. About Ninety-five percent of the exertion put into pedal power is transformed into energy. Pedal power can be applied to a wide range of jobs and it is a simple, cheap, and convenient source of energy. However, human kinetic energy can be useful in a number of ways but it can also be used to generate electricity based on different approaches and many organizations are already implementing human-powered technologies to generate electricity to power small electronic appliances (Hausler, and Stein, 1984). Whenever a person walks, energy is released towards the floor by means of influence, vibration, and audio etc., as a result of the movement of excess weight to the floor. That energy may be used and converted into electrical energy. An actual electro-kinetic floor is an example of an approach to generate electrical energy by using the kinetic energy of the person who walks on the floor (Lakic, 1989).

The energy produced by the piezo-electrical effect is environmentally friendly without having smog. Producing this type of energy will be cost effective as the power floor does not need any fuel or perhaps any sort of energy resource, simply making use of kinetic energy based upon the excess weight from a person moving on the floor.

Energy surrounds us in every area of our lives, it’s up to us to either use it constructively for the benefit of mankind or to use it destructively to endanger others (Crawley, and De Luis, 1986).

The concept of footstep power generation is considered a new perspective and approach of clean power generation of electrical energy, which utilizes the energy being generated from the exertion of force from human movement across an electromechanical conversion material being embedded in a foot mat like

platform (Anil, 2011). The footstep power generator (FSPG) is synonymous with the conventional sources of power generation systems and designs which could be applied and utilized in most electrical power consuming devices, appliances, equipment’s as well as cases some of which are listed below:

1. The power supply of household appliances such as television, fans, computers etc.
2. (FSPG) can also be used to illuminate our roads and walkway (e.g. in case of street lights).
3. It can be used to illuminate our railway stations.
4. It can be used as a source of electricity for our street lights.
5. It can be used to illuminate our lift system.
6. It can be used in the airport.

**MATERIALS AND METHODS**

The concept of the footstep power generation system is shown below.

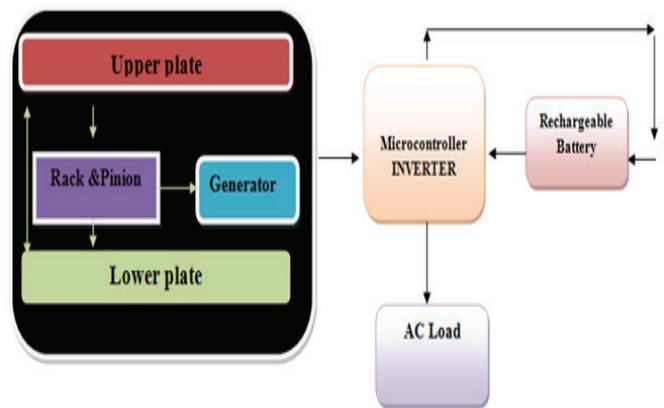


Fig. 1 block diagram of the project

The overall system design would follow the stipulated block flow diagram as shown in fig.1 in terms of component placement as well as power flow.

The footstep power generation design consists of different modules which include;

- i. The input section which contains footstep generation unit.
- ii. The control processing section which is the inverter with the battery.
- iii. The output section which contains the load.

The modules are extensively discussed below.

**The Input Section (Footstep Power Generation Unit)**

Spring Design and Description

Spring constant:

For the spring in this discussion, as shown in fig. 2, Hooke’s Law is typically assumed to hold,  

$$F=k\Delta \tag{1}$$

where

-F is the force exerted on the spring

- Δ is the spring displacement

- k is the spring constant

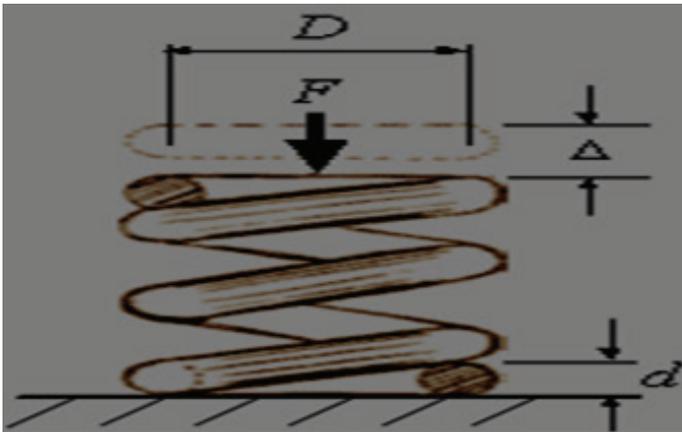


Fig. 2: Spring constant

$$\Delta = \frac{f}{k} = \frac{8fD^3n_a}{Gd^4} \dots\dots\dots (2)$$

The spring constant  $k$  is a function of the spring geometry and the spring material's shear modulus  $G$ ,

$$k = \frac{Gd^4}{8D^3n_a} \dots\dots\dots (3)$$

where  $G$  is the shear modulus,  $n_a$  is the number of the active coils.  $D$  and  $d$  are defined, respectively, as the diameter of the spring surface which both experiences the actual contact of the pressure of the foot, and the spring material itself.

The number of active coils is equal to the total number of coils  $n_t$  minus the number of end coils  $n^*$  that do not help to carry the load,

$$n_a = n_t - n^* \dots\dots\dots (4)$$

Spring Force and Stress: The maximum force the spring can take occurs when the spring is deformed all the way to its solid height,

$$F_{max} = K(L_{free} - L_{solid}) \dots\dots\dots (5)$$

$L_{free}$  = The length at which the spring is free from force exertion.

$L_{solid}$  = The length at which the spring is compressed from the pressure of the foot.

$F_{max}$  = The maximum force exerted on the spring.

NOTE:  $l_{(def)} = l_{solid}$

The maximum shear stress as shown in fig.3 in the spring associated with the maximum force is given by

$$\tau_{max} = \frac{(8FD)}{\pi d^3} \left( 1 + \frac{d}{2D} \right) \dots\dots\dots (6)$$

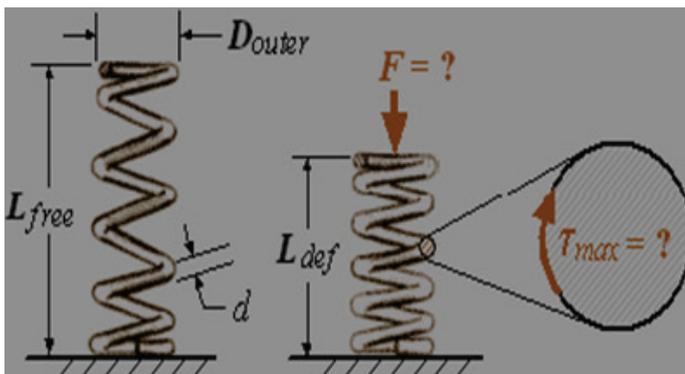


Fig. 3: Maximum shear stress description

**Rack and Pinion System (Movement Mechanism)**

The footstep power generation system consists of mechanisms that are interconnected to one another to drive the generation of the electric charge. Example of such interconnection is the rack and pinion system. The rack and pinion system refers to the combination of a chain being fixed to a gear teeth that drives or controls the motion of a wheel that is interconnected to the motor via a belt, which ensures that the circular motion of the wheel is equivalent to the motion of the motor that produces the charge from the piezo unit. When a footstep or weight of unknown magnitude is exerted on the platform, it induces a form of contraction on the spring, which makes the chain (rack) or gear teeth (pinion) operation to drive the wheel, hence, moving the motor into generating an electric charge. Fig. 4 shows the rack and pinion system.

**Charge Generator**

A generator is a device that converts mechanical energy into electrical energy, either by the use of a prime mover or other known force for driving its action into producing an electrical charge. The footstep power generator utilizes a simple single phase, generating a device that rotates in a clockwise direction when force is exerted on the springboard that houses it. By specification of design, the generator electrical circuitry is interconnected to a pinion that controls the motion of the rotor of the generator to produce sufficient current in the rotor so as to produce a flux in the system which in turn produces electrical current in the entire set up of the system as an output that is fed into the battery of the inverter. Below are the components of the generator;

**Rotor:** In its simplest form, the rotor consists of a single loop of wire made to rotate within a magnetic field. By design, the rotor setup consists of coils of wire wound on an armature. The rotor is thus the moving component of the footstep electromagnetic system that induces a flux of which its rotation is due to the interaction between the windings and magnetic fields, being a function of footstep pressure exerted on the springboard.

**Coil:** Within the circuitry of the generator consists of electrical coils i.e. conductors or basically wires that are fixed in the generating system, each coil usually consists of many turns of copper wire wound on the armature. The coils are of two categories, the rotor coils, and the stator coils. They serve as the medium of flux and current passage, as it rotates in the presence of a magnetic field, within the system.

**Armature:** The armature is a cylinder of laminated iron mounted on an axle. The axle is carried in bearings mounted in the external structure of the generator. Torque is applied to the axle to make the rotor spin.

**Stator:** The stator is the fixed part of the generator that supplies the magnetic field in which the coils rotate. It may consist of two permanent magnets

with opposite poles facing and shaped to fit around the rotor. Alternatively, the magnetic field may be provided by two electromagnets.

**Brushes:** The brushes are carbon blocks that maintain contact with the ends of the coils via the slip rings alternating current (AC) or the split-ring commutator direct current (DC), and conduct electric current from the coils to the external circuit.

**Magnet periphery:** The magnet periphery within the device consists of a set of permanent magnet. The type of permanent magnet used in this project is called NEODYMIUM which is the strongest type of magnet commercially available. Although, the magnetic properties of Neodymium magnets depend on the alloy composition, microstructure, and manufacturing technique employed, Neodymium magnets are graded according to their maximum energy product, which relates to the magnetic flux output per unit volume. Some of the properties of a Neodymium magnet are stated below;

- i. High maximum working temperature.
- ii. Resistance to being demagnetized.
- iii. Has high saturation magnetization.
- iv. Greater strength.
- v. Neodymium magnets have much higher coercivity and energy product, but often lower Curie temperature than other types.
- vi. Higher efficiency since no electrical energy is used.
- vii. Higher torque and power density.
- viii. More compact size etc.

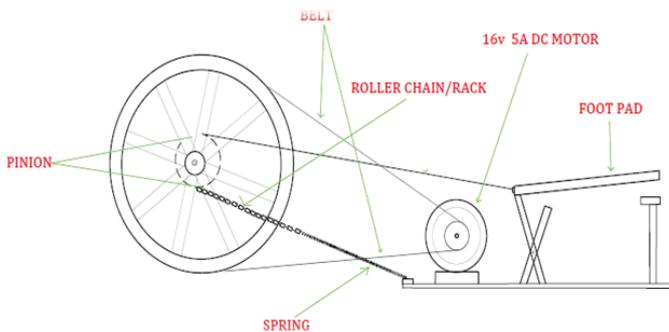


Fig. 4: Assembly drawing

**The Control Processing Section (Inverter section)  
Inverter**

In this design, the control processing unit is made up of an inverter. An inverter is an electrical device that converts DC to AC; the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries (Meiling, Emma, and Ashutosh, 2010). There are two main types of inverter. First, the output of a modified sine wave inverter is similar to a square

wave output except that the output goes to zero volts for a time before switching (example of which is used in this work). It is simple and low cost, and it is compatible with most electronic devices, except for sensitive or specialized equipment, for example, certain laser printers. Secondly, a pure sine wave inverter produces a nearly perfect sine wave output (<3% total harmonic distortion) that is essentially the same as utility supplied grid power. Thus, it is compatible with all AC electronic devices (Meiling, Emma, and Ashutosh, 2010). The electrical inverter is a high-power electronic oscillator. It is so named because early mechanical AC to DC converters was made to work in reverse, and thus was “inverted”, to convert DC to AC. The inverter performs the opposite function of a rectifier. The AC output frequency of a power inverter device is usually the same as standard power line frequency, 50 or 60 Hertz. The AC output frequency used in this case is 50Herz which is the standard AC output frequency used in Nigeria.

The AC output voltage used in this project is the same as the standard power line voltage, such as household 240VAC. This allows the inverter to power numerous equipment designed to operate off the standard line power (Crawley, and De Luis, 1986), (Meiling, Emma, and Ashutosh, 2010).

A power inverter has overall power rating expressed in watts or kilowatts. The power rating of this inverter is 1.5kw which describes the power that will be available to the device the inverter is driving and indirectly the power that will be needed in the DC source.

**Operating Principle of an Inverter**

An inverter can be taken as a crude form of UPS. Obviously, the main use of an inverter is only for powering common electrical appliances like lights and fans during a power failure.

As the name suggests, the basic function of an inverter is to invert an input direct voltage (12VDC) into a much larger magnitude of the alternating voltage (generally 220VAC) as in the case of Nigeria. The following is the fundamental elements of an inverter and its operating principle:

**OSCILLATOR:** An oscillator converts the input DC from a lead acid battery into an oscillating current or sine wave which is fed to the secondary winding of a power transformer. In the present circuit, integrated circuit (IC) PIC16F84A has been used for the oscillator section.

**TRANSFORMER:** Here, the applied oscillating voltage is stepped up as per the ratio of the winding of the transformer which in this case 20:1 is used and an AC much higher than the input DC source becomes available at the primary winding or the output of the inverter.

**CHARGER:** During power backups when the battery gets discharged to a considerable level, the charger section is used to charge the battery once the AC mains is restored.

**PIC16F84A**

PIC16F84A is an 8-bit microcontroller which means that it is capable of processing only 8-bits at a time. The following are the specifications of the PIC16F84A:

- Operating frequency – up to 20 MHz
- i. 68 Bytes data random access memory (RAM).
- ii. 64 Bytes of data EEPROM.
- iii. 15 Special function registers (SFRs).
- iv. Operating voltage – 2.0 to 5 volts.

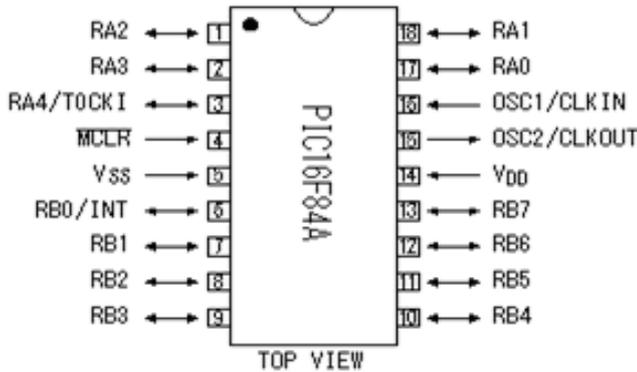


Fig. 5: Microcontroller (PIC16F84A)

**Circuit Description of the Inverter**

In the circuit diagram in fig.6, the microcontroller (PIC16F84A), resistors (4.7k, 1k), a capacitor (100n), a voltage regulator (7805) are all used for oscillating the DC current coming from the mechanism or the battery. The alternating voltage from the buffer stage is applied to the base of the current amplifier transistors. These transistors conduct in accordance with the applied alternating voltage and amplify it to the base of the output transistors. These output power transistors oscillate at full swing, delivering the entire battery voltage into each half of secondary winding alternately.

This secondary voltage is induced in the primary winding of the transformer and is stepped-up into a powerful 220 volts (AC). This voltage is used to power the output load.

The step-up transformer used in this design has more turns of coils on the secondary. This makes a larger induced voltage in the secondary coils.

$$I_{max} = \frac{P_{max}}{V_s} \therefore P_{max} = \text{output power} \dots\dots\dots(7)$$

$$I_{max} = \frac{1500}{220} = 6.818 A$$

The above result is the maximum output current.

**Operation of the System**

The complete diagram of the power generation using FOOT STEP is shown in fig.4. Although this device design and construction serves on a small scale due to it being a prototype that could serve as building block for further designs, it still implies a wide range of application of the fundamental ideology of

mechanical and electrical system.

The design is so created that it constitutes various mechanical and electrical components in order to achieve the sole aim of producing electricity by conversion of human energy via footstep.

The mechanical systems employ the use of a well-shaped metallic casing that houses a spring, a chain, a gear disc, a wheel, all interconnected with one another such that an effect of any form of force on the platform induces changes in the position of the other subcomponents of the system to induce the production of electric charges.

The device is so designed that when a force is exerted on the platform i.e. human footstep, the spring (originally inclined at an angle of 30 degrees to the horizontal plane, so as to aid its easy contraction and compression whenever the slightest of forces are exerted on the spring board) which is inter connected to it contrast (i.e. expands), and since the spring is interconnected to the chain, its contraction induces the chain to aid a circular motion of the gear disc which controls the wheel that serves as the control for the charge generator.

By status of the design, since the interconnection of the subcomponents of the mechanical systems are all directed towards producing a circular motion, its operation induces the charge generator (a neodymium motor) to rotate, which then produces a large (current) as output, which is then fed into the charge bank (the battery).

The design of the springboard /platform is basically a fabricated/constructed form of the naturally existing materials such as quartz, which produces the electric charge when a force is exerted on their surface. The footstep platform serves as the mechanical subsystem of the entire device; hence, the entire device is a form of cascaded system in which the output of one subsystem is fed into the other before it can attain its actual operating function.

As the charge is produced as output, it is fed into a battery of 12V, 100Ah. Being a DC supply source, batteries are always restricted to loads that operate on mainly DC; hence, for the design to be achieved, an inverter system is also situated at the output of the battery to aid the conversion of the DC (12V from battery) supply into AC (rated at 220V), to serve AC loads as well.

Below are the processes involved in the footstep power generation using piezoelectric technology:

**Step1:** When force is applied on the plate, by stamping on the plate, the spring expands.

**Step2:** The rack/roller chain which is meshed with the spring interconnected with the gear is used to drive the wheel.

**Step3:** When the wheel moves, the belt terconnected with the wheel drives the rotor of the motor.

**Step4:** When the rotor rotates, which is because of the rotation of the wheel, it generates charges or

current. This current generated is based on the principles of electromagnetic induction.

**Step5:** The DC generated is used to power the inverter directly and to charge the battery.

**Step6:** The DC signal received by the inverter either directly from the mechanism (motor) or from the battery is inverted to AC signal via the oscillator.

**Step7:** The AC output signal produced is then supplied to the load.

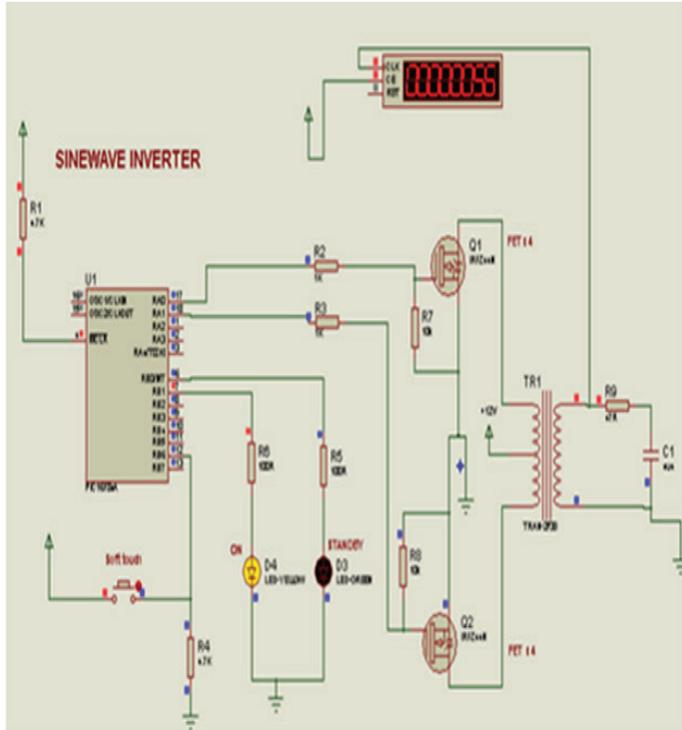


Fig. 6: Sine wave inverter circuit

**TESTING AND RESULT**

**Testing**

The footstep power generation system (F.P.S.G) has been successfully created using the previously outlined materials. The following procedures were carried out and observations were noted, to determine its characteristics/efficiency about its operations, via the various outlined tests.

The device is considered to be an alternative source of power generation, to the already existing forms such as solar energy, wind, hydro, thermal etc. except for the fact that its operation is based on human motion, thus its power generation relationship as per various weights exerted on its springboard platform is considered to be giving as expressed below:

It is considered that the weight of a person is considered to be the effect of gravitational pull on its entire body all multiplied by its mass i.e.

$W=mg$ , which is equivalent to the force exerted on the platform by various persons.

But power  $P = \frac{F \times S}{T}$

where

S = is the distance traveled by the compression of the springboard.

T = time for compression.

F = weight of the person.

Thus, for the testing process of the piezo unit (i.e. unit comprising the springboard, motor etc.) if an individual of average weight of about 71kg (which is equivalent to the average weight of the individual members of the project group) compresses the springboard through a distance of 0.0533m (equivalent distance between the springboard when not compressed and when fully compressed) over a time frame of 1.2 sec, the devices average power output would be:

$P=(71 \times 0.0533)/1.2=3.8021$  watts

**Result Analysis**

Table. 1: shows the relationship of the various Human weights with respect to their related voltage output from the piezoelectric Generator unit.

S/N	Human Weight (Kg)	Piezoelectric Generator unit output voltage (V)	Battery terminal Voltage (V)
1	38.67	14.86	12.02
2	41.37	15.24	12.15
3	43.65	15.49	12.21
4	45.32	15.64	12.30
5	47.52	15.80	12.42
6	51.98	16.44	12.51
7	56.42	16.64	12.58
8	58.56	16.68	12.63
9	63.72	17.05	12.97
10	64.22	17.26	13.01
11	67.43	17.56	13.15
12	68.47	17.69	13.16
13	73.64	18.16	13.42
14	74.82	18.36	13.48
15	79.67	18.78	13.64

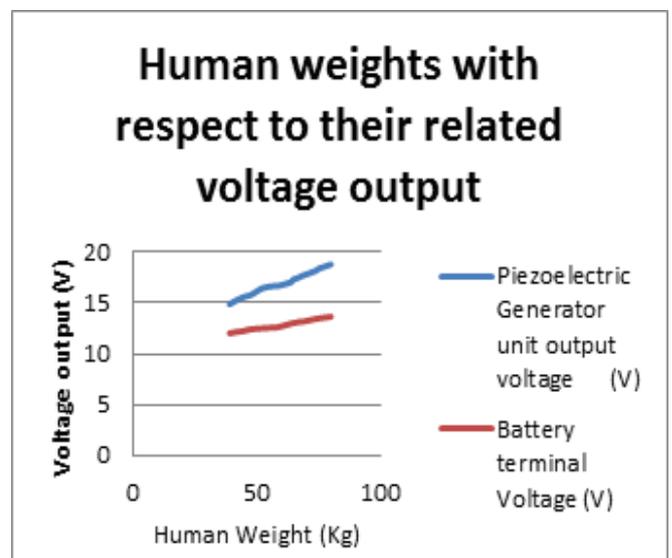


Fig. 7: Human weight and piezoelectric Generator unit output voltage

Table. 2. Analysis of Human weight and piezoelectric Generator unit output voltage

Anova: Single Factor Analysis of Human weight and Piezo Unit Output voltage						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Human Weight (Kg)	15	875.46	58.364	173.6334		
piezo unit output voltage (V)	15	251.65	16.77667	1.447695		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	12971.3	1	12971.3	148.1747	1.06E-12	4.195972
Within Groups	2451.135	28	87.54055			
Total	15422.43	29				

Table. 3. Analysis of piezoelectric Generator unit and Battery terminal voltages

Anova: Single Factor of Piezo output volatage and Battery terminal voltage						
SUMMARY						
Groups	Count	Sum	Average	Variance		
piezo unit output voltage (V)	15	251.65	16.77667	1.447695		
Battery terminar Voltage (V)	15	191.65	12.77667	0.271724		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	120	1	120	139.582	2.15E-12	4.195972
Within Groups	24.07187	28	0.85971			
Total	144.0719	29				

From the table 2 above, the average human weight is 58.364Kg. This is the weight of an average youth which gives the output voltage of 16.77667 V. Also, table 3 proves that the system has the capability to charge the battery conveniently with an average charging voltage of 16.77667V which is greater than battery voltage of 12V.

**Tests for Charging Rate of Power Storage (Battery)**

From the previous experiment and analysis of the design of the footstep power generation system, its operation has been noted to be based on the continuous variation of human weight which produces a constantly varying power, thus the battery being implemented in the design of the entire device doesn't align its charging rate on the number of footsteps, but rely on the weight/power generated from the piezo unit.

In the design of this device, a battery rated with the following specifications was used;

- Voltage potential=12V
- Charge rate =100Ah

Hence, from the above state, it can be mathematically proven that its power rating is =100Ah ×12V =1200Wh.

Thus, relating the above-derived power rating to the equivalent average power being fed into it by the piezo unit i.e.

$$P_{average} = 3.8021watts$$

Note: The above derived average power was obtained on a per seconds' basis.

Hence, for the derived average power given above, it would take the following time duration:

$$Average\ charging\ time = \frac{1200VAh}{3.8021 \times 60} = 5.26hrs$$

Table. 4: Load Analysis of Piezoelectric Generator with an Inverter

S/N	Load (W)	Current (I)	Inverter output voltage (V)
1	0	0	226
2	100	0.78	225
3	200	0.96	225
4	300	1.6	224
5	400	2.43	222
6	500	2.78	221
7	600	3.06	220
8	700	3.26	216
9	800	3.42	212

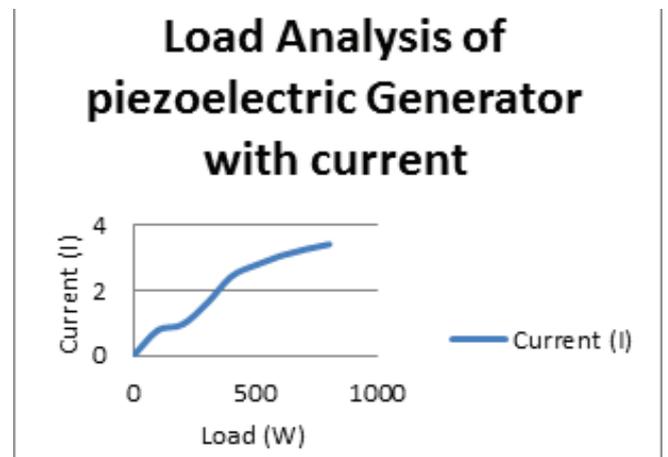


Fig. 8: Load Analysis of piezoelectric Generator with current output

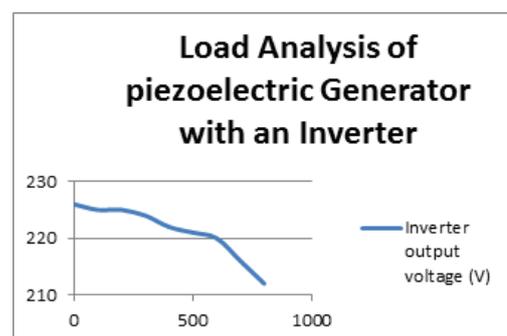


Fig. 9: Load Analysis of piezoelectric Generator with an inverter

The data in Table 4 shows that the system is reliable, with the load of 800W, the inverter voltage output is still 212V.



Fig. 7: The footstep unit, inverter, and the battery

## CONCLUSION

This method of producing electricity generates electric power without polluting the immediate environment. This energy source is continuous and renewable. Accordingly, this method of power generation can be used for rural electrification and to fulfill various power needs. Also, this system is very eco-friendly from the environmental point of view.

Successful test and implementation results carried out on the prototype model as shown in Fig.9 above reveals that this model can serve as the best economical, affordable energy solution for common people. This can be used for many applications in rural areas where power availability is limited or totally absent as in some parts of Nigeria; a country with huge population. This technology would facilitate the future creation of new urban landscapes such as athletic fields with spectator's area, music halls, nightclubs, churches, mosques, and large gathering spaces for rallies, demonstration and celebration, railways stations, bus stands, airports etc.

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