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ENGINEERING A SUSTAINABLE BIOMECHANICAL ENERGY HARVESTING SOLUTION WITH A CDO NANO GENERATOR

Mohamed Mustaffa, Electrical and Electronics Engineering, Indian Institute of Industry Interaction Education and Research, Chennai.
Radhakrishnan V, Electrical and Electronics Engineering, Indian Institute of Industry Interaction Education and Research, Chennai.
Harikumar, Electrical and Electronics Engineering, Indian Institute of Industry Interaction Education and Research, Chennai.
Puviarasan V, Electrical and Electronics Engineering, Indian Institute of Industry Interaction Education and Research, Chennai.

ABSTRACT
Natural resources including water, sunshine, carbon dioxide, geothermal energy, and wind can all be used to produce green energy. These energy sources are substitutes for fossil fuels as a source of electricity. Since green energy doesn't produce toxins or greenhouse gases, it is safe for the environment. A variety of tools and technologies have been employed to gather renewable energy. However, most technologies require a significant amount of expensive equipment and infrastructure to supply the power required for wearables, smart sensors, and electrical devices. The development of self-sustaining systems has been the subject of much research because to the growing popularity of wearable technology. Recently, the effectiveness of using triboelectric nanogenerators (TENGs) to gather biomechanical energy has been demonstrated. A creative way to create uneven surfaces on poly (PDMS) film is demonstrated by recycling a plastic petri dish that was previously used in a scientific setting. A thorough investigation is carried out to assess the efficacy of single- and multi-unit SBP-TENGs. The study demonstrates how human actions, such as sprinting, jogging, and squatting, can be used to capture electrical energy in real-time. This study confirms that the SBP-TENG is a very efficient bio-mechanical power harvesting system. It can power a variety of low-power electrical devices, such as lightbulbs, clothing sensors, and Global Positioning System (GPS) systems.

Keywords:
Biomechanical Energy Harvesting, CdO Nano generator, and Global Positioning System

I. Introduction
The demand for renewable energy has become increasingly pressing as pollution levels rise and conventional fossil fuels run out more quickly. Renewable energy sources hold great promise for real-world applications, including wind, solar, and ocean wave power. Additionally, they don't produce any additional emissions. Distributed sensing technology is becoming more and more important for identifying and adapting to complex settings, and the Internet of Things (IoT) is expanding at an incredible rate. The Internet of Things is developing at a rapid pace thanks in large part to advancements in wireless sensor network technologies [1]. A useful and necessary complement to centralized power generation is distributed generation of clean and renewable energy. It is strategically crucial for tackling the expanding energy and environmental problems. Scientific research is currently centered on power generating technologies, including thermoelectric, solar, and electromagnetic power generation. However, the energy acquisition device that employs these power producing methods is hampered by the high costs, large physical space requirements, and negative environmental effects. This places additional limitations on its application in distributed sensor networks. Electronic devices often draw their electrical power from chemical batteries. The drawback of this dependence is that it necessitates regular battery replacements, which raises maintenance costs [2]. Therefore, the development of new energy harvesting technology is helpful in enabling the spread of the Internet of Things (IoT)-based distributed sensor network. Conventional batteries, which have drawbacks because

of their bulk, short lifespan, and polluting, environmentally harmful components, are frequently used in these devices. The efficacy of wearables, smart sensors, and future IoT devices may be hampered by the limitations of traditional batteries. Therefore, there are current and upcoming research challenges in developing new ecologically sustainable alternative technologies to power these gadgets. Nanogenerators that may harvest renewable energy through a variety of transduction mechanisms, such as piezoelectric, triboelectric, electromagnetic, and thermoelectric effects, have been demonstrated by recent study [3]. Compared to conventional batteries, the nanogenerators have several unique features, including lightweight design, low manufacturing costs, tiny size, easy signal processing and operation, high power density, and longer lifespan. By using renewable energy from the environment, nanogenerators offer an affordable way to power consumer electronics, intelligent sensors, and forthcoming IoT gadgets. Additionally, nanogenerators can power autonomous sensors for a variety of uses, such as smart cities, agriculture, aerospace, automotive and military industries, and telecommunications. Rectifier circuits are required in the majority of commercial low-power electronic devices in order to convert the variable output current of nanogenerators into direct current (DC). Additionally, a number of researchers have developed rectennas—which can absorb radio frequency (RF) energy and convert it to direct current—by combining rectifiers with antennas. Nanogenerators may use supercapacitors to store the energy they generate. Supercapacitors and rectifier circuits assist in ensuring that nanogenerators maintain a constant output power. Moreover, hybrid nanogenerators can gather many renewable energy sources by employing two or more acquisition processes [4]. This performance feature enables hybrid nanogenerators to increase their output power densities in comparison to single nanogenerators. Through the utilization of several renewable energy sources, including wind, heat, rain, solar radiation, and mechanical vibrations, hybrid nanogenerators are able to effectively support the functioning of electronic equipment for prolonged periods of time. The hybrid nanogenerators possess the capability to effectively gather various forms of renewable energy, hence offering an uninterrupted power supply for electronic gadgets and sensors. This could potentially make it easier to convert easily accessible renewable energy sources into electrical power, indoors or out, at any time of day. To improve the dependability, durability, and efficiency of nanogenerators, more research is needed. The most efficient electrical and structural topologies, as well as material selections, can be predicted during the design of nano-generators for particular applications using optimization approaches [5]. The power density and output lifespan of this optimized nanogenerator could be improved by its design. An alternate idea is to create nanogenerators that can adapt to the human body and capture biomechanical energy by employing materials that are wearable and malleable. In addition, the development of effective packaging solutions is necessary to improve the robustness and temperature and humidity tolerance of nanogenerators. Their dependability may be increased by improving the packing materials' quality and employing sturdy materials for nanogenerators. Direct current (DC) power output could be raised by optimizing the electronic component by making rectification circuits used in nanogenerators more sensitive. Additionally, the fabrication of these circuits employing microelectronic technology can reduce their size. The remaining work is organized as follows: Section 3 describes the materials and procedures, whereas Section 2 summarizes the literature review. Section 4 discusses and plots the results, and Section 5 wraps up the paper.

II. Review of literature

Piezoelectric, photovoltaic, and rectifying atomic methods were introduced by Liu et al. [6]. One way to think of the CdO layer in the piezoelectric generator is like a flat-plate capacitor. A discharge is released during compression, and charging occurs when pressure is reduced. This work challenges the accepted piezoelectric theory while revealing the essential features of both the bulk photovoltaic and piezoelectric phenomena. It is possible to create high-performance piezoelectric and optoelectronic materials and devices using polar-oriented films. A polyethylene oxide/copper (I) oxide composite nanofiber (PCNF) was introduced by Mohamadbeigi et al. [7] as a sensing material for detecting ethanol levels (varying from 1 to 200 ppm) in a simulated exhaled breath environment. PCNFs were synthesized using the electrospinning technique. The self-powered PCNFs exhaled breath sensor was powered by an integrated contact-separation triboelectric nanogenerator. With detection values of 0.9 and 3.2 for ethanol concentrations of 5 ppm and 200 ppm, respectively, the gas sensor based on PCNFs exhibits promising results. At 90% relative humidity, these observations were made with interfering gas present. Relative to methanol and acetone, the sensor showed remarkable ethanol selectivity, with ratios of 10:1 and 25:1, respectively. At a relative humidity (RH) of 90%, the response and recovery times for a 200 parts per million (ppm) ethanol concentration were rapid—2.7 and 5.8 seconds, respectively. Based on PCNFs (polymer composite nanofibers), the exhaled breath sensor demonstrated dependable and durable performance in practical scenarios, underscoring its ability to be seamlessly integrated into wearable devices. This self-powered breath sensor makes it possible to continuously monitor lung cancer symptoms. It also aids in guaranteeing adherence to legal restrictions on alcohol use. In order to support ecologically friendly and sustainable development, Singh et al. [9] presented the idea of waste to energy conversion and the use of waste energy—specifically, finger tapping—to power sensors. This work shows how to use polymerization to create 2D PANI-PPY (2P) nanosheets, which are then used in a TENG that is built on PDMS/PANI-PPY (3P). The constructed triboelectric nanogenerator (TENG) exhibits an output voltage of 142 volts and a current of 80 µA, which is noteworthy. In just 35 minutes, the 3P polymer nano-composite showed signs of quick self-healing ability. When exposed to light illumination, the self-powered LPG sensor, which is based on the 3P assembly, exhibits exceptional responsiveness and sensitivity. When subjected to visible light brightness of 30 mW/cm2, the sensor showed a maximum response of 94.67% (9367% response) and a sensitivity of 52.67 SR/vol%. This shows that even at low LPG concentrations below the lower explosive limit (2 vol%), the produced material is extremely responsive and sensitive to light. The material showed the fastest recovery and response times ever measured, at 172 and 580 ms, respectively. Cl-doped 2P was shown to have strong reactivity and places with high negative potential to interact with the H+ ion of LPG, which is supported by theoretical study. Xiao et al. [10] developed a unique tactile sensing system that makes use of triboelectric sensors improved by quantum rods, drawing inspiration from the platypus' sixth sense. In single-electrode mode, this terminal can operate as a triboelectric nanogenerator, providing very sensitive and quick response time for accurate location and vertical force sensing. Furthermore, when CdSe/CdS quantum rods are added, the altered luminescence of an imprinted polydimethylsiloxane screen may be used to detect different degrees of lateral stretching. The tactile perception system on a micro-controller unit platform obtained a high identification accuracy of 98.5% by utilizing machine learning technology for 18 different products. This development opens the possibility of robots in smart homes with intelligent sorting.

III. Supplies and procedures

In our daily lives, triboelectric effect is often perceived as undesirable or even harmful, as it can cause irritation and even be a cause of fire or dust buildup. However, TENG can take advantage of this unwanted occurrence to convert regular, but frequently wasted, biomechanical motions into electrical energy. When two materials with different electron affinities come into contact, a process known as triboelectrification takes place. In addition to commonly used metals and semiconductors, a wide range of materials, both natural and artificial, are employed to manufacture TENGs. Many of them demonstrate biodegradability, biocompatibility, and even bioabsorbability. Silicone rubber and polytetrafluoroethylene (PTFE) typically have a negative electron charge, whereas metal and nylon frequently have a positive charge. The material that has a higher electron affinity will cause its surface to become charged, whereas the other surface will become positively charged. These stationary charges are immobile and have a long self-sustaining life. The electric fields in the vicinity of their intersection split as the two materials separate. As a result, there is a voltage differential between the electrodes, which forces electrons to oscillate in the external circuit to maintain electrical equilibrium. Over the past eight years, triboelectric nanogenerators (TENGs) have seen substantial advancements in the development of their fundamental operating modes. These modes include of the freestanding triboelectric-layer mode, vertical contact-separation mode, lateral sliding mode, and single electrode mode. The configuration and relative motion of the constituent parts determine the particular mode that is employed [11].

3.1 Cleaning of the plastic petri dish's surface

After cleaning the ABS plastic petri dish with ionized water and alcohol, dust particles were removed by blow drying it with compressed nitrogen gas. After that, the Petri dish was extracted after being submerged in methanol-filled beaker for a number of minutes. The petri dish was dried in a hot air oven set at 50º C for an hour after being cleaned with deionized water and ethanol [12].

3.2 SBP-TENG Fabrication

For twenty minutes, the PDMS monomers and crossing linker (10:1) were mixed and agitated with a magnetized stirrer. After that, the mixture was introduced to the petri dishes that had undergone surface modification. The mixture was degassed to remove any air bubbles. After the degassing procedure, spin coating was used to apply the PDMS for 30 seconds at a speed of 500 revolutions per minute. Thereafter, it was left to firm for forty minutes at seventy degrees Celsius. Following this, two electrodes made of copper (Cu; 12 mm × 50 mm) and aluminum (Al; 12 mm × 50 mm) were attached with a small gap between them. Finally, a PET sheet was attached to serve as an additional layer for the SBP-TENG [13].

3.3 Electrostatic Nanoscale Generators

The piezoelectric effect is used by piezoelectric nanogenerators (PENGs) to harvest renewable energy from a variety of sources, including wind, waves in the ocean, biomechanical motions, and mechanical vibrations in the surrounding environment. This specific nanogenerator's output voltage is directly affected by piezoelectric layer properties and mechanical deformations. Mechanical vibrations in the surrounding environment can cause a variety of deformations in the piezoelectric nano-generators, which can then provide an AC output voltage. These nanogenerators are made up of two electrodes, a substrate, and a piezoelectric layer. PENGs are characterized by their simple structural design, easy operation, easy construction, remarkable stability, and affordable cost [14].

3.4 Electrical characterizations and measurement

Using a Field Emission Scanning Electron Microscope (FE-SEM), the surface-modified PDMS and additional textile materials were examined for surface morphology. Additionally, a linear motor that is sold commercially was used to apply external motion in order to assess the electrical output of the SBP-TENG. The output voltage signal and short circuit current of the SBP-TENG were measured using an SR 570 low noise current amplifier and an electrometer (model 6514; Keithley Instruments Inc., Cleveland, OH, USA). All of the contact materials were heat treated for thirty minutes at 70 oC to remove any moisture before the electrical tests were performed. The electrical tests were conducted within a temporary, grounded Faraday cage. LabVIEW was used in the development of a software platform intended for real-time data gathering, control, and analysis [15].

3.5 TENGs operational concepts

TENGs harness the triboelectrification phenomenon, which happens when two substances come into contact, in four different ways to produce energy. Charged particles migrate from one tribo-material onto the other as a result of their interaction and independent operation. All four of the TENGs' operating modes—horizontal contacting–separating modes, in-plane sliding, free-standing triboelectric layer, and single-electrode—are shown in Figure 1. An S-TENG is made up of two triboelectric material layers, and the metal layer contains a single electrode that is used to generate electricity. During the S-TENG's operation, two triboelectric layers repeatedly come into touch with one another, which charges the outermost layers of the triboelectric substances' electric particles. This generates a current of electricity due to the voltage distinction between the electrode's surface and the surface of the ground. An S-TENG is characterized by its voltage of open circuit (OC_V), a short-cir charge (SC_Q), and capacitor (C), all are determined by the next equation. Figure 1 shows the steps working steps involved in TENG.

$$SC_Q = OC_V \times C \qquad (1)$$

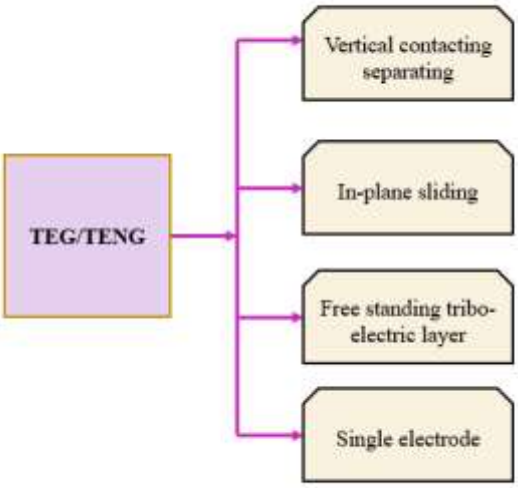

Figure 1: The steps working steps involved in TENG

$$OC_V = \frac{2\alpha y}{\delta_0} \qquad (2)$$

The open circuit voltage is OC_V with tribo-electric charge density is α. Where, δ_0 and y are the vacuum permittivity and separating distance.

$$r\frac{dQ}{dt} = -\frac{1}{c}Q + OC_V \qquad (3)$$

It is c and r for the capacitance and resistance. Triboelectric materials interact and make contact with one another to produce an electric current, which is essentially how TENGs work. Triboelectric materials, such as metal and polymer compounds, are combined to create TENGs, which have a simple architecture. Due to their operating principles, triboelectric nanogenerators (TENGs) may effectively absorb a wide range of types of underutilized mechanical energy, from minor stimuli to considerable forces. For instance, contacting-separating mode TENGs have been developed to harvest sound waves' energy. These TENGs can charge at a rate of 61 µC/s and have a maximum current output of 0.45 mA. The frequency range in which they function is 50 Hz–425 Hz. Additionally, TENGs with the contacting-separating system can generate power, with a maximum power density of about 7 W/m2, a short-circuit voltage of 400 V, and a short-circuit current of 175 µA. At a frequency of 170 Hz and an air pressure of 115 dB, these TENGs can record sound from sources. A maximum power density of roughly 5.07 W/m2 can be produced by TENGs operating in the contacting-separating mode. They also have a short-circuit voltage of roughly 1080 V and a short-circuit current density of roughly 16.9 mA/m2. These TENGs make use of the 1.25–6.25 kPa pressure features related to vehicle motion. Furthermore, TENGs designed for single-electrode operation can also generate an output of around 750 millivolts by converting the eye's motion into electrical energy. Communication systems can be powered by this voltage level without the use of external power sources. It is also possible to construct TENGs in a self-supporting arrangement to convert the energy of ocean waves into electricity. Their electrical characteristics are impressive, with a maximum power density of 28.2 W/m3. Finally, direct current with electrical characteristics of 270 µA/m2 and 80 V can be produced by TENGs operating in the in-plane sliding mode.

Components built with trio-electric:

Utilizing a tribomaterial pair's triboelectric characteristics, tribomaterials are essential to producing electricity in TENGs. Dielectric materials can be found in nature and originate from a variety of substances, including inorganic minerals, metals, polymers, and biological molecules. Advanced tribo-materials have easy production properties, are cheap, easily obtainable, and are environmentally beneficial. They can function effectively in natural settings, extracting mechanical energy and utilizing renewable resources to transform it into electrical energy. In particular, even in challenging circumstances, these materials can endure friction conditions for an extended length of time. The desirable qualities of sophisticated tribo-materials with triboelectric characteristics have therefore piqued researchers' interest in creating more triboelectric nanogenerator (TENG) models in order to capture substantial amounts of energy from the environment. Triboelectric nanogenerators (TENGs) can produce electricity through sliding modes or contact-separation between two surfaces with distinct triboelectric characteristics. During the TENG's operating cycle, the electrical charge density is dependent on the properties of the triboelectric material pair. The tribo-materials' electron acceptor and donor characteristics. In the triboelectric series, tribo-materials can either gain or lose electrons to one another. The diagram shows the distinct electrification properties of various materials. Triboelectric material pairings are essential for producing electrical energy through the triboelectric effect, which uses donor or acceptor electrons, in addition to its operating system. A common donor material is a metal, such as copper or aluminum, due to its improved capacity to induce electrostatically. Because negative triboelectric materials, like polymers, wood, fiber, paper, and composites, exhibit a triboelectric effect, polymers are frequently employed as recipients of electrons in TENG harvesters. When negatively charged and positively charged triboelectric materials are mixed, a triboelectric nanogenerator is produced that is capable of effectively capturing and converting wasted motion energy into useful power for a variety of real-world applications. These applications are made up of aluminum and Kapton-based Triboelectric Nanogenerators (TENGs). Operating at a frequency of 4 Hz, these TENGs showed an output performance of 2.8 μA for short-circuit current and 40 V for open-circuit voltage. Additionally, the utilization of polytetrafluoroethylene (PTFE) and aluminum in TENGs results in electrical characteristics with a peak power output of 350 μW, a maximum open-circuit voltage of 130 V, and a maximum short-circuit current of 6.6 μA. Furthermore, utilizing polytetrafluoroethylene and copper particles to create a Triboelectric Nanogenerator (TENG) produced an output power profile that could reach a maximum current density of about 41.4 milliamperes per cubic meter (mAm^{-3}). Ultimately, the development of electric power was brought about by the addition of polytetrafluoroethylene and a bimetallic hydroxide made of copper and nickel. This system reached an open-circuit voltage of 328 volts, a short-circuit current of 36.15 microamperes, and a peak power density of about 1.3 milliwatts per square centimeter.

3.6 The energy storage model

One of a TENG's most important applications is energy storage (ES), which enables the long-term storage of extra or wasted energy produced by TENG sources. In the event of varying currents, the ES stage is a workable solution for preserving ideal operating conditions for electric consumption devices. The ES is a useful tool for improving the output performance stability of the TENG. The term "energy storage" (ES) refers to effective techniques for utilizing the triboelectric nanogenerator's (TENG) electrical output to power small electronic devices. Triboelectric nanogenerator (TENG) technology and methodologies are now being studied by several research organizations. Their areas of interest include creating theories and methods for managing TENG energy storage, building rigid-flexible energy storage systems to store TENG output energy and produce a sustainable power source for temperature sensors, improving TENG charging systems to achieve effective energy storage, creating sustainable and renewable systems for TENG energy storage, using robust TENGs with nanoarray structures to store energy, and designing rigid-flexible energy storage systems. A possible energy storage device made to hold the energy from a TENG is shown in Figure 2.

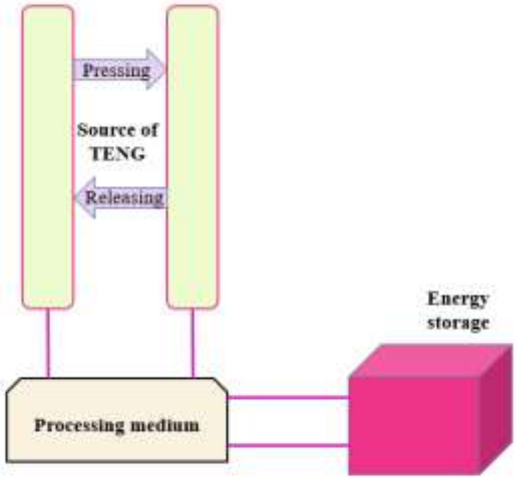

Figure 2: Energy storage model for TENG

The processing unit (PU) is made up of a power management circuit that can be built with an LTC-3588 linear technology chip, a rectifier bridge, or a combination of the two. Its function is to control the TENG's output voltage and balance value while it stores energy in an energy storage medium. Using a rectifier bridge, inductors, and a capacitor to build a specific power management circuit is another way to manufacture a power unit (PU). The purpose of this circuit is to increase a triboelectric nanogenerator's (TENG) energy storage efficiency. An additional type of power unit (PU) is a passive power management circuit, which consists of a diode, an inductor, and a capacitor. The purpose of this circuit is to increase the triboelectric nanogenerator's (TENG) capacity for energy storage.

VI. Assessment of performance

We have created a Triboelectric Nanogenerator (TENG) that effectively transforms biomechanical energy into electrical energy using fabric technology. Wearable electronic sensors and self-sustaining gadgets could be powered by this energy. Common human movements like walking, jogging, jumping, bending, and lifting legs can all provide this energy. The conductive macrofibers of this TENG are made of cellulose, which is known for its remarkable strength, biodegradability, and washability. Here, we created a triboelectric-electromagnetic hybrid nanogenerator (TEHG) that can both harvest wind energy and power electronics at the same time. This nanogenerator is made up of an electromagnetic generator (EMG) that operates in the rotating mode and a triboelectric nanogenerator (TENG) that operates in the sliding independent triboelectric-layer mode.

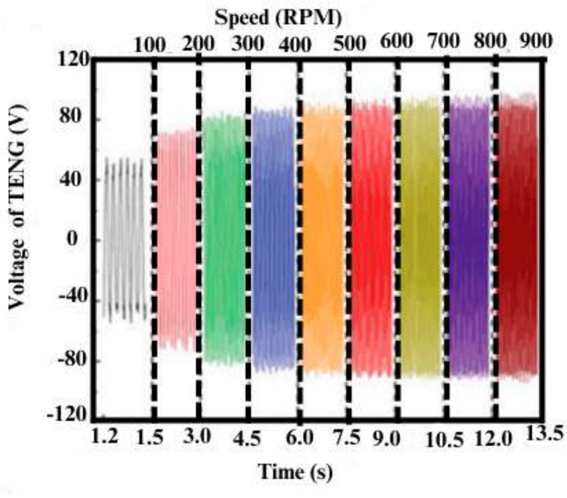

Figure 3: TENG output voltage with varying the rotation speed

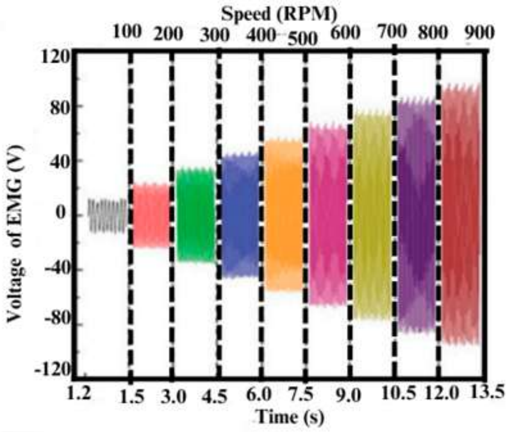

Figure 4: EMG output voltage with varying the rotation speed

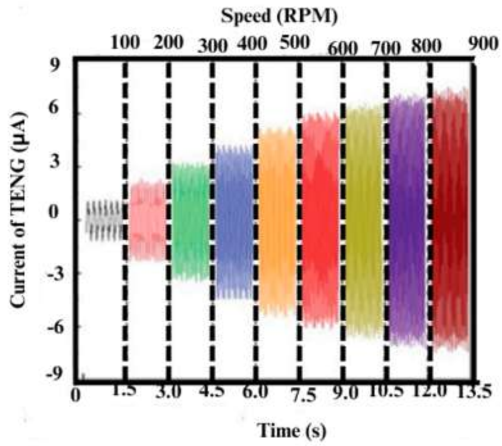

Figure 5: Outputs short circuits current with varying rotating speed for TENG

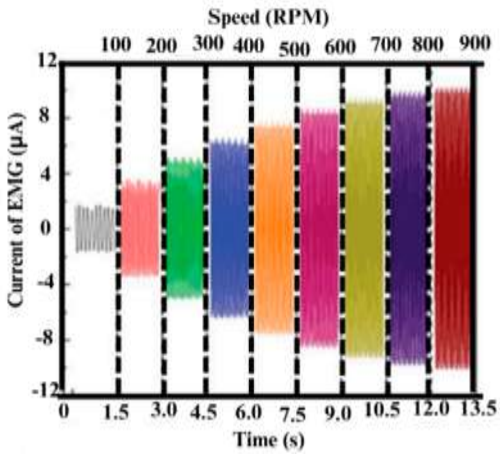

Figure 6: Outputs short circuits current with varying rotating speed EMG

The TEHG's open-circuit voltage and short-circuit current measurements at various rotating velocities are displayed in Figures 3 to 6. When the rotation rates range from 100 rpm to 900 rpm (corresponding to a wind speed of 14 m/s), the peak-to-peak voltage and peak-to-peak current of the TENG increase from 106 V to 190 V and from 2.27 µA to 14.6 µA, respectively. According to Faraday's law, electromagnetic induction causes the magnet and coil to rotate, which determines the EMG output response. When the rotational speed increases from 100 rpm (corresponding to a wind speed of 5 m/s) to 900 rpm, the amplitude of the voltage and current rises from 5 V to 38 V and from 3.3 mA to 20 mA, respectively. The Triboelectric Nanogenerator (TENG) linked to an ideal load resistance of 12 megaohms reaches a maximal average power output of 0.33 milliwatts. On the other hand, the EMG can provide up to 32.87 milliwatts of maximum average output power and 1.25 kilo-ohms of maximum load resistance.

V. Conclusion

In conclusion, we have repurposed a plastic petri dish—which is frequently thrown away after use in the laboratory—to produce a novel design for the extraction of biomechanical energy. This dish has been modified to function as a self-powered triboelectric nanogenerator (SBP-TENG) by using parts that are frequently found in daily life. The results clearly show that the device performs exceptionally well as a freestanding, self-sustaining triboelectric nanogenerator (TENG). Energy can be produced by the SBP-TENG by the separation and contact of the contact materials. With the help of this project, a standard school bag can be improved to become an intelligent one that can gather energy depending on the weight of its contents and the user's movements. It can also serve as an independent emergency LED light source. These tests validate the SBP-TENG's real-time energy collection efficacy and its stand-alone capability to supply low-power electronic devices with electricity during emergencies. The SBP-TENG also has the benefit of an easy-to-manufacture technology, remarkable electrical capability, and durability. This experiment demonstrates a new process for creating wearable, portable, and self-sustaining Triboelectric Nanogenerators (TENGs) for energy collection.

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