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Harvesting Wind Energy with TENG at Low Wind Speeds

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ABSTRACT
The Triboelectric Nanogenerator (TENG) is an emerging novel approach to capture wind energy, particularly at low wind speeds. In this study a TENG of dimensions, 8 cm width, 2 cm thick and 12 cm in length was modelled. For a wind velocity of 1.5 m/s it was observed that the power that can be achieved was 15.25 mW/m^3. On the other hand, for a high wind speed of 4.6 m/s, it was observed that the power achieved was 277.98 mW/m^3. The use of this TENG has been demonstrated to extract power at the low wind speeds that traditional wind turbines struggle or are unable to produce power.

***Keywords* -** Triboelectric Nanogenerator (TENG), Gentle Wind Driven Triboelectric Nanogenerator (GW-TENG), LabVIEW, electrode, tribo-layer, Fluorinated ethylene propylene (FEP),

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I. INTRODUCTION

Trinidad and Tobago is attempting to boost its usage of renewable energy and reduce its reliance on fossil fuels, as well as making a transition to clean energy. This is evidenced by the recent announcement to increase renewable energy generation from 10% to 30% of total electricity generation in the country.

Since wind turbine technology has been widely explored over the years, several big wind farms have been created and are generating energy, both off and on grid. By the end of 2021, the total installed capacity will have risen to 837 GW. China accounted for 80 percent of new offshore wind capacity added globally in 2021, raising its total offshore wind capacity to 27.7 GW (1).

To generate power, most of these turbines require average wind speeds of over 3 meter per second. Wind speed ranges from 5.2 meter per second to 8.8 meter per second offshore East Coast Trinidad from 2019 to 2020 as recorded, whereas onshore data from the met station at Piarco (Figure 1) from 2016 to 2019 shows wind speeds ranging from 1.5 meter per second to 4.6 meter per second, with a monthly average of 3.07 meter per second.

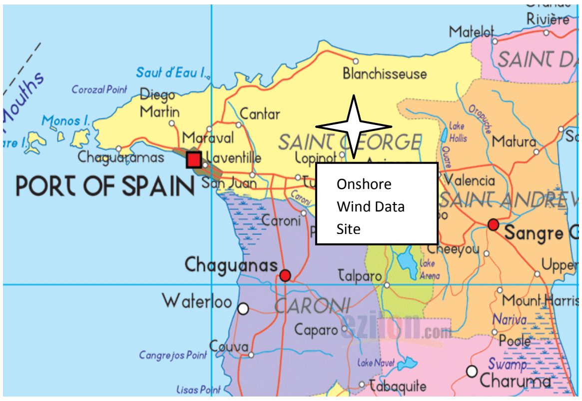

Figure 1. Map of Trinidad showing where data was collected

Onshore data was gathered at a height of 4 meters to highlight the influence of ground effects on the wind profile. Small portable electrical equipment can use these low wind speed values. Most wind turbines are ineffective at converting lower wind speeds (3.07 meter per second) and are inefficient in energy conversion. The usage of a Triboelectric Nano Generator (TENG) has provided a successful strategy for turning environmental agitations, such as wind, rain drop, and water wave, into high electric outputs in recent years (2–7).

There have been some TENG prototypes investigated expressly for wind energy gathering, using a variety of unique architectures and materials (8, 9). These papers, on the other hand, concentrated on the usage of high-speed wind energy (more than 5 meter per second). The TENG gadget must be adjusted to acquire multiplied-frequency outputs in order to harness the low wind speeds.

II. TENG TECHNOLOGY

2.1 TENG Overview

The Triboelectric Nano Generator (TENG) was first invented by Zhong Lin Wang in 2012. Triboelectric Nano Generators belong to a type of mechanical energy harvesting mechanism where Electrical Energy is turned into Mechanical Energy (10).

In terms of mechanical, electrical, optical, acoustic, fluidic, and other aspects, triboelectric nanogenerator (TENG) technology is a promising study topic for energy harvesting and nanoenergy and nanosystem (NENS).

One of the most prominent research procedures in TENGs is converting wind energy into electricity. The interaction of triboelectrification and electrostatic induction effects lies at the heart of TENG's operation. When two dissimilar triboelectric materials come into contact and separation from one another, electrons will flow back and forth across the external circuit to maintain balance due to the immediate voltage difference (11, 12).

Vertical contact separation, in-plane sliding, single-electrode mode, and free-standing mode are the four primary modes of TENG's operating mechanism. This technology has several advantages, including high output power, high conversion efficiency, and low production and material costs.

2.2 TENG's Technology

As the name implies, the contact-separation mode is a technique in which two different parts come into contact and then separate. To generate electrical energy via the contact separation method, these two portions should be made of distinct materials. The basic principle is the charge exchange between the two components.

The Contact Mode TENG (CM-TENG) consists of two plates, each of which has a contact layer and an electrode layer, but the contact layers are composed of different materials. When two surfaces collide as a result of an external force, one loses charges while the other gains them. When the two materials are separated, their contact surfaces have different electric potentials due to the unbalance of electric charges. When a contact-separation action is done on two surfaces connected by a wire, a charge exchange mechanism occurs, resulting in an electric current flow.

The dielectric arrangement in sliding mode is identical to that in contact mode, with the exception that the two materials will slide over one other, causing charges to form on the surface. When two triboelectric layers are connected across a load, they periodically slide away and close, forming an AC output.

The single electrode TENG's functioning principle is based on charge transfer between an Aluminum electrode and the ground.

The three primary components of a freestanding TENG structure are two stationary electrodes and one freestanding layer that moves in response to mechanical energy (Figure 2).

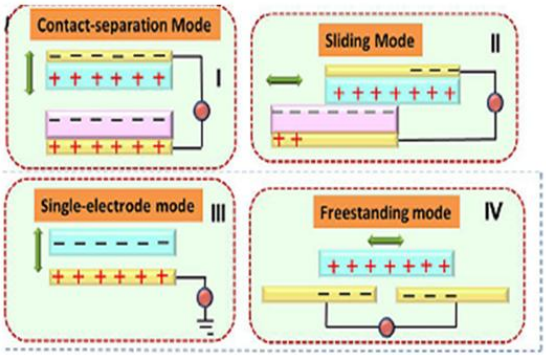

Figure 2. TENG contact modes in operation.

An electrode and a lead wire are attached to each triboelectric layer in traditional TENG designs, making the device non-versatile. Traditional TENG cannot harvest energy from a random moving object or wind energy since the thing must be connected to the entire system via an interconnection. One solution to this problem is the freestanding TENG structure.

2.3 Applications of TENG's

TENGs are devices that convert mechanical energy into electrical energy through the processes of contact electrification and electrostatic induction. Wind, sea waves, or any other sort of vibration or mechanical motion can generate mechanical energy. A raindrop energy harvesting system was also described by Lin et al. (13). The energy from ocean waves, waterfalls, and rainwater is unlimited and can be used to supplement other renewable energy sources. They developed two distinct mechanisms: one for raindrops and the other for flowing water. Wang et al (14) developed a TENG based on a fully enclosed rolling spherical frame for gathering low frequency water wave energy. A TENG-based water wave energy harvester was proposed by Zhu et al. (15) and is based on the asymmetric screening of electrostatic charges on a nanostructured hydrophobic thin-film surface. A completely enclosed duck-shaped TENG was developed by Ahmed et al. (16) to harness energy from low-frequency, erratic water waves. Mao et al. (17) used TENG technology to take use of the friction energy created by rolling tires to scavenge energy. TENGs have a high power conversion efficiency (PCE), however they only need a little amount of energy to operate, resulting in low output power.

III. GENTLE WIND DRIVEN TENG (GW-TENG)

A TENG that could gather energy even at low wind speeds was the subject of earlier research. To effectively harvest energy from extremely low-speed wind/airflow (0.7–6.0 m/s), a gentle wind-driven TENG (GW-TENG) has been developed (18).

Using an ultra-stretchable, perforated film electrode that simulates an elastic band when stretched by moderate flow, the GW-TENG generates an effective output from multiple frequency vibration.

The GW-TENG is made up of arch-shaped frames, a negative tribo-layer, and an ultra-stretchy film electrode sandwiched between them.

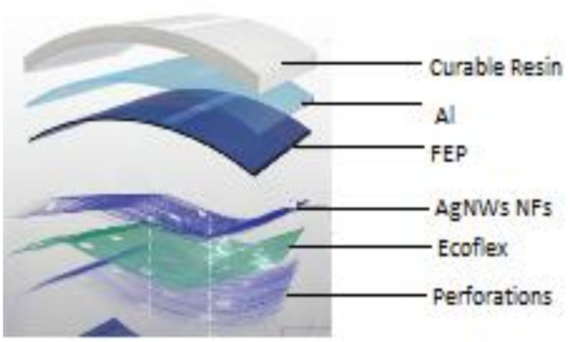

Figure 3. Structural Design of the GW-TENG

The arching components are made via 3D printing and UV curable resin. Fluorinated ethylene propylene (FEP) was chosen as the dielectric material for GW-TENG, and its surface was modified with plasma etching to introduce nanostructures to increase the tribo charge density. The underlying idea behind GW-TENG is that wind flow deforms an elastic electrode, and electrode deformation produces electricity. When the middle film electrode deforms and vibrates in the airflow due to continuous contact electrification and electrostatic induction between this elastic electrode and the FEP dielectric layer, the external circuit can cause the alternating output.

A positive correlation between the output of the TENG device and the frequency of contact separate motion exits is also required, as is a suitable vibration amplitude of the motional electrode, to give sufficient contact-separate distance based on the equations.

For contact-mode TENG of the conductor to dielectric type, the conductor and dielectric plate are stacked face to face as two triboelectric layers (with thicknesses of d2 and relative dielectric constants εr2). One metal serves as both the top triboelectric layer and the top electrode in this structure, while the metal layer on the outer surface of the dielectric serves as the bottom electrode. Under the agitation of mechanical force, the separation x(t) between the two triboelectric layers will be changing. A potential difference (V) between the two electrodes can be induced when the two triboelectric layers begin to separate from one another with rising distance (x). Q is the quantity of charges that are transported between the two electrodes as a result of the induced potential. It is acceptable to assume that the two electrodes are indefinitely large because the area size (S) of the metals is several orders of magnitude more than their separation distance (d2 + x(t)) in the experimental scenario.

Equation 1 for inside the air gap:

$$E_{air} = -{}^{(-Q/S+\sigma(t))}/_{\varepsilon_0} \tag{1}$$

Inside the Dielectric is shown by equation 2:

$$E_{air} = {}^{-Q}/_{S\varepsilon_0\varepsilon_{r2}} \tag{2}$$

The voltage between the two electrodes can be given by equation 3:

$$V = E_2 d_2 + E_{air}\, x \tag{3}$$

The total charges in metal now have two components: one is the triboelectric charges, Sσ, and the other is the transferred charges between the two electrodes, Q. This is because the metal serves as both the top triboelectric layer and the top electrode. The total charge on the metal is now -QSσ.

The relationship below comes from combining equations 1 to 3:

$$V = -Q/S\varepsilon_0[(d_2/\varepsilon_{r2}) + x(t)] + \sigma x(t)/\varepsilon_0 \tag{4}$$

The maximum charge transfer amount is maintained at

Qmax = Q*(x(t) = xmax) with the fixed displacement range from 0 to xmax. The average short-circuit current is

$$I_{SC} = 2S\sigma d_0\, x_{max} f/(d_0 + x(t))^2 \tag{5}$$

$$\overline{P_{opt}} = \log_{10} f + D \qquad (6)$$

Where
Isc – The absolute short circuit current of the TENG,
S – Contact area,
σ - Triboelectric surface charge density,
f - Mechanical energy triggering frequency,
x (t) - Real-time contact-separate distance,
d0 - Effective thickness of the dielectric layer,
Popt - The optimized average output power of TENG,
D – Constant.

$$V_{OC} = -\ Q/S\epsilon_0 * \left(d_0 + x(t)\right) + \sigma x(t)/\epsilon_0 \qquad (7)$$

Where
VOC – Open circuit voltage of the TENG,
Q - Transferred charges between the two tribo-layers,
€0 – Permittivity of the vacuum.

For harvesting light breeze energy, the average energy conversion efficiency of GW-TENG is:

$$\eta = \left(2\, I_{SC}^{2} R dt\right)/\rho S[U(t)]^{3}\ dt \qquad (8)$$

Where
R – Internal impedance of the TENG,
ρ – Air density,
S – Inlet area,
U (t) – Wind speed

The electrode has been thoroughly examined, with a final optimal dimension of 8 cm, 2 cm and 12 cm.

IV. RESOURCE MODELLING

The onshore wind data was obtained from the Meteorological office at Rawinsonde Building, South Terminal Piarco International Airport, Piarco Trinidad. Piarco is located at 10035`N, 061020`W, it is 35 km inland from the nearest coastline.

Table 1: The monthly average wind speeds recorded at Piarco.

	2016	2017	2018	2019
Month	Average Wind Speed (m/s)	Average Wind Speed (m/s)	Average Wind Speed (m/s)	Average Wind Speed (m/s)
January	3.1	3.3	3.0	2.9
February	3.9	3.4	3.1	3.5
March	4.2	3.5	3.5	3.3
April	4.1	3.8	3.8	3.7
May	3.6	4.0	4.6	3.7
June	3.8	4.1	4.2	2.9
July	2.4	3.5	3.1	2.6
August	1.8	1.9	2.3	2.5
September	1.7	2.1	2.2	2.1
October	2.1	1.5	2.5	1.9
November	2.2	2.3	2.5	2.3
December	2.8	2.5	3.1	2.9

V. GW-TENG MODELLING

Simulations utilizing LabView software demonstrate the performance of the GW-TENG for breeze energy harvesting.

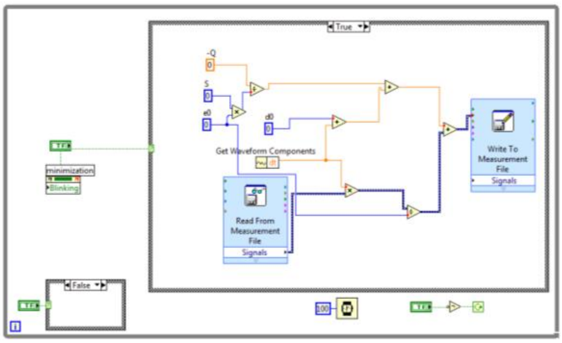

Figure 4. LabVIEW Block Diagram.

VI. MODELLING RESULTS

The LabVIEW software was used with the wind speed database to yield the GW-TENG power output. Figures 5 to 8 shows the GW-TENG power curves. The power produced varies directly to the wind speed that has the highest values. The average power produced may seem small, but the low wind speeds is very difficult to harness with conventional wind turbines.

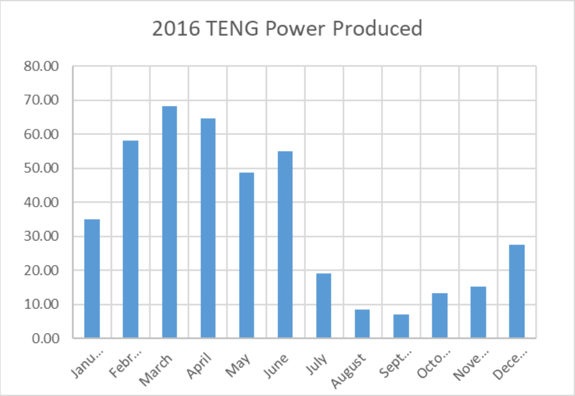

Figure 5. Average power produced by TENG in 2016.

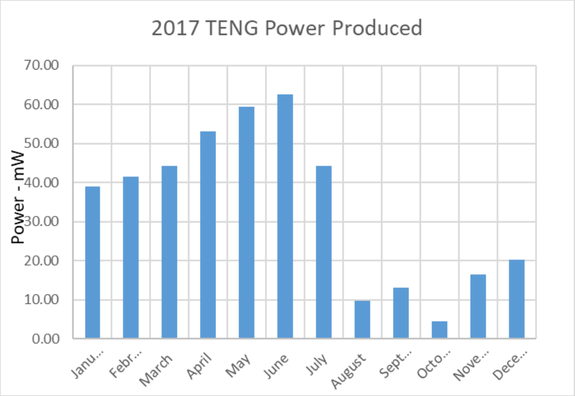

Figure 6. Average power produced by TENG in 2017.

It is important to note that up to 3 m/s, the V_{oc} and I_{sc} almost expand linearly with flow velocity before the peak value starts to slope. This happens for two reasons: the AgNW NFs film electrode's contact area with the negative layer becoming saturated, and the AgNW NFs electrode's vibration frequency fluctuating. The link between the AgNW NFs electrode's lift force and elastic restoring force can be used to explain this shift.

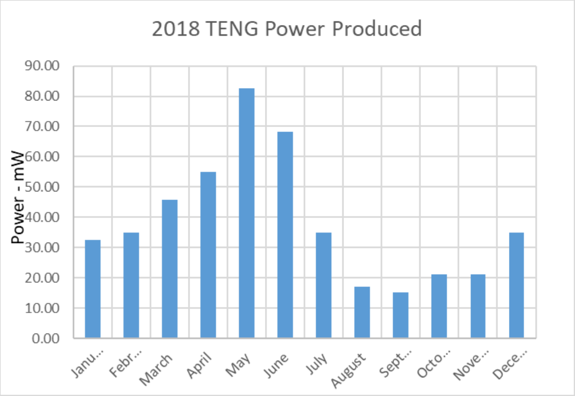

Figure 7. Average power produced by TENG in 2018.

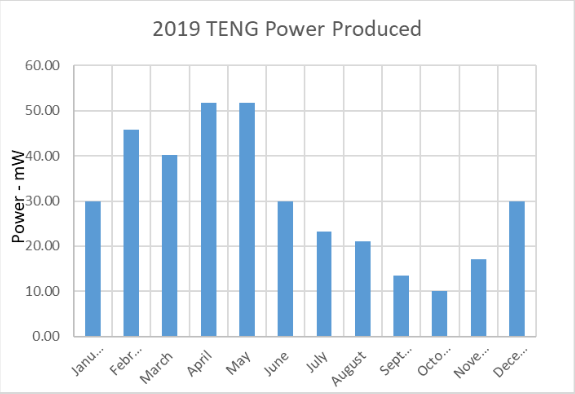

Figure 8. Average power produced by TENG in 2019.

VII. CONCLUSION

In this study, we can see that a high-performance strategy can be utilized to efficiently harvest breeze energy based on TENG technology. Different from the previous reported generators, the GW-TENG utilize the ultra-stretchable, perforated electrode that resembles a stirred rubber band when driven by gentle flow, to acquire effective output from multiplied-frequency vibration. The highest power generation is noticed for months January to May. For the lowest wind velocity of 1.5 m/s we observed that the power achieved was 15.25 mW/m^3. On the other hand, for the highest wind speed observed, 4.6 m/s we observed that the power achieved was 277.98 mW/m^3. The basis of the TENG ability to capture energy can be built on.

By modifying triboelectric nanogenerators and extending the range of wind speeds that can be captured by moderate wind-driven TENG, the method of collecting wind energy can been enhanced. To increase energy efficiency, hybridized TENG can be built in conjunction with other generators that capture various environmental energies.

REFERENCES

[1]. Global Wind Report (GWEC). 2021. Accessed on 14th March 2022. https //gwec.net/wp-content/uploads/2021/03GWEC-Global-Wind-Report-2021.pdf
[2]. Fan, Feng-Ru, Zhong-Qun Tian, and Zhong Lin Wang. "Flexible triboelectric generator." Nano energy 1.2 (2012): 328-334.
[3]. Wang, Zhong Lin. "Triboelectric nanogenerators as new energy technology for self-powered systems and as active mechanical and chemical sensors." ACS nano 7.11 (2013): 9533-9557.

[4]. Cui, Siwen, et al. "Self-powered ammonia nanosensor based on the integration of the gas sensor and triboelectric nanogenera-tor." Nano Energy 49 (2018): 31-39.

[5]. Yang, Hongmei, et al. "A nonencapsulative pendulum- like paper–based hybrid nanogenerator for energy harvesting." Advanced En-ergy Materials 9.33 (2019): 1901149.

[6]. Bae, Jihyun, et al. "Flutter-driven triboelectrification for harvesting wind energy." Nature communications 5.1 (2014): 1-9.

[7]. Ren, Zewei, et al. "Environmental energy harvesting adapting to different weather conditions and self-powered vapor sensor based on humidity-responsive triboelectric nanogenerators." ACS ap-plied materials & interfaces 11.6 (2019): 6143-6153.

[8]. Feng, Yange, et al. "Leaves based triboelectric nanogenerator (TENG) and TENG tree for wind energy harvesting." Nano Ener-gy 55 (2019): 260-268.

[9]. Quan, Zuci, et al. "Robust thin films- based triboelectric nanogen-erator arrays for harvesting bidirectional wind energy." Advanced Energy Materials 6.5 (2016): 1501799.

[10]. Hamilton, Michael C. "Recent advances in energy harvesting tech-nology and techniques." IECON 2012-38th Annual Conference on IEEE Industrial Electronics Society. IEEE, 2012.

[11]. Wang, Zhong Lin, and Aurelia Chi Wang. "On the origin of con-tact-electrification." Materials Today 30 (2019): 34-51.

[12]. Wang, Jiahui, et al. "Investigation of low- current direct stimula-tion for rehabilitation treatment related to muscle function loss us-ing self- powered TENG system." Advanced Science 6.14 (2019): 1900149.

[13]. Lin, Zong- Hong, et al. "Harvesting water drop energy by a sequen-tial contact- electrification and electrostatic- induction pro-cess." Advanced Materials 26.27 (2014): 4690-4696.

[14]. Wang, Xiaofeng, et al. "Triboelectric nanogenerator based on fully enclosed rolling spherical structure for harvesting low- frequency water wave energy." Advanced Energy Materials 5.24 (2015): 1501467.

[15]. Elvin, Niell, and Alper Erturk, eds. Advances in energy harvesting methods. Springer Science & Business Media, 2013.

[16]. Ahmed, Abdelsalam, et al. "Self- powered wireless sensor node enabled by a duck- shaped triboelectric nanogenerator for harvest-ing water wave energy." Advanced Energy Materials 7.7 (2017): 1601705.

[17]. Mao, Yanchao, et al. "Single-electrode triboelectric nanogenerator for scavenging friction energy from rolling tires." Nano Energy 15 (2015): 227-234.

[18]. Ren, Zewei, et al. "Energy harvesting from breeze wind (0.7–6 m s− 1) using ultra- stretchable triboelectric nanogenerator." Advanced Energy Materials 10.36 (2020): 2001770.