COLLABORATIVE RESEARCH
AGREEMENT

between

UNIVERSITI KEBANGSAAN MALAYSIA

and

FERDOWSI UNIVERSITY OF MASHHAD, IRAN

DEVELOPMENT OF TRIBOELECTRIC NANOGENERATOR BASED ON CERAMIC\POLYMER\GRAPHENE NANOCOMPOSITE FOR SUSTAINABLE ENERGY HARVESTING

COLLABORATIVE RESEARCH AGREEMENT
BETWEEN
UNIVERSITI KEBANGSAAN MALAYSIA
AND
FERDOWSI UNIVERSITY OF MASHHAD, IRAN

THIS COLLABORATIVE RESEARCH AGREEMENT (hereinafter referred to as "Agreement") is made on this 15th day of February 2022

Between

UNIVERSITI KEBANGSAAN MALAYSIA an institution of higher learning established and incorporated under the Universities and University Colleges Act 1971 [*Act 30*], and having its address at 43600 UKM Bangi, Selangor Darul Ehsan, MALAYSIA (hereinafter referred to as "**UKM**") of the one part;

And

FERDOWSI UNIVERSITY OF MASHHAD, an institution of higher learning established in 1949, and having its address Ferdowsi University of Mashhad, Azadi Square, Mashhad, IRAN (hereinafter referred to as "**FUM**") of the other part;

UKM and **FUM** shall hereinafter be referred to singularly as "the Party" and jointly as "the Parties".

WHEREAS:

A. **UKM** is one of five research universities in Malaysia with a strategic direction to be the regional leader in research and academic excellence. In taking initiatives to enhance its research and academic excellence, **UKM** has entered into various collaborative arrangements with other parties to enhance its research collaborations.

B. **FUM** is one of the leading universities in Iran with mission to share the knowledge and innovative research for the development of communities as well as to educate the citizens and citizen-leaders of society based on divine principles of Islam and scientifically qualified centers of excellence has set it to be among the most prestigious universities in Iran.

C. **FUM** wishes to carry out one (1) research projects entitled "**Development of Triboelectric Nanogenerator Based on Ceramic\Polymer\Graphene Nanocomposite for Sustainable Energy Harvesting**" (hereinafter referred to as "the Research") as set out in **Schedule 1** attached to this Agreement.

D. **UKM** has agreed to collaborate with **FUM** in carrying out the Research as specified in the Research Project Proposal attached hereto in **Schedule 1**. Following negotiations, the Parties have agreed to enter into this Agreement to set forth their rights and obligations in implementing and regulating their relationship in relation to the Research Project.

NOW THIS AGREEMENT WITNESSETH as follows:

1. DEFINITIONS

In this Agreement, except insofar as the context or subject matter otherwise indicates or requires, the following terms and expressions shall have the following meanings:

"Agreement"	means this Agreement and all Schedules and Annexure to it;
"Background Intellectual Property"	means any Intellectual Property owned by the Parties prior to the commencement of this Agreement and which is made available by a Party or Parties to carry out the Collaboration Program or to achieve the Intended Project Outcomes;
"Bench Fee"	means the amount payable by the Students to **UKM** to cover extra costs such as specialist laboratory or materials or field work as in Clause 5.9 of this Agreement;
"Collaboration Tasks"	means the research and development (R&D) works to be conducted separately or jointly by the Parties;
"Commencement Date"	means 30th March 2022 irrespective of the date first appearing on this Agreement;
"Confidential Information"	means all information passing from the Disclosing Party to the other Party relating to the Research;
"Intellectual Property"	means all rights in relation to inventions (including patents), registered and unregistered trademarks (including service marks), copyright, and confidential information in the industrial, scientific and artistic fields;
"Project"	means research project as set out in **Schedule 1** attached to this Agreement;

“Project Intellectual Property”	means any Intellectual Property arising from or out of the Collaboration Program and contributing to the Intended Project Outcome;
“Research Supervisor”	means the senior lecturers to be in charge of each Party for the Research from **FUM**, Dr. Mehdi Khojastehpour from Department of Biosystem Mechanical Engineering of FUM, being assigned or appointed by **FUM** (First Research Supervisor) and a representative from **UKM**, Dr. Mohsen Ahmadipour from Institute of Microengineering and Nanoelectronics (IMEN) of UKM being assigned and/or appointed by **UKM** (Second Research Supervisor);
“Research”	means the research projects entitled “**Development of Triboelectric Nanogenerator Based on Ceramic\Polymer\Graphene Nanocomposite for Sustainable Energy Harvesting**” as set out in **Schedule 1** attached to this Agreement;
“Research Period”	means **TWO (2) YEARS** from the Commencement Date of this Agreement and may be further extended subjected to mutual agreements, with or without change of any term, through writings;
“Services”	means supervision and co-supervision and other comprehensive consultancy services as well as the necessary research and developmental works in relation to the Research.
“Student”	means the person named **Neda Asgarifar (Passport Number: W51872186**) is studying and doing research at **FUM** and **UKM**.

2. INTENDED PROJECT OUTCOME

The intended outcome from this project is analysis and in-depth characterization of Nanogenerator properties for Sustainable Energy Harvesting.

3. OBLIGATION OF PARTIES

3.1 Subject to all the provisions herein contained, **UKM** hereby grants to **FUM** the right and authority to make use equally of the information of the research findings in manufacture.

3.2 **UKM** shall within the limits of its competence and expertise, provide the Services to the following areas: To carry out synthesis, characterization and performance of nanocomposites on triboelectric nanogenerators application, to support Student research articles.

3.3 **FUM** shall within the limits of its competence and expertise, provide the Services to the following areas: To provide the Theoretical background of triboelectric nanogenerator development, to support Student in all stage of research, Modeling, analysis and validation of triboelectric using COMSOL software. Synthesis of Graphene, Graphene oxide and decreased Graphene oxide, MATLAB software modeling, analysis and validation of electrical circuits, Part of analysis of electrical circuits, Making Polyurethane foam with different structures for separating layers, Fabrication of triboelectric nanocomposites for primary data entry.

4. TERM AND TERMINATION

4.1 This Agreement shall take effect from the Commencement Date and shall continue for a period of **TWO (2) YEARS** unless sooner terminated or extended subject to the completion of the Collaboration Tasks in accordance with the provisions of this Clause (hereinafter referred to as the "Term").

4.2 If Parties wish to extend the Term of this Agreement for additional periods as desired under mutually agreeable terms and conditions, Parties shall reduce such intention to writing and signing for the purpose of the acknowledgement of both.

4.3 Notwithstanding anything contained in this Agreement, any Party hereto may terminate this Agreement for any reason whatsoever by giving at least two (2) months' notices in writing to the other Party and the Parties shall consult each other to agree on a reasonable program of work for the notice period leading up to termination date.

4.4 If either Party commits a breach of this Agreement, the other Party may request in writing that the breach be remedied. If the Party committing the breach does not remedy the breach within thirty (30) days, then the other Party may terminate this Agreement immediately by giving out further notice.

5. COLLABORATION TASKS AND PAYMENTS

5.1 The Parties shall cause their employees, servants, agents or contractors to carry out the Collaboration Tasks in order to achieve the Intended results/improvements.

5.2 The Parties shall provide each other with the materials, facilities, information and assistance as may reasonably be required by the Parties to satisfactorily perform the Collaboration Tasks and achieve the Intended Project Outcome.

5.3 Each Party shall use its best endeavors to assist the other Party in the carrying out the Collaboration Tasks and subsequently to achieve the Intended Project Outcome.

5.4 The Parties and the Student agree that the Student shall provide all the expenses including air ticket, living allowance, insurance and other related expense, during the stay at **UKM.**

5.5 The Parties agree that for the purposes of this Agreement, the Home Institution of the Student is **FUM** and the Partner Institution is **UKM**.

5.6 For the implementation of this Agreement, the faculties or schools in which the Student will be enrolled at **FUM** shall be the Department of Biosystem and Engineering; and attached to the Institut Kejuruteraan Mikro dan Nanoelektronik (IMEN) at **UKM**.

5.7 The Student is subject to the usual policies, rules and/or regulations of both institutions with respect to the Student's admission, enrolment and academic progression.

5.8 Any matters related to authorship and publication shall follow the protocols of the Student's Home Institution, although the Student is required to indicate his or her affiliation with both institutions in respect of any published works.

5.9 The bench fee of Ringgit Malaysia Three Thousand (RM3,000.00) shall be made payable by the Student within twelve (12) months, commencing from 30th March 2022 until 29th March 2023. The payment shall be paid to the **UKM** Bursary.

6. CONFIDENTIALITY

6.1 The Parties shall take reasonable actions to keep confidential all results or information created as part of Collaboration Tasks at all-time including information that is obtained from and/or to be extended to other universities, unless prior written consent of the Parties hereto has been duly obtained.

6.2 The obligations of confidentiality contained in this Agreement shall not apply to any information which:

6.2.1 has been made public by the Disclosing Party or by others with the permission of the Disclosing Party;

6.2.2 is independently received from a third party who is free to disclose it; or

6.2.3 is in the public domain or is a compilation of materials in the public domain.

7. INTELLECTUAL PROPERTY RIGHTS

7.1 The protection of intellectual property rights shall be enforced in conformity with the respective laws, rules and regulations applicable in Malaysia, and acknowledgements shall be made on any publication or any form of dissemination of findings derived from the Research. Notwithstanding, intellectual property rights in respect of any technological development, products and services development, carried out –

7.1.1 jointly by **UKM** and **FUM** including research results obtained through the joint activity effort of **UKM** and **FUM**, shall be jointly owned with the terms to be mutually agreed upon;

7.1.2 solely and separately by **UKM** or **FUM** and research results obtained through the sole and separate effort of **UKM** or **FUM**, which shall be solely owned by the party concerned;

7.1.3 rights in intellectual property developed by Student in the course of exchanges, collaborative or research activities shall be dealt in accordance mutually agreed terms between **UKM** and **FUM** in separate agreement.

7.2 **UKM** and **FUM** shall own equal rights to any invention and publications made solely by both parties in this joint project.

8. OTHER ACTIVITIES

The existence of this Agreement shall not prevent either Party from engaging in any other activities similar to or in competition with those of the subject matter of this Agreement nor shall it prevent a Party from developing or exploiting other products and/or processes.

9. ADVERTISING

Parties shall obtain a prior consent from other Party, in making any public statement regarding the Research, or in relation to any product, process or invention developed as a result of the Research, include in such public statement, an acknowledgement of the technical assistance received from **UKM**.

10. WARRANTIES

Both Parties shall ensure that all Services provided to the other Party in relation to this Agreement are being provided with due care, diligence and skill reasonably expected of professional persons providing services of the kind described. The Parties make no other warranty or assurance with respect to the Services carried out in relation to this Agreement, or to its quality, accuracy or suitability for any purpose.

11. LIABILITY

Neither Party shall be liable to the other Party for any loss nor damage arising from its failure to perform work on time or within estimated costs, provided that the Party has used its reasonable endeavors in all respects.

12. GENERAL

12.1 This Agreement shall be read and construed according to the laws presently in force in Malaysia.

12.2 Any difference or dispute between the Parties concerning the interpretation and/or application of any of the provision of this Agreement shall be settled amicably through mutual consultation and/or negotiations between the Parties without reference to any third party.

12.3 Any change to the terms of the Agreement must be in writing, mutually agreed on and signed by the Parties.

12.4 Should any provision of this Agreement be held by a Court to be unlawful, invalid, and unenforceable or in conflict with any rule, statute, ordinance or regulation, the validity and enforceability of the remaining provisions shall not be thereby affected.

12.5 Any notice under this Agreement shall be served by hand delivery or by being forwarded by prepaid post to the address of the Party shown in **Schedule 1** or to such other address as may be notified in writing by the Party from time to time and in the case of service by post shall be deemed to have been received within seven (7) days after posting. Such notices may be served by facsimile provided that confirmation is served by hand or post as described in this clause.

12.6 The Parties shall not be bound by any amendment or addition to this Agreement except where the Parties have agreed expressly in writing to be so bound.

12.7 This Agreement constitutes the entire agreement between the Parties. Any prior arrangements, agreements, representations or undertakings are hereby superseded.

12.8 Any stamp duty payable in respect of and/or in connection with this Agreement shall be fully borne by **UKM**, wherein each Party shall retain one original copy of this Agreement, being duly stamped.

12.9 Time shall be in the essence of the contract in relation to all provisions of this Agreement.

[THE REST OF THIS PAGE HAS BEEN LEFT BLANK]

IN WITNESS WHEREOF, the undersigned being duly authorized thereto, have signed this Agreement as of the day and year first above written in two (2) original texts.

Signed for and on behalf of:
UNIVERSITI KEBANGSAAN MALAYSIA

PROF. DATO' TS. DR.]
MOHD. EKHWAN HJ. TORIMAN]
Vice-Chancellor]
Universiti Kebangsaan Malaysia]

In the presence of:

PROF. DR. AZRUL AZLAN HAMZAH]
Director]
Institute of Microengineering & Nanoelectronics]
Universiti Kebangsaan Malaysia]

Signed for and on behalf of:
FERDOWSI UNIVERSITY OF MASHHAD, IRAN:

ASSOC. PROF. DR. ABBAS ROHANI]
Head of Department]
Department of Biosystem and Engineering]
Ferdowsi University of Mashhad]

In the presence of:

PROFESSOR DR. MEHDI KHOJASTEHPOUR]
First Research Supervisor]
Department of Biosystem and Engineering]
Ferdowsi University of Mashhad]

M. Khoja

SCHEDULE 1
RESEARCH PROPOSAL

DEVELOPMENT OF TRIBOELECTRIC NANOGENERATOR BASED ON CERAMIC\POLYMER\GRAPHENE NANOCOMPOSITE FOR SUSTAINABLE ENERGY HARVESTING

1.0 Introduction

Triboelectric nanogenerators (TENGs) convert environmental mechanical vibrations into electrical energy (Fan et al., 2012b) by changing the capacitance of an electromechanical converter (Basset et al., 2016). These systems include energy absorption devices with very high voltages (Fan et al., 2012a; Fan et al., 2012b; G. Zhu, 2013). The materials used in this technology are selective and unrestricted (JH Lee, 2015), have a good stability and durability (Lin et al., 2015), their applications are very wide (Lin et al., 2013a), have a simple structure (Yang et al., 2013). They are low cost (Hou et al., 2013; Wang, 2017), and have a good environmentally friendly (Xu et al., 2017). Although TENG do not yet produce high power, they have been shown to be usable in some commercial applications and have a good durability and energy efficiency (Xu et al., 2019).

The application of the triboelectric effect can be categorized into two different areas of energy harvesting and self-powered active systems (Fan et al., 2016; Wang et al., 2015b; Wang, 2013). TENG is made in the form of a capacitor that has a fixed electrode and a moving electrode (Figure 1). If the range of motion of the upper electrode is large enough, contact loads will accumulate on the insulation surface. Accumulation of frictional loads on the surface of the dielectric layer in TENGs is one of the main factors for generating output power in these instruments. Frictional loads on the surface of dielectric insulation layers can be created by the contact of two surfaces (Chen et al., 2018; Mallineni et al., 2018). Figure 1 shows a typical layer arrangement of a TENG.

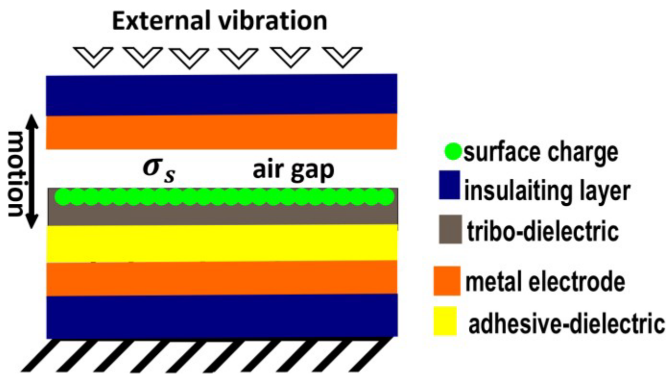

Figure 1. View of TENG and the layers used in it (Ghaffarinejad et al., 2019)

Although it is not long since triboelectric were introduced, much research has been done, and researchers are working to improve the efficiency of these new power generation tools by developing and engineering new structures.

Surface load accumulation is a positive feature that can increase the output power density (Bai et al., 2018). On the other hand, the type, density and stability of the loads transferred due to the contact of the two surfaces depend on various physicochemical factors (Kim et al., 2018; Li et al., 2017), (Grosshans and Papalexandris, 2018; Musa et al., 2018; Yao et al., 2015).

Load accumulation is directly related to the material of the selected layers in TENG. The right way to choose the material of the layers is important. In general, when in contact, one surface grabs some electrons from the other and the opposite layer (equally) has a positive surface charge. One of the descriptive models of contact charge transfer is the triboelectric series, which classify materials according to their tendency to absorb electrons (Bill W. Lee and Orr, 2019; Wang et al., 2016b). Figure 2 shows an example of a triboelectric series.

	Polyformaldehyde 1.3-1.4	(continued)	
	Etylcellulose	Polyester (Dacron)	
	Polyamide 11	Polyisobutylene	
Positive	Polyamide 6-6	Polyuretane flexible sponge	
	Melanime formol	Polyethylene Terephthalate	
	Wool, knitted	Polyvinyl butyral	
	Silk, woven	Polychlorobutadiene	
	Aluminum	Natural rubber	
	paper	Polyacrilonitrile	
	Cotton, woven	Acrylonitrile-vinyl chloride	
	Steel	Polybisphenol carbonate	
	Wood	Polychloroether	
	Hard rubber	Polyvinylidine chloride (Saran)	
	Nickel, copper	Polystyrene	
	Sulfur	Polyethylene	
	Brass, silver	Polypropylene	
	Acetate, Rayon	Polyimide (Kapton)	Negative
	Polymethyl methacrylate (Lucite)	Polyvinyl Chloride (PVC)	
	Polyvinyl alcohol	Polydimethylsiloxane (PDMS)	
	(continued)	Polytetrafluoroethylene (Teflon)	

Figure 2. Triboelectric series for qualitative comparison of the magnitude and sign of accumulated loads due to contact of two different materials with each other (Wang et al., 2016b).

Recently, TENGs have been developed in the fields of energy absorption, self-powered sensors, self-charging systems, self-powered wearable electronic devices, etc. (He and Wang, 2018; Park et al., 2018). Research results show that increasing the output power density produced by TENG tools is possible by selecting suitable materials with different polarity, changing the morphology of the joint surface and raising the contact surface of the two materials (Dhakar, 2017). In this regard, different materials have been used as active insulation layers such as Kapton, PMMA, PDMS, Nylon, PTFE and other polymeric materials. To improve the power and to have layers with more load accumulation, it is necessary to select the appropriate materials and more precise engineering of the TENG layers structure.

Ferroelectric materials have high dielectric properties. But to produce more power, the dielectric property needs to continue to improve. Some ceramic materials have much higher dielectric properties than ferroelectrics. However, due to some physical and mechanical properties, it is not possible to use in TENGs. If ceramic materials are used independently in TENG layers, the ceramic layer will be damaged due to vertical impact. Therefore, providing a solution to solve this challenge is very important. On the other hand, charge accumulation by increasing the dielectric property alone is not sufficient to improve TENG performance; Rather, the maximum transfer of accumulated loads from the TENG to the consumer is another important challenge in this regard. In this study, the synthesis and introduction of nanocomposites based on ceramic-polymer materials that have high dielectric (higher charge accumulation) and suitable mechanical strength and flexibility will be investigated. The conductivity (electrical conductivity) of the insulation layer is another effective parameter in TENG power (Haque et al., 2016; Huang et al., 2015; Zhu et al., 2016) and since Insulating materials are not electrically conductive, so the effect of adding conductive materials such as graphene and its derivatives to the structure of the ceramic-polymer composite for transferring the accumulated loads to the external circuit (load conductivity) will be investigated. As a result, the main goal is to develop a suitable nanocomposite for the TENG structure, which increases the surface charge density of the triboelectric layer and improves the output power of the TENG tool following higher load transfer.

2.0 Objectives

2.1 Improving the power of TENG by using nanocomposites based on ceramic-polymer materials

2.2 Improving the property of load conductivity using graphene derivatives Increasing the stability of the developed TENG in comparison with the conventional polymer TENG

2.3 Improving the electrical efficiency of TENG by increasing the conductivity and load density

2.4 Introducing TENG with suitable power and efficiency with ideal ratios of polymer, ceramic, and graphene materials

3.0 Methodology

Measurement and evaluation of electrical power requires materials engineering, fabrication and testing of TENG in the laboratory. In this regard, the testing process will be described. Analytical methods and laboratory instruments are used to establish the relationship between measurable TENG characteristics (such as current, voltage and output power) and surface density of loads. The general structure and constituents of TENG, the structure of dielectric insulation, usable polymers and their special properties will also be briefly described.

3.1 Synthesis of materials

3.1.1 Synthesis of chemical derivatives of graphene

In addition to direct methods of producing graphene, a very common method in the synthesis of this material is the production of **graphene oxide (GO)** and then its reduction and production of **reduced graphene oxide (rGO)** or graphene. In this synthesis method, known as chemical lamination, graphene oxide is obtained by oxidizing graphite in the presence of strong acids and oxidizers (Hamers method (Huang et al., 2012)). The amount of oxidation varies depending on the method, reaction conditions and graphite used. Graphene oxide is formed on the surface of graphene by combining graphite with oxygen and bonding with oxygenated functional groups (such as carboxyl, epoxide, and hydroxyl groups) (Novoselov, 2011). The presence of these polar functional groups makes GO highly hydrophilic, turning it into an electrically non-conductive material whose layered structure is curved in the presence of a carbon-carbon bond. Therefore, GO is reduced with reducing agents such as hydrazine or under heat and vibration to bring it closer to the main structure of graphene.

To synthesize graphene by the **Hummers method**, expanded graphite (99%, Alfa Aesar) is added to concentrated sulfuric acid (98%, Merck) and placed on a magnetic stirrer. Potassium permanganate (> 99% Sigma Aldrich,) is then gradually added. After mixing, the suspension is divided into two equal parts, one washed to obtain GO and the other processed to prepare rGO (Abdolhosseinzadeh et al., 2015). It should be noted that GO washing is adapted from the modified Hammers method (Akhavan, 2010).

Then, for GQD synthesis, the **method of Jiang** et al. (Jiang et al., 2015) will be used, so that first the GO solution is prepared and mixed with hydrogen peroxide and $FeCl_3$ solution in a quartz tube and stirred. Then, by adding HCl, the pH of the solution reaches 4. The quartz tube containing the solution is then placed under a mercury lamp (ultraviolet radiation). In this case, the reaction products are placed in a dialysis bag to remove iron ions and other excess micro molecules. After preparation, the solution is mixed with hydrogen peroxide and ammonia in a Steel-Teflon autoclave.

3.1.2 Synthesis of CCTO / P (VDF – TrFE) nanocomposites with graphene derivatives

The review of the researchers clearly showed that each of the polymer materials P (VDF-TrFE) and CCTO ceramic have special capabilities to increase the dielectric of the triboelectric layer and improve the charge accumulation. Therefore, contribute significantly to increasing the output power of the TENG. The steps of combining these two materials and making CCTO-P (VDF-TrFE) are described below.

First, copolymer P (VDF-TrFE) is used as the matrix, because this copolymer has a very weak piezoelectric effect and a high dielectric constant (about 15) at room temperature. To investigate the possibility of making a flexible composite with a high dielectric constant using CCTO, the researchers reported a composite with 50 vol % CCTO ceramic and 50 vol % by volume polymer P (VDF-TrFE). Ceramics are prepared using the traditional powder processing method, such as high-purity metal oxide powders including calcium carbonate (CaCO3, 99.5%, Alfa Aesar), copper oxide (CuO, 99.7%, Alfa Aesar) and Titanium dioxide (TiO2, 99.8%, Alfa Aesar) is used. The ceramics are baked in a kiln and the ceramic pellets are pulverized using a mill.

Composite are prepared by combining solution-cast and hot-pressing methods. Copolymer P (VDF-TrFE) is dissolved in dimethylformamide (DMF) and CCTO ceramic powder is poured into solution. Graphene derivatives with specified weight percentages are then added to the existing contents and subjected to ultrasonic solution for uniformity. The final solution is poured on a glass plate to form the desired composite in the oven and the end result is a flexible film. To improve the uniformity of the film, the solution is pressed with a hot-press, and for greater thickness, four to six layers can be pressed together. If necessary, the dielectric properties of CCTO – P (VDF-TrFE) can be determined using an impedance analyzer (Agilent 4294 A) (Arbatti et al., 2007). It should be noted that the synthesis method may vary according to the test conditions.

3.1.3 Development of Triboelectric Nano-generator

Another factor influencing the output of TENG energy harvester is the selection of triboelectric materials with the highest electro-amplitude difference for higher electrical efficiencies, which are determined by the triboelectric series. In the manufacture of triboelectric generators, a wide range of materials are used as the layer, which vary according to the construction conditions and the output of the TENG. One of the most widely used polymers is PVDF with the chemical formula - $(C_2H_2F_2)_n$−, which has a higher dielectric fluorine than other basic polymers. The position of this polymer in the triboelectric series and its chemical composition are shown in Figure 3. On the other hand, the electrodes of the TENG are Cu and the operating mode of the contact-separation instrument will be considered.

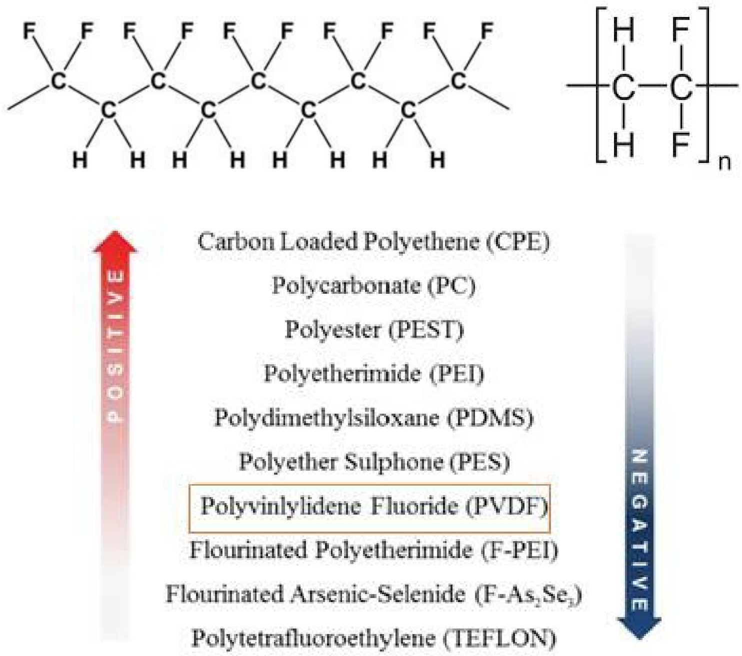

Figure 3. Closed and open view of PVDF chemical formula (top), position of PVDF in triboelectric series (bottom)

The samples of this layer are CCTO-P (VDF-TrFE) nanocomposites with specific weight percentages of graphene base derivatives such as GO, rGO and GQD. Will be tested and analyzed.

3.2 Characterization and measurement

3.2.1 Characterization of nanocomposites

The structural and morphological characteristics of the nanocomposite surface prepared using **scanning electron microscopy (SEM)** and **Fourier transform infrared (FTIR)** and **X-ray diffraction (XRD)** spectroscopy will be determined and reported.

3.2.2 Dynamic measurement of capacitance changes of TENG

The performance of TENG shows that as the electrodes move, capacitive value changes over time and a C_{var} (t) function is generated that varies depending on the type of mechanical excitation applied. If the electrodes move alternately relative to each other, the C_{var} (t) function will also have an alternating shape. Measure two values of maximum C_{max} corresponding to the contact state of the upper electrode with the surface of the dielectric layer (contact capacitor value) and minimum C_{min} corresponding to the state of maximum distance between the two electrodes (always $C_{max} > C_{var}(t) > C_{min}$), One of the most important parameters to characterize energy harvester devices. Figure 8 shows the structure of the electrical circuit used to measure the temporal variation of $C_{var}(t)$, in which the alternating V_{ac} signal source with a frequency of 100 kHz and a range of 500 mV is connected in series to TENG and the optimal $R_{ac}(opt)$ resistance. The output signals are connected to channels 1 and 2 of the oscilloscope and are processed by storing information in the computer using MATLAB software. Figure 4 shows the electrical circuit between the electrodes of the TENG instrument and the oscilloscope.

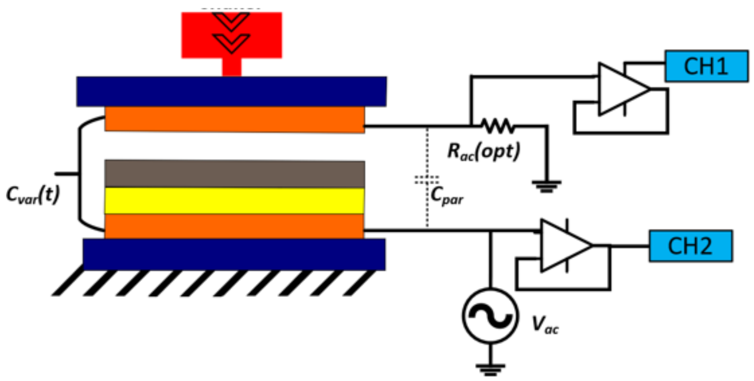

Figure 4. Electrical circuit for measuring changes in capacitance of a TENG instrument (Ghaffarinejad et al., 2019)

To calculate the changes in the capacitance of TENG, the theoretical equation (**1**) is used, in which f_c is the frequency of the sample signal and θ is the phase difference of the oscilloscope channel 1 and 2 signals. Also, to minimize the error in calculating time changes, the optimal R_{ac} value is calculated from equation (**2**), in which the mean initial estimate C_{var}^{avg} is the maximum and minimum capacitive value of the TENG (Equation **3**). To obtain the initial values, the use of the classical relationship of capacitors and the measurement-based method using the impedance measuring device in both contact and high electrode release modes have been proposed (Basset et al., 2009).

$$C_{var} = \frac{1}{2\pi f_c \tan(\theta) R_{ac}} \tag{1}$$

$$R_{ac}(opt) = \frac{1}{2\pi f_c C_{var}^{avg}} \tag{2}$$

$$C_{var}^{avg} = \frac{(C_{i\,max} + C_{i\,min})}{2} \tag{3}$$

3.2.3 Investigation of the structure and components of the TENG energy harvester test

An important part of the activities related to this research will be done in laboratory environments. The required laboratory tools are in the figure provided (Figure 5). The set of test instruments consists of four main parts: the mechanical excitation system, the access to information and data recording, the built-in TENG instrument, and the electrical circuits. In addition, a force or displacement sensor is required to measure the magnitude of the impact and amplitude of the signal generation source.

The mechanical excitation part consists of an amplifier, a magnetic shaker with a movable axis, and its amplitude, frequency, and type of oscillating motion are controlled by a magnetic core. This type of device is produced by modal shop (www.modalshop.com/default.asp, 2019), and is a signal generation source that acts as a control signal for the percussion device. This signal adjusts the amplitude of the vertical motion, the shape and the frequency of the oscillations (sine, square, triangular ...) of the moving axis. As the range of the control signal increases, the range of motion of the moving shaft in the percussion device increases and a stronger force is applied to the surface of the insulation layer in the TENG. The maximum amplitude supplied for alternating current from this source is 10 V, the minimum is 20 mV and the output voltage resolution is 1 mV. The sine waveform will also be used in all cases, and the amplitude and frequency of the moving axis excitation will vary depending on the type of test. The sensor used in the tests has a sensitivity of about 25 mVN^{-1}. This sensor is mounted on the moving axis of the impactor and is used to measure the maximum force applied to the surface of the insulation layer. The output of this sensor, produced by Dytran, is connected to the oscilloscope by means of an electrical circuit (https://www.dytran.com, 2019).

It should be noted that the output of TENG will be measured with the help of an oscilloscope, and to record and maintain the output, a personal computer is needed to receive the desired curves from the output port of the oscilloscope. The data logger also includes various circuits required to automatically calculate and record the TENG output specifications.

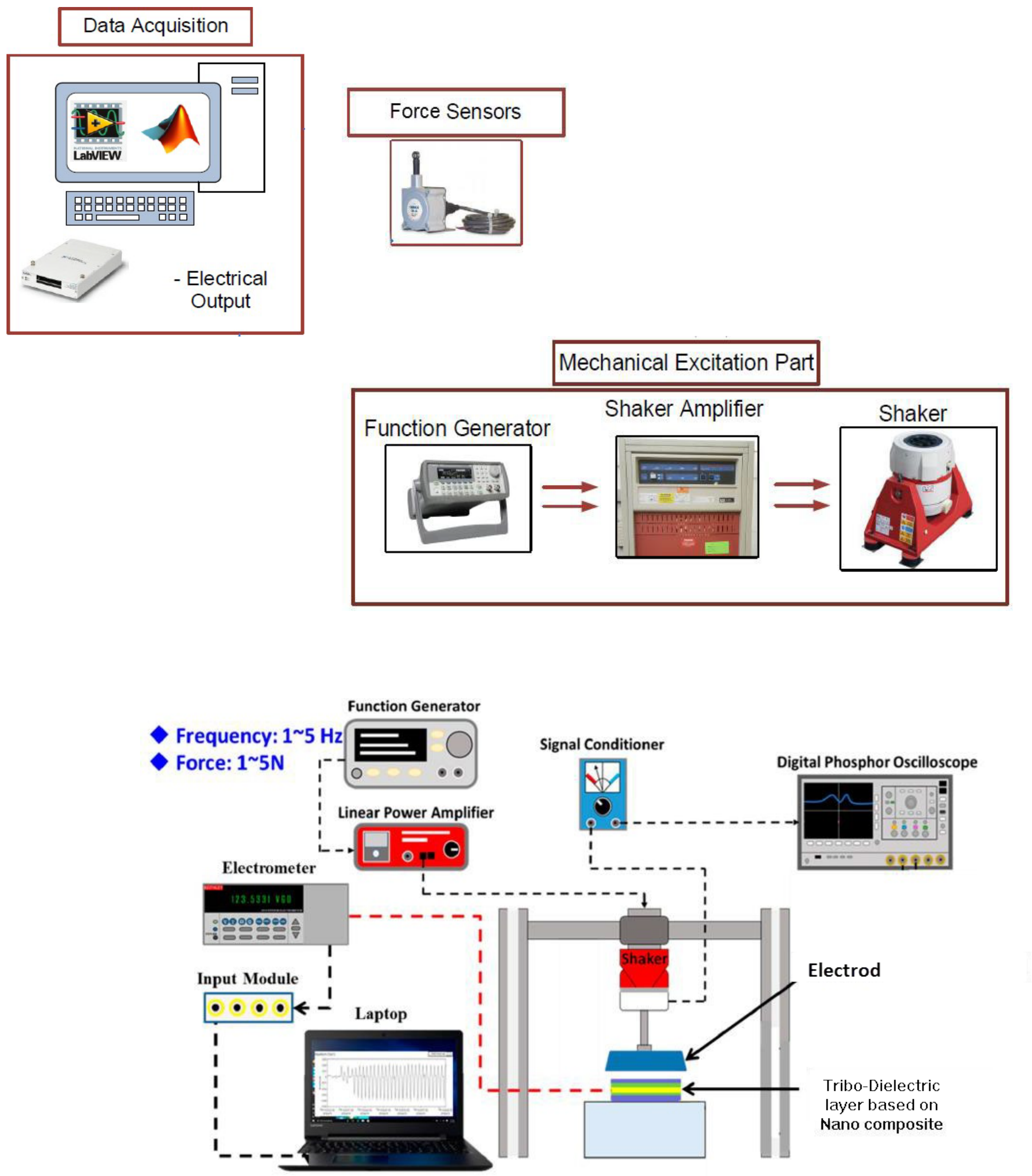

Figure 5. Testing devices (top) Schematic of TENG output measuring devices (bottom)

4.0 Expected results

1- The use of ceramic-polymer-graphene nanocomposites improves the power of TENG.

2- GQD-based TENG has better load conductivity compared to other graphene derivatives.

3- Increasing the conductivity of nanocomposites is effective in the output performance of TENG.

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