Different Trends of Hybrid Solar And Raindrops Energies to Generate Photovoltaic

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Abstract. New trends for making an all-weather photovoltaic (PV) that is able to trigger by both sunlight and raindrops become trends in developing the solar energy systems to generate electricity for households, industries and buildings. The idea is to develop a hybrid device that harvests kinetic energy from water without destroying the output of the solar cell during sunny times. This paper reviews the two devices of hybrid sunlight and raindrops, namely are the Triboelectric Nano Generator (TENG) and Pseudo Capacitor Graphene Layer (PCGL), respectively. Both TENG and PCGL similarly in such way places two transparent polymer layers on top of PV cell. When raindrops fall on to the layers and then roll off, the friction generates a static electricity charge. In addition, these devices even could provide electricity at night whenever there is rain. These two trends of all-weather PV obviously have advantages and drawbacks, as they have been developed in order to make them more compact and efficient as the device that harvesting sunlight during dry seasons and rainfall during wet seasons both for days and nights.

1. Introduction

Solar energy harvesting is one of the well-developed and fruitful technologies due to the low cost and superior performance. The only element lacking is that the solar cell can only work well under the full sun. On cloudy, rainy days, or at night, the output of photovoltaic (PV) panels is always largely suppressed or even vanished [1].

The PV panels rapidly extending across the rooftops globally as the solar radiation power is now very popular. However, the output of the PV panels is highly reliant on weather conditions, which making it rather unstable. Therefore, a hybridized PV panel that can simultaneously generate power from sunlight and raindrop is mitigated, when any or all of them are available in the ambient environment. Exclusively of compromising the output performance and conversion efficiency of the PV itself, the presented hybrid cell can deliver an average compensation to the common PV cells, especially in rainy seasons or at night time [1].

Assuming the compelling features, such as cost-effectiveness and a greatly expanded working time, the reported hybrid cell renders an innovative way to realize multiple kinds of energy harvesting and as a useful compensation to the currently widely used PV cells. The demonstrated concept here possibly be adopted in a variety of circumstances and change the traditional way of solar energy harvesting. Although the rooftop PV panels are efficient and affordable, a big disadvantage remains in the fact that PV cells produce no power when it is raining. This is a challenge to introduce a new approach to making an all-weather solar cell that is triggered by both sunlight and raindrops. The
developed devices that can hybrid absorb solar radiation and raindrops are firstly called the Triboelectric Nano Generator (TENG) [2] and secondly called Pseudo Capacitor Graphene Layer (PCGL) [3].

Before we continue the mitigation of TENG and PCGL, let us consider the PV itself. PVs are devices that convert the sun’s energy directly to electricity. Sunlight provides the energy to make the current flow from the n-type side to the p-type side. They also called as the sandwiches of silicon, that incapacitated with an impurity to help electrons flow (electricity) n-type incapacitated with arsenic, antimony or phosphorous, that could add an extra electron p-type incapacitated with boron, aluminum or iridium, that could take up an electron. Each sandwich produces only a small amount of electricity (±0.5 volts). Around the group, 40 or 50 sandwiches can make a solar cell of 20-25 volts [4]. Figure 1 illustrates PV as it described above.

![PV cell and circuit](image1.png)

![PV module anatomy](image2.png)

(a) PV cell and circuit  
(b) PV module anatomy  

Figure 1. PV form and anatomy [5]

According to [4] and [5], there are commonly two physical PV, Crystalline silicon and Amorphous silicon. The first one is expensive to make as silicon must be very pure, but these are most efficient, about 10 to 15%. Maximum efficiency is about 25%. The second one is the newer technology than crystalline silicone, lower in efficiency, about 5%, then can be improved by stacking layers to get about 10% efficiency. It is very durable and can be made into roof shingles.

Figure 2 shows three different kinds of PVs as common-commercially popular for housing or industrial needs. In addition, the common trend today as PVs mounted to the rooftop, is the singles PVs, as shown in Figure 2(c).

![Crystalline PVs](image3.png)
![Amorphous PVs](image4.png)
![Shingles PVs](image5.png)

(a) Crystalline PVs  
(b) Amorphous PVs  
(c) Shingles PVs  

Figure 2. Different kinds of PVs  

As PVs has been mitigated from the physical point of view, then it also can be mitigated from the cost competitiveness point of view. There are three points that should take into account. Firstly, the
concentrators; these should be mirrors that concentrate the energy of the sun to improve efficiency. Secondly, hybrid solar systems; this system should combine solar with other forms of energy production to make overall reliability becomes higher and the cost becomes cheaper. For example, solar-wind. Finally take cost of pollution into account. Cost of coal-based electricity is cheaper in part since the pollution is not factored into cost. Pollution from solar would add in massive amount, excluding some pollution in manufacturing [4].

Researchers of [2] and [3] have mitigated the trending of hybrid solar and raindrops PVs, which can perform as both sun radiation and raindrops catcher. The technologies of this hybrid device are able to harvest kinetic energy from water without destroying the output of the solar cell during sunny times [2]. Additionally, these devices also can generate more electricity by separating the positively charged ions in salty rain and then able to get them binding to the graphene which then performed as a pseudo-capacitor. Afterward the two layers with different energy levels that then produced an electric current [3].

This paper reviewed the advantages and disadvantages of both trends, which organized as follow; section 1 described the material of PVs from early year until today’s trends. Section 2 discuss the trends separately, section 3 conclude the reviews, and section 4 is the acknowledgement.

2. Trend of hybrid solar and raindrops PVs

The trends of hybrid solar and raindrops PVs that had been developed as TENG and PCGL. TENG is a device which creates electric charge from the friction of two materials rubbing together, as with static electricity. In other words, it is all about the shifting of electrons. TENGs can draw power from car tires that hitting the roads, clothing materials rubbing up against each other, or in this case the rolling motion of raindrops across a solar panel [3]. The study regarding TENG in [3] has successfully demonstrated the new concept in utilization of energy during various weather conditions. Although TENGs are not new, but by putting two polymer layers o top of PV cell can form TENG as the hybrid solar and raindrops PVs.

However, back in 2016, a study has been conducted in order to generate electricity from raindrops falling on a solar panel through the addition of an extra graphene layer and then performed as pseudo-capacitor[2]. Moreover, this study then become the benchmark of PCGL.

2.1. Triboelectric Nano Generator

According to [6], the today trend of self-powered systems is the one that can harvest energy from the working environment of the device to power directly the devicefor application in ultrasensitive chemical and bimolecular sensors, nanorobotics, micro-electromechanical systems, remote and mobile environmental sensors, homeland security and even portable/wearable personal electronics. This new technology is sustainable self-sufficient micro/nano-power sources that newly emerging field of nano-energy, which is concerned with the application of nanomaterials and nanotechnology for harvesting energy to power micro/nano-systems is called TENG.

The design of the TENG for the metal-to-dielectric in contact-separation mode is illustrated in Figure 3(a). According to the triboelectric series, electrons are injected from cellulose paper to PTFE, resulting in net negative charges (Q) on the PTFE surface. In a simplified model, the equivalent circuit of the TENG with an external load of R is illustrated in Figure 3(b-d), in which the device can be regarded as a flat-panel capacitor [6]. Although the mechanism illustrated in Figure 3 is for a flat surface, micro- or nano-patterns can be generated on surfaces to enhance the contact area and the effectiveness of the tribo-electrification.
Figure 3. Design, operating principle, and performance of a TENG in the metal-to-dielectric in contact-separation mode [6]

As can be seen in Figure 3(a), the schematic diagram and digital photography of an arch-structured flexible triboelectric nano-generator. Then the equivalent circuit of the TENG with an external load of R when the device can be seen at (b) origin, (c) is shown the pressing, and (d) is shown the releasing states and (e) is the corresponding current-time curve. While (f) is the linear superposition tests of two TENGs (G1 and G2) connected in parallel with the same polarity (G1 + G2) and opposite polarity (G1 - G2). Detail output of this TENG mode can be seen in reference [6].

In reference [1], a transparent dual-mode TENG can can not only harvest energy from sunlight, but also from light wind and natural raindrops. Provided no compromise of the solar energy harvesting, the presented hybrid cell holds a greatly expanded working time and also provides good output compensation except for solar energy. In a windy day, the hybrid cell can harvest energy from ambient wind, and also can deliver an average output of 8mW m⁻² at a wind speed of 2.7m s⁻¹. On a rainy day, it can harvest energy from the dripping water-drops. The hybrid cell can achieve an average output of 86mW m⁻² at a dripping rate of 13.6mL s⁻¹. These functions render that the hybrid cell plays an important and compensative role in the current field of solar energy harvesting. Provided a collection of advantages, such as being cost-effective, easy fabrication, greatly expanded working time without compromising the original solar energy harvesting, the presented hybrid cell is a unique and practical step toward a high efficiency ambient green energy harvesting with a lower production cost per watt. Figure 4 illustrates TENG; the schematic diagram of dual-mode (a) and its enlarge view in detail (b). Detail output of this dual-mode TENG can be seen in reference [1].

Figure 4. (a). Schematic diagram of dual-mode TENG; (b) enlarge view of dual-mode TENG in detail [1]
2.2. Pseudo Capacitor Graphene Layer

As TENG has been developed to efficiently gain electricity from sun radiation and raindrops, the electric energy that has been produced can be more than it used to be. The technology of pseudo-capacitor can be applied due to implement the PCGL.

According to [7], A pseudo-capacitor is a hybrid between a battery and an electric double layer capacitor. It also consists of two electrodes separated by an electrolyte. Charge storage occurs by chemical and electrostatic means. Figure 5 illustrates the cell of pseudo-capacitor. Meanwhile, as stated in [2], graphene layer is is a two-dimensional form of carbon in which the atoms are bonded into a honeycomb arrangement. It can readily be prepared by the oxidation, exfoliation, and subsequent reduction of graphite. Graphene is characterized by its unusual electronic properties: It conducts electricity and is rich in electrons that can move freely across the entire layer (delocalized). In aqueous solution, graphene can bind positively charged ions with its electrons (Lewis acid-base interaction). This property is used in graphene-based processes to remove lead ions and organic dyes from solutions.

Figure 5. Pseudo-capacitor cell [7]

According to [8], the transition of metal oxides that exhibit pseudo-capacitor are very fascinating. Pseudo-capacitance occurs when reversible redox reactions occur at or near the surface of an electrode material and are sufficiently fast so that the device's electrochemical features are those of a carbon-based capacitor. However, it has significantly higher capacitances that both materials systems and electrochemical characteristics lead to high energy density at high charge–discharge rates are still being identified. Up to the present time, transition metal oxides exhibit the widest range of materials with pseudo-capacitive behavior. By selecting the proper transition metal oxide, utilizing the most effective electrode architecture, and analyzing the electrochemical behavior for pseudo-capacitive behavior, such materials are expected to become the basis for electrochemical energy storage devices which offer high energy density at high rates.

In [9] is reported a work of PCGL that technically and chemically conducted as a simple method to obtain nano-Bi$_2$WO$_6$/reduced graphene oxide composite which demonstrate larger specific capacitance, higher energy density and longer cycle life. As comparison, pristine Bi$_2$WO$_6$ nanoparticles have poor specific capacitance and weak cycle life due to the low electric conduction and over oxidation of Bi which causes non-reversible destroy on structure. In this nano-Bi$_2$WO$_6$/reduced graphene oxide composite, graphene with well conductivity then enhance the electrically conducting as charge transfer channel. In this composite, electrons are able to transfer timely in oxidation and most Bi oxidized then ensure long cycle life.

Unfortunately, several redox during charge-discharge of pseudo-capacitive materials such as hydroxides, oxides and polymers can sharply increase the specific capacitance and high energy density. However, the electrical conductivity these pseudo-capacitive materials are too low to support
high rate electron transport [9]. Figure 6 illustrates three different kind of pseudo capacitances that in such ways have eversible redox mechanisms that rise their capacitance.

![Figure 6. Reversible redox mechanisms that rise the pseudo-capacitance [9]](image)

3. Conclusion

This paper reviewed the advantages and disadvantages of TENG and PCGL as new PVs’ development to not only catch sun radiation but also raindrops so that PVs can work under any sunny and rainy days and nights. TENG works by putting two transparent polymer layers o top of PV cell can form TENG as the hybrid solar and raindrops PVs. While PCGL works similarly to TENG but additionally makes the electric energy that has been produced become massive in quantity by involving the technology of pseudo-capacitor in such ways in the two transparent polymer layers. In other words, PCGL is the new development of TENG.

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