

Research Article

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Investigating the effect of green composite back sheet materials on solar panel output voltage harvesting for better sustainable energy performance

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Abstract: Clean sustainable energy and proper utilization of the available natural resources are of paramount importance for the modern societies. In this work, green composite materials were designed, fabricated and utilized as back sheets for the solar photovoltaic panels to investigate their effects on the output voltage of the solar cell unit. Such replacement of the back sheet of the solar cells would improve their efficiency while reducing the cost and enhancing better environmental conservations. Green back sheet composites were designed with 25 wt% and 50 wt% of high-density polyethylene with all *Rhus typhina*, *Punica granatum* and *Piper nigrum* powders. Investigations of the effect of green composite back sheet materials on solar panel output voltage harvesting have been carried out in Jordan at Zarqa city (latitude 32.07°, longitude 36.08°). Results have revealed that *R. typhina* and *P. nigrum* based composites with 25 wt% fiber loading have demonstrated much better output voltage comparable to the original back sheet cell. The maximum output voltage was found to be enhanced about 58 % with the green composite back sheets. This in order would improve the efficiency of such solar cell units and enhance better environmental indices.

Keywords: energy harvesting; green composites; natural fibers; photovoltaic; PV panels; solar cell.

1 Introduction

Since energy demand is rapidly increasing worldwide, as well as environmental issues growing concern, green energy has become potential alternative due to its numerous benefits (Talaat et al. 2018; Tudisca et al. 2013). This includes its sustainability as it depends upon renewable sources with minimal environmental impact, in addition to its better socio-economical acceptance (Elashmawy 2020; Srivastava and Yadav 2018). Photovoltaic (PV) modules as a solar cell electricity generating scheme is one among the available renewable energy sources. Individual solar cells are often the electrical blocks of photovoltaic solar panels. The commonly used standalone junction silicon solar cell could approximately harvest 0.5–0.6 V in an open-circuit voltage scheme (Fadaam et al. 2020; Khan, Hussaini, and Hussain 2021; Sarkar, Ghosh, and Mandal 2018). Photovoltaic back sheets are multi-layer support scheme consisting several polymeric materials as well as inorganic modifiers. These assemblies are utilized to support the electrical properties of the PV as well as the thermo-mechanical characteristics. Back sheets usually made of polyvinylidene fluoride (PVDF), fluoropolymers and thermoplastics, such as polyvinyl fluoride (PVF), polyamides (PA), ethylene vinyl acetate copolymer (EVA), polyesters (PET) as well as others (Alaaeddin et al. 2018, 2019a, 2019b; Das et al. 2019).

Natural fiber composites revealed several desired mechanical, physical, dielectrical, thermal, and technical properties that make it highly suitable for PV applications (AL-Oqla, Alaaeddin, and El-Shekeil 2021; AL-Oqla, Sapuan, and Fares 2018; Alemán-Nava et al. 2018; Fares and AL-Oqla 2020; Fares, AL-Oqla, and Hayajneh 2019; Hayajneh, AL-Oqla, and Mu'ayyad 2021; Li et al. 2020; Nawafleh and AL-Oqla 2023; Thakur et al. 2019). Adequate material selection is essential to the quality of the produced products. Natural fibers' efficiency varies regarding specific features in each type and composites' final product characteristics depend upon the combined characteristics of both the matrix and the properties of the

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reinforcement (AL-Oqla 2021a; AL-Oqla and Sapuan 2023; AL-Oqla and Thakur 2022; AL-Oqla, Hayajneh, and Aldhirat 2021; Al-Shrida, Hayajneh, and AL-Oqla 2023; Akhshik et al. 2017; Jawarneh, AL-Oqla, and Jadoo 2021; Madhu et al. 2020; Zielińska et al. 2021). Moreover, the utilization of the natural fiber composites in innovative back sheets would decrease the complete reliance on synthetic and inorganic materials that are unfavorable to the environment (AL-Oqla 2023a; AL-Oqla, Hayajneh, and Hoque 2023a; AL-Oqla, Hayajneh, and Nawafleh 2023; Zhang and Xu 2022). Composites with green fibers have recently become the subject of interest. Due to their several beneficial characteristics, they may open new horizons since they are significant alternatives to harmful synthetic fibers (AL-Oqla 2021b, 2023b; AL-Oqla and Hayajneh 2021; Aridi et al. 2016; El-Shekeil, AL-Oqla, and Sapuan 2020; Rababah and AL-Oqla 2020; Rababah, AL-Oqla, and Wasif 2022; Voicu and Thakur 2021). Short natural fibers were found to be capable of adjusting the dielectric behavior of selected polymeric matrices. This would help governing their mechanical and electrical characteristics (AL-Oqla 2021c; AL-Oqla and Sapuan 2020; AL-Oqla et al. 2015; Fares, AL-Oqla, and Hayajneh 2019; Rana, Frollini, and Thakur 2021).

On the other hand, commercial back sheets usually suffer from various disadvantages and several failure styles including delamination, poor adhesion, staining, thermal instability and hydrolysis failures (Li et al. 2018; Rosenthal et al. 2018). Thus, green composite materials can be utilized for the PV panel back sheet to enhance their overall performance as it was reported that PVDF base short surge palm fibers back sheet was utilized as new composites for improving several characteristics like thermal stability, durability, and overall performance of the PV module under various weather conditions (AL-Oqla et al. 2022; AL-Oqla, Hayajneh, and Nawafleh 2023; AL-Oqla, Hayajneh, and Hoque 2023b; Alaaeddin et al. 2019a). Such composite sheets were found very suitable and potential for the PV panels as they demonstrated excellent mechanical, thermal, optical, and physical characteristics. Therefore, green composite back sheets could enhance the durability and thermal stability of the solar cells that inspire implementing green composites in photovoltaic applications.

Consequently, this work aims to introduce newly fabricated natural fiber composite photovoltaic back sheets to enhance their performance efficiency while reducing the cost and enhancing better environmental conservations. This was performed by means of proper design and fabrication of high-density polyethylene with all *Rhus typhina*, *Punica granatum* and *Piper nigrum* green fillers and investigating their effects on the overall output voltage of the photovoltaic panel.

2 Materials and methods

To fabricate the back sheets, *R. typhina*, *P. granatum* and *P. nigrum* fibers were collected, washed with distilled water to remove dust and other inclusions, dried and grinded to make powder. High-density polyethylene (HDPE) was collected from SABIC Company in Saudi Arabia. Each fiber with 25 wt% and 50 wt% were further prepared and mixed with the HDPE utilizing a Brabender measuring mixer. The filler contents were determined to ensure desired environmental, physical, and mechanical characteristics of the designed back sheets. The composites experienced hot and cold pressings at a maximum pressure of 12 MPa. This was carried out in three successive phases of preheating, hot pressing, and cold pressing to ensure overcoming shrinkage and maintaining dimensional stability. The obtained composites were maintained to ~1 mm thick and suitable to the PV panels. The fabricated back sheets were then directly joined to the panels using a heat gun to ensure getting rid of air bubbles between the panel and the back-sheet composites. The utilized fillers and samples of the fabricated sheets are demonstrated in Figure 1. The solar cell, and the heat gun utilizing during joining and properly accomplishing the fabrication are demonstrating in Figure 2. The experiments were carried out in Jordan at Zarqa city (Latitude 32.07°, Longitude 36.08°). The ambient temperature, solar radiation, and relative humidity variations during a sample of three successive dates in October 2021 were measured and demonstrated in Figure 3. Zarqa city in Jordan is considered as a hot arid region, thus the experiments were carried out there to enhance the validity of utilizing natural based composites as PV panel back sheets.

The output current (I) of a PV cell can be approximately represented as.

$$I = I_{sc} - I_0 (\exp (V/V_T) - 1) \quad (1)$$

where I_{sc} is the short circuit current, I_0 is the dark saturation current, and V is the operating voltage. V_T is the thermal voltage represented as.

$$V_T = KT/q \quad (2)$$

where K is the Boltzmann's constant, T is the ambient temperature in Kelvin, and q is the electron charge. It is worth noting here that factors affecting I_{sc} and I_0 include the structure of the PV cell, the physical properties of the material used, and the biasing conditions. Figure 4



Figure 1: Fillers utilized in the fabricating the PV back sheets.

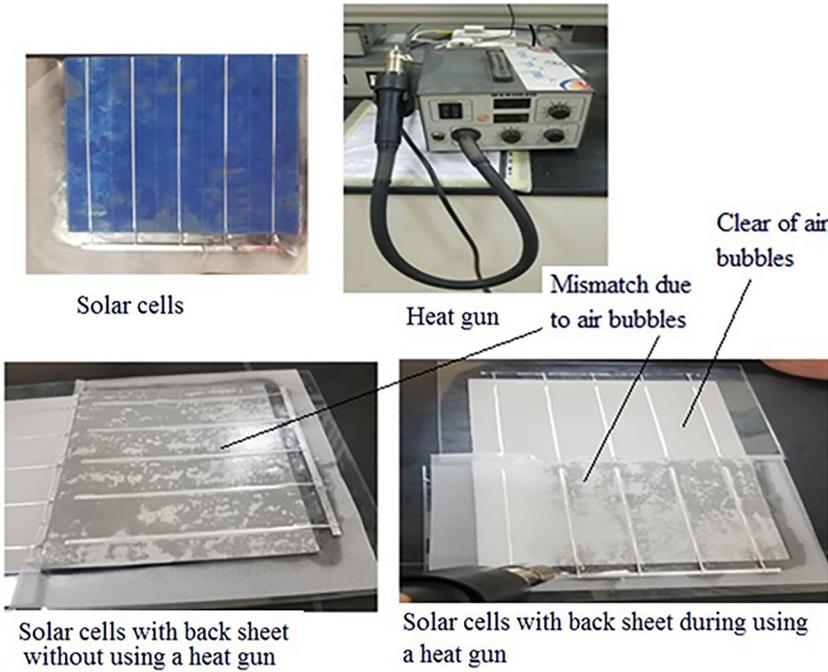


Figure 2: Solar cell and back sheet joining using the heat gun to remove air bubbles.

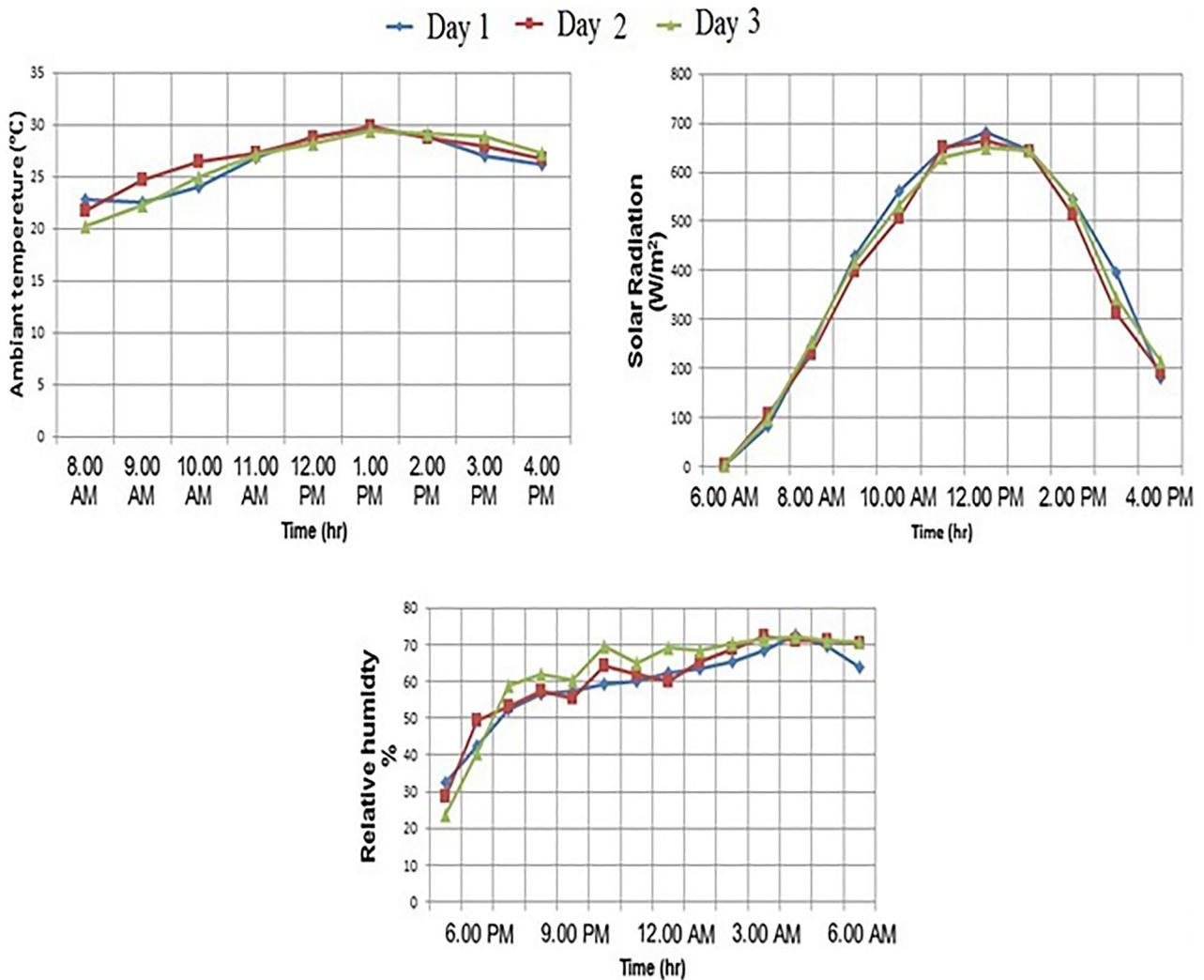


Figure 3: Ambient temperature, solar radiation, and relative humidity variations.

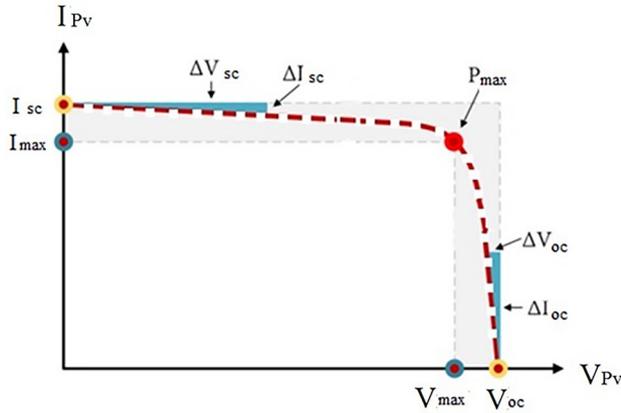


Figure 4: I–V characteristic curve of silicon PV cell (de Carvalho Neto 2021).

shows the I–V characteristic curve of a silicon PV cell (de Carvalho Neto 2021).

One important performance index of PV cell is the fill factor (FF), which is the ratio of the area of the square resulted from the maximum power point (V_{MP} , I_{MP}) to the area of the square resulted from the (V_{OC} , I_{SC}) point. That is.

$$FF = I_{MP}V_{MP}/I_{SC}V_{OC} \quad (3)$$

The FF is always less than one and can be calculated from the empirical formula (2).

$$FF = \frac{V_{OC} - \frac{kT}{q} \ln [qV_{OC}/kT + 0.72]}{V_{OC} + kT/q} \quad (4)$$

This formula shows that the FF is heavily decided by the V_{OC} . To understand the relationship between the FF and V_{OC} , Equation (4) is plotted in Figure 5 below assuming room temperature.

From Equation (4) and Figure 5 it is obvious that studying the open circuit voltage of PV cells and thus increasing it, is of major importance

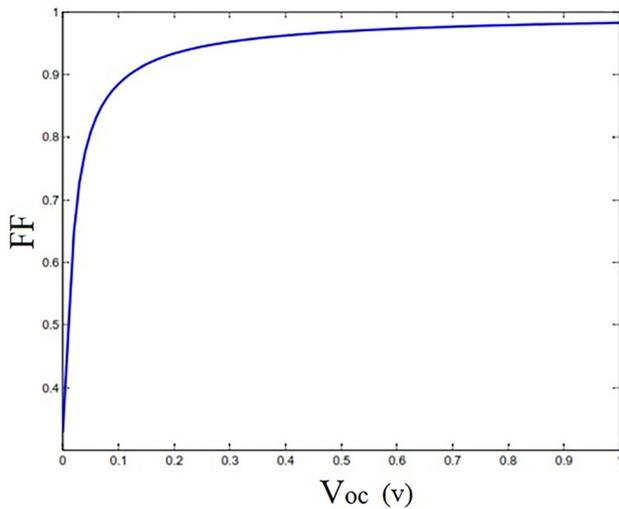


Figure 5: Relationship between FF and V_{OC} .

in enhancing their overall performance. Referring to Equation (1) and assuming open circuit condition, the open circuit voltage can be approximately represented as.

$$V_{OC} = V_T \ln (I_{SC}/I_0 + 1) \quad (5)$$

Thus, V_{OC} is clearly affected by the short circuit current and the dark saturation current and it depends upon the structure of the cell and the properties of the material used. Another key parameter influencing V_{OC} is the ambient temperature.

3 Results and discussion

The results of the fabricated green fiber based back sheets on the overall output voltages of the PV panels are discussed here. The output voltages of HDPE/fillers at 25 wt% content in addition to the original photovoltaic panel voltage are demonstrated in Figure 6, and the output voltages of HDPE/fillers at 50 wt% content are illustrated in Figure 7. It can be confirmed that the original PV voltage was 0.6 V. However, the 25 wt% HDPE/*R. typhina* composite has demonstrated about 58 % improvement on the output voltage comparable to the original PV one. It can also be demonstrated that all voltages of panels with green composite back sheets were higher than that of the original one. However, *P. granatum*/HDPE composites showed lower voltage than that of HDPE/*R. typhina* and *P. nigrum* back sheet at 25 wt% due to the intrinsic physical characteristics of the fillers themselves (Fares, AL-Oqla, and Hayajneh 2019).

On the other hand, the PV output voltages with green composite back sheets at 50 wt% filler content were not similar to that of 25 wt% filler content cases as illustrated in Figure 6. It can be seen that the original photovoltaic output voltage was better than most of the composite based back sheet PV panels except the HDPE/*P. nigrum* one. It was found that the output voltage of the PV panel with HDPE/*R. typhina*

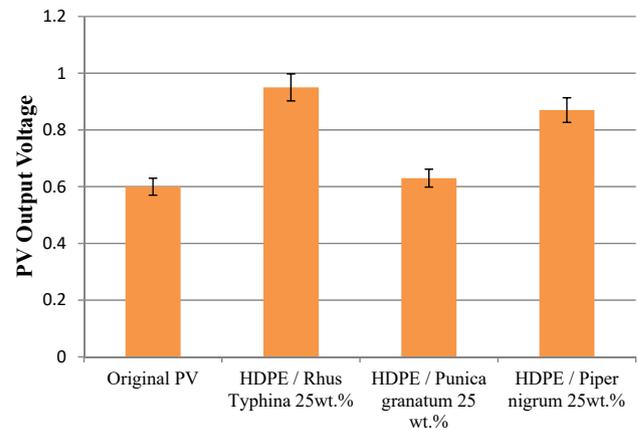


Figure 6: The output voltages of HDPE/fillers at 25 wt% content.

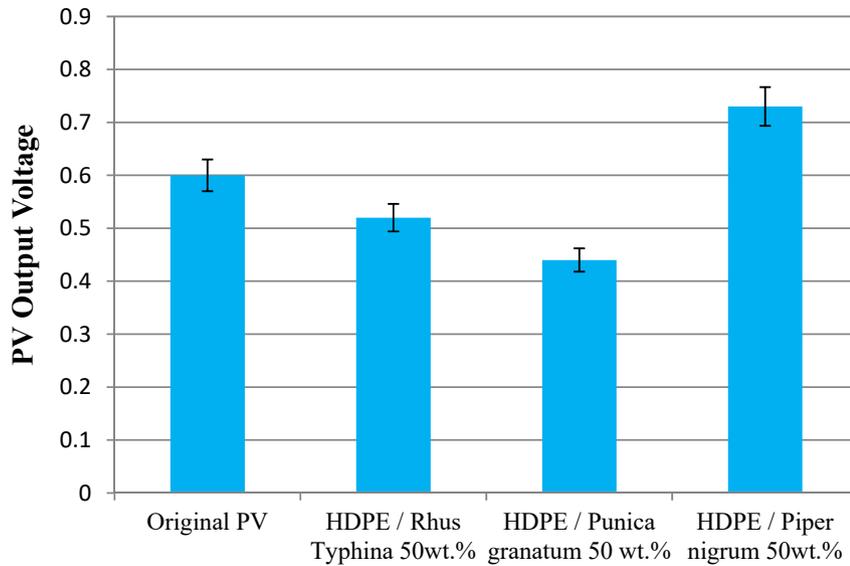


Figure 7: The output voltages of HDPE/fillers at 50 wt% content.

back sheet was reduced to only 0.52 V and the voltage of panel with HDPE/*P. granatum* back sheet was only 0.44 V.

To illustrate the improved performance in the output voltage of the fabricated back sheet composite, a microstructure effect of the fillers/polymer should be considered. It is known that materials with intermediate disorder can store considerable polarization energy (Aneli, Zaikov, and Mukbaniani 2012) and enhance proper temperature distribution inside the back sheet (Alaeddin et al. 2019a). Moreover, external stress due to either thermal or mechanical would then enhance detrapping of the local trapped charges causing a release of the stored polarization energy that can support improving the overall performance of the PV panel (AL-Oqla et al. 2015; Aneli, Zaikov, and Mukbaniani 2012). Thus, the behavior of the fabricated back sheet is related to the density and energy of traps that the material have as well as its capability of proper diffusing thermal energy results in proper temperature distribution inside the back sheet that would contribute to the overall performance of the photovoltaic cell (AL-Oqla, Omar, and Fares 2018; AL-Oqla, Sapuan, and Fares 2018; Fares, AL-Oqla, and Hayajneh 2019; Katouah and El-Metwaly 2021; Pathania and Singh 2009; Wang et al. 2021).

Furthermore, the improvement achieved in the output voltage from the utilization of the *R. typhina* filler/HDPE composite back sheets was due to its ability to enhance more stable heat distribution inside the back sheet because of the existing compound interaction between current and voltage as well as the dominant discrepancy of insolation or temperature fluctuation inside the panel (Alaeddin et al. 2019a). It is known that the panel efficiency is affected by

the ambient temperature and weather, thus the fabricated 25 wt% HDPE/*R. typhina* was capable of enhancing the temperature distribution stability inside the panel causing a reduction in radiation flow or heat growth resulting in better performance and higher output voltage. That is; the temperature of the back sheet dramatically affects the orientational polarization of the system, which in case of the HDPE/*R. typhina* has led to enhance the electrical performance of the panel due to the composite's net polarisability that depends upon factors including the structural, interfacial, and orientational polarisability (George et al. 2013). This in order has enhanced proper temperature distribution in the back sheet of the solar panel. In green fiber reinforced composites, the net polarisability that enhances the dielectrical properties is dramatically affected by both orientational and interfacial polarisability. This is occurred since the mobility of water dipoles as a result of moisture content of the natural fillers inside the composites that would be improved with temperature increase leading to enhance the orientational polarization and dielectric constant of the composite. Thus, temperature has influential role in enhancing the electrical properties that comes in favor of the green composite back sheet comparable to the original one of the PV panel.

On the other hand, a comparison of the PV output voltage with various filler contents of the backsheet composites is illustrated in Figure 8. The output voltage was about 0.95 V at 25 wt% filler content and its voltage at 50 wt % was dramatically reduced to about 0.4 V. However, the voltage of HDPE/*P. nigrum* back sheet panel was not dramatically reduced at 50 wt% filler due to better

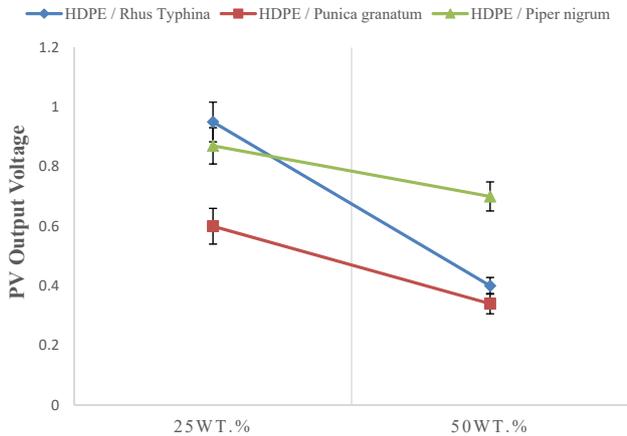


Figure 8: PV output voltage trend comparison.

interfacial bonding inside the composite comparable to HDPE/*R. typhina*, and *P. granatum* ones. This was due to the intrinsic characteristics of the fillers and their interaction with the polymer matrix that had enhanced the mechanical and chemical bonding inside the composites in case of HDPE/*R. typhina*, and *P. granatum* resulting in reducing the composite's net polarisability.

Moreover, the effect of filler content on each filler type on the output voltage PV panels is demonstrated in Figure 9. It can be seen that wide variation has been occurred in voltage of HDPE/*R. typhina* filler type when changed from 25 wt% to 50 wt% filler content. However, this gap was reduced for the HDPE/*P. granatum* and was minimal in case of HDPE/*P. nigrum* and that was due to the intrinsic filler characteristics and their interaction with polymer matrix.

The overall performance of PV panel with HDPE/filler back sheets is demonstrated in Figure 10. It is obvious that most of the considered composites have better performance

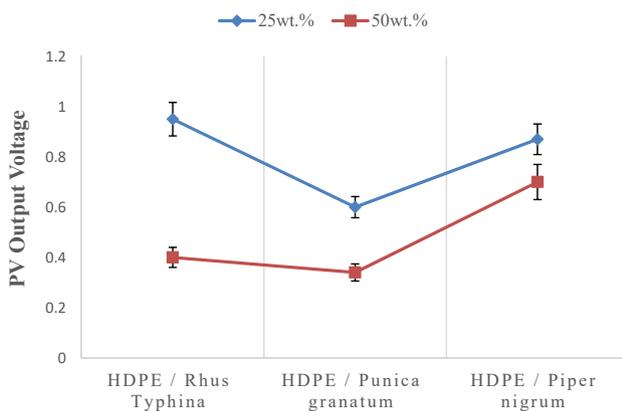


Figure 9: Voltage variation comparisons of each filler type with filler content.

on the output panel voltage comparable to the original PV panel. HDPE/*P. granatum* was found to be with the least beneficial for enhancing the output voltage at both filler content as they have almost similar or less value of original back sheet output voltage. However, HDPE/*P. nigrum* composite sheets were beneficial in enhancing the PV panel output voltage at both filler contents. Moreover, HDPE/*R. typhina* was the best in harvesting panel output voltage at 25 wt%, but the worst at 50 wt%.

4 Conclusions

This work was capable of introducing a novel green composite as a suitable visible alternative solution for the photovoltaic panel back sheets to enhance their output harvesting voltage. It can be concluded that the intermediate disorder structure of the fabricated green composites has improved the PV panel energy harvesting as it was capable to store considerable polarization energy inside. Moreover, the fabricated back sheet composites have demonstrated variations in their performance according to the filler content and type. The best enhancement of the green composite back sheets was reached to more than 50 % comparable to the original PV panel. The fabricated HDPE/natural fillers were also capable of enhancing the output voltage of the PV panel due to their potential in enhancing the temperature distribution inside, which improved the net polarisability inside the composite comparable to the original back sheet. It was found that the 25 wt% HDPE/*R. typhina* composite has demonstrated about 58 % improvement on the output voltage comparable to the original PV one. The output voltage of the green based composites on the other hand, reached about 0.95 V at 25 wt% filler content. This in order would enhance the usage of natural fiber composites in photovoltaic applications with lower cost and more environmentally friendly manner to encourage more sustainable solutions of energy harvesting for the near future.

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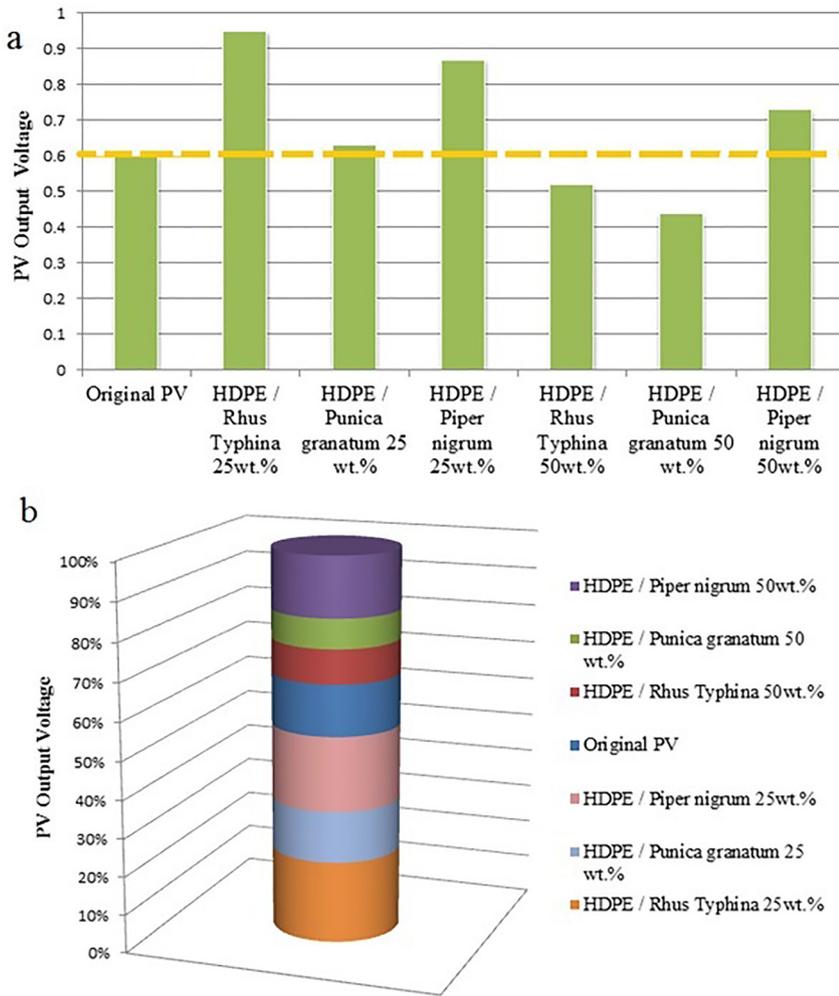


Figure 10: Performance of PV composite back sheets, (a) all composites relative to the original back sheet voltage, (b) percentage of each back-sheet voltage.

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