

Research Article

Kyrillos K. Selim*, Saeid Khalid, Dina El-nawam, Mohamed Abdel Fattah and Demyana A. Saleeb

Solar energy harvesting-based built-in backpack charger

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Abstract: Developing renewable energy sources has gained considerable attention recently. Solar energy is the fastest-growing alternative renewable energy source. A solar energy harvesting-based built-in backpack charger is introduced here. The proposed system aims to utilise the surrounding solar energy and overcome the power limitations of batteries installed in mobile phones in cases where power sockets are unavailable. A 6 cm × 6 cm solar module is employed. Additionally, current, voltage, and power were measured under the two scenarios; the first scenario is when the electrical load is 100 Ω, and the second scenario is when the load is a power bank. The maximum harvested power noticed in the first scenario of the resistive load was 140 mW by the proposed system in the southeast direction from 10:30 a.m. to 4:30 p.m. Moreover, the top-generated output voltage and current in this scenario were 3.6 V and 36 mA. On the other hand, 55 mW was the top value for the second scenario of the power bank as a load in the flat direction with the highest generated output voltage and current of 4.1 V and 13 mA, whereas 4.27 V was the highest generated voltage in this scenario in the west direction.

Keywords: charger; mobile phone; power bank; photovoltaic (PV); solar energy

1 Introduction

Due to an increase in industrial activity and global population growth, the world's energy consumption has been rising every day. Fossil fuels, which are now widely employed as the primary energy source to supply this demand have limited supplies. Additionally, widespread usage of these types of energy will have unfavourable and hazardous influences on the environment and global climate by 2050 because of their high carbon dioxide emission levels. If this continues long enough, the supply of fossil fuels will run out. Consequently, the global ambient temperature is expected to increase by approximately two °C by 2050 due to the pollutant emissions caused by non-renewable energy resources. For this reason, developing renewable energy has received a lot of attention lately in order to solve these issues; Quick action must be taken to reduce adverse environmental effects and investigate cost-effective and efficient renewable energy alternatives. Thus, the last century saw a substantial diversification in fossil fuel usage, from 94 % of overall energy consumption in 1990 to 79.6 % in 2015, primarily phased out by renewables [1, 2, 5].

Solar energy is the fastest-growing alternative renewable energy source since it is the most abundant of all renewable energy sources. On average, around 10,000 TW of solar energy strikes the earth's surface daily, while, as of 2015, only 17.4 TW of solar energy were claimed to be used [3]. The potential of solar energy to solve present and future global energy needs can always be emphasised when comparing the hourly solar energy obtained with the present use. Considering the enormous energy usage and demand on a worldwide scale, It becomes necessary to unlock solar energy's full potential. Some nations, such as Germany, have switched to solar energy for about 38 % of their energy demands, intending to replace nuclear with solar by 2050. However, developing countries are yet to get their feet wet with solar technology. A solar cell uses the photoelectric effect, which is present in some semiconductor materials like silicon and selenium, to convert the energy contained in sunlight's photons into electric current. Since the efficiency of PV panels depends on the solar parameters of PV panel properties (temperature, insolation, sunlight's spectrum properties, etc.), successful

***Corresponding author: Kyrillos K. Selim**, Electronics Technology Department, Faculty of Technology and Education, Helwan University, Cairo, Egypt, E-mail: Kyrillos.k.selim@techedu.helwan.edu.eg

Saeid Khalid, Air Conditioning Technology Department, Faculty of Technology and Education, Helwan University, Cairo, Egypt, E-mail: dfghkllkhkhgfd@gmail.com

Dina El-nawam and Mohamed Abdel Fattah, Electronics Technology Department, Faculty of Technology and Education, Helwan University, Cairo, Egypt, E-mail: dina.ainwampost@techedu.helwan.edu.eg (D. El-nawam), maiahmed@techedu.helwan.edu.eg (M.A. Fattah)

Demyana A. Saleeb, Faculty of Engineering, Kafrelsheikh University, Kafrelsheikh, Egypt, E-mail: demyanasaleeb@eng.kfs.edu.eg

solar power applications in a given location are influenced by the region's solar potential. Even though solar energy is available to all countries, the Middle East boasts the most solar resources on the world [3, 10].

Photovoltaic systems are generally categorised into two main groups: grid-connected and stand-alone systems. Grid-connected systems are those that are connected to the public grid. On the other hand, stand-alone systems are not connected to the grid since the energy produced by the system is usually matched with the energy required by the load. Stand-alone systems are typically supported by energy storage systems, such as rechargeable batteries, to provide electricity without sunlight.

In the building sector, small photovoltaic power systems are frequently utilised for producing energy for appliances such as water heaters, TVs, refrigerators, and lighting have a solar energy system that is sufficient to operate all house appliances. Other typical applications for standalone systems are solar-powered vehicles, boats, remote cabins, houses, parking ticket dispenser machines, traffic lights, applications in gardening and landscaping, pump systems and desalination, and systems for microwave communication networks. Since rural regions lack connection to the public grid and the cost of connecting and transmitting power to them is high, standalone solutions appear to be required. Standalone systems rely on the electricity produced from photovoltaic panels [4, 10]. Moreover, solar energy can power and recharge portable and wearable devices to make them self-powered devices [8, 9, 12, 17], especially in applications such as mobile phones [13, 14, 15].

This study introduces a solar energy harvesting-based built-in backpack charger. The proposed system aims to utilise the surrounding solar energy and overcome the power limits of mobile phone batteries, especially when power sockets are unavailable. The remainder of this paper is organised as follows: Section 2 introduces the solar cell model. The corresponding experimental setup is presented in Section 3. Experimental results and analysis are provided in Section 4. Finally, the study is concluded in Section 5.

2 Solar cell model

Figure 1 shows a simple diode model of a solar cell in which a current I_L represents the amount of electrical energy (based on the created current) produced by a photovoltaic panel (PV) cell that is proportional to solar irradiation, and I is the

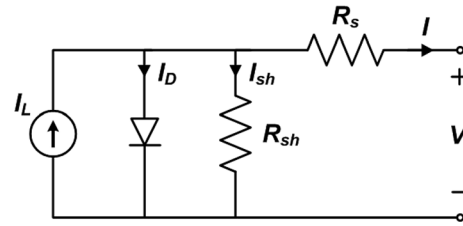


Figure 1: A simple diode model of a solar cell.

output current. Moreover, a shunt resistance (R_{sh}) represents the leakage current in the figure. The internal resistance is characterized by a series resistance (R_s). The mathematical formulas that describe the PV cell are given as follows:

$$I = I_L - I_d - \frac{V_d}{R_{sh}} \quad (1)$$

The expressions for photocurrent I_L and diode current I_d are expressed as:

$$I_L = (I_{sc} + K_1(T - T_{ref}))\lambda \quad (2)$$

since I_{sc} is the cell's short circuit current at test conditions (1000 W/m^2 and 25°C), K_1 is the short circuit current coefficient, T_{ref} is the cell reference temperature, and λ is the solar irradiance in unit W/m^2 .

$$I_d = I_o \left(e^{\frac{V_d}{V_T A}} - 1 \right) \quad (3)$$

where I_o is the cell saturation current, and V_d is the voltage drop between the anode and cathode of the diode. V_T is the PV cell thermal voltage, which may be calculated as KT/q , with K is the Boltzmann constant that is equal to 1.38×10^{-23} , T is the temperature of the PV cell in Kelvin, q is the electron charge ($1.6 \times 10^{-19} \text{ C}$), and A is the diode ideality factor, which depends upon the material doping [6, 7, 11, 16].

3 Methods

A $6 \text{ cm} \times 6 \text{ cm}$ PV solar module was used in this design. The small dimensions of the PV module were adopted to fit the backpack size. The standard generated voltage by the PV module is 4.5 V , which is close to the mobile phone's charger output voltage. The PV module output can be connected directly to the mobile phone or via the power bank. An LED as an indicator is connected in series with a push button via the power bank output, as shown in Figure 2. The PV solar module was mounted on the back of the backpack, whereas the power bank, mobile phone, and one LED connected to a push button were mounted inside the backpack, as illustrated in Figure 3.

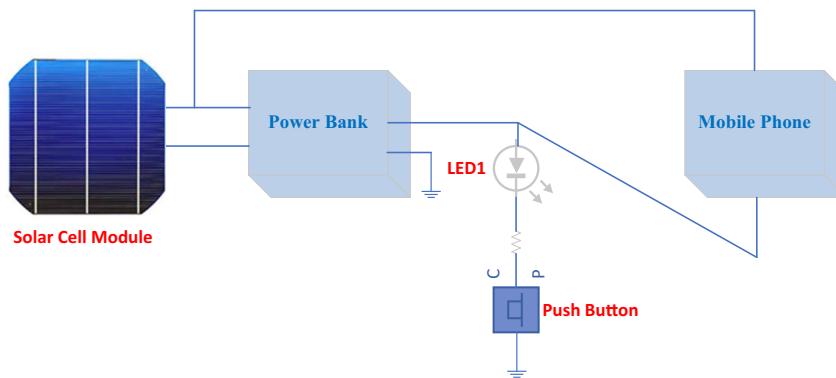


Figure 2: A block diagram for the proposed solar energy harvesting-based built-in backpack charger.

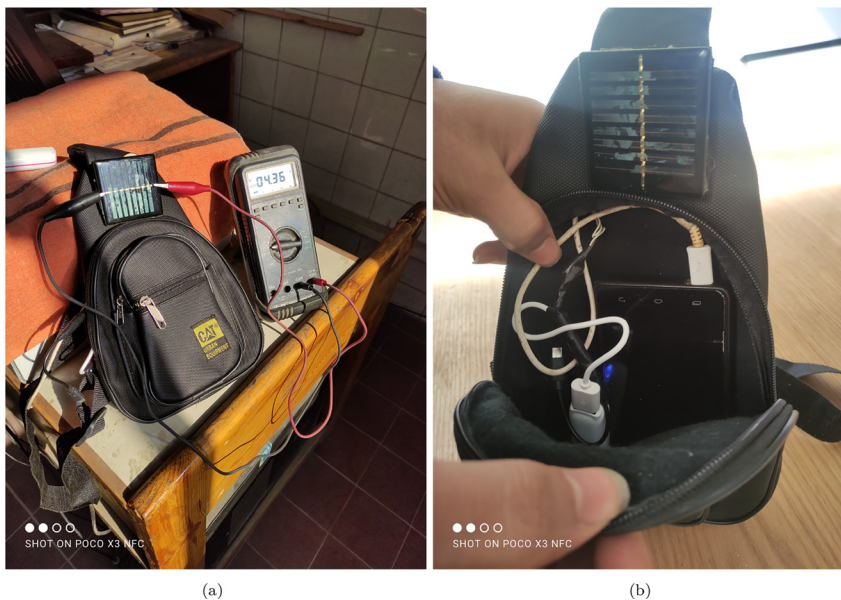


Figure 3: Experimental setup of the proposed system.

The proposed system was tested under different conditions and parameters, such as various hours of the day, load type, and different motion directions, as a function of the measured current, the generated voltage, and the harvested power, and the test period extended from 10:30 a.m. to 4:30 p.m. with a one-hour step. Moreover, the load tested was either a $100\ \Omega$ resistive load or a power bank. Measurements were taken during motion in the directions east, west, south, and north. Current, generated voltage, and harvested power were measured. The used power bank brand TEVDY has a 2600 mA h charging capacity.

4 Results and discussion

Figure 4 shows the measured output voltage and current when there is a resistive load. The measurements were

taken between 10:30 a.m. and 4:30 p.m. Five cases were considered: the solar cell looking (a) east, (b) west, (c) southeast, (d) flat, and (e) north. Looking east between 10:30 a.m. and 12:30 p.m., where the sun's rays are normal to the solar cell, gives high output. Looking west between 2:30 p.m. and 4:30 p.m., the sun's rays are normal for the solar cell, giving it a high output. When the solar cell is flat (looking upwards) in the period 12:30 p.m.–2:30 p.m., the sun's rays are normal to the cell, and the output is high. Looking southeast, the output is high in the morning and decreases with time until it is very low at 4:30 o'clock. Looking north, the sun's rays are oblique to the cell; therefore, the output is low all the time. The results are summarised in Table 1 below.

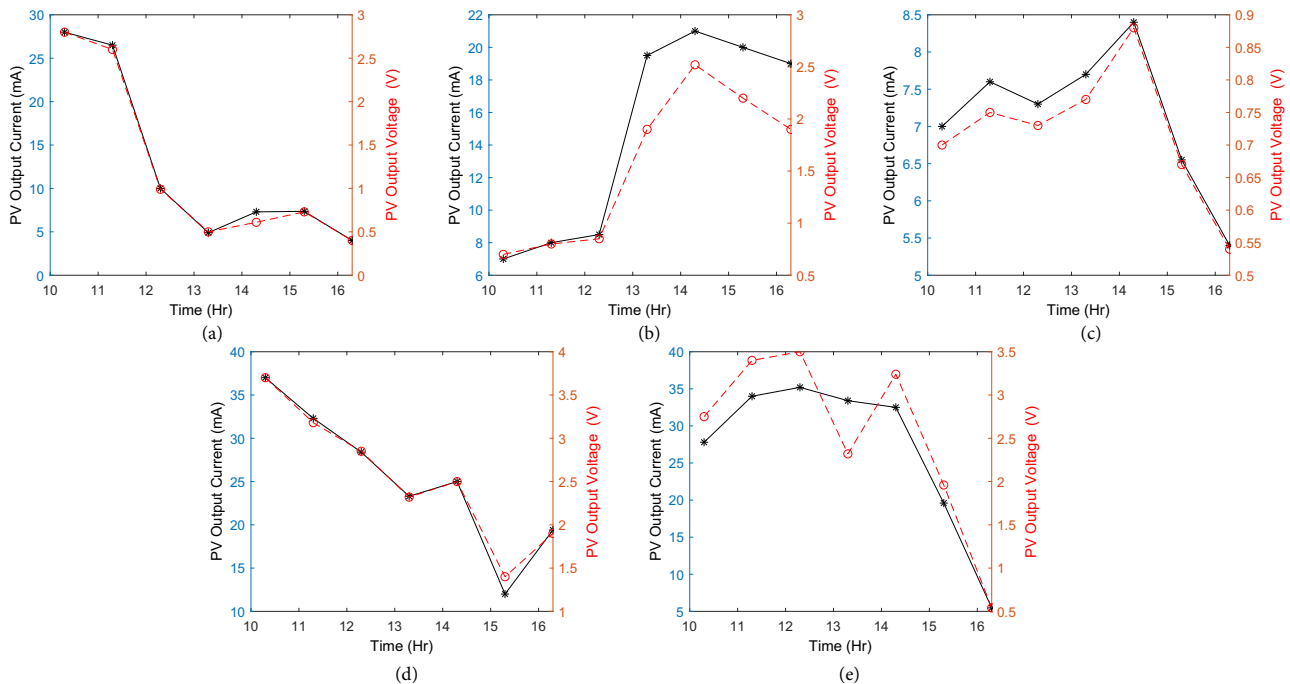


Figure 4: The measured output voltage and current for the resistive load of 100Ω at different motion directions (a) east (b) west (c) southeast (d) flat (e) north.

Table 1: The measured output voltage and current for the resistive load of 100Ω at different motion directions.

Direction	Voltage (V)	Current (mA)	Power (mW)	Time
East	2.8	27	80	10–12
West	2.5	21	55	2–4
Southeast	3.6–1.5	36–12	140–20	10–4
Flat	3.5	35	120	10–2
North	0.7–0.9	7–8.5	7.5	10–2

Figure 5 shows the measured output voltage and power for the resistive load of 100Ω at different motion directions (a) east, (b) west, (c) southeast, (d) flat, and (e) north. The power variation with time follows the same trend as that of voltage.

Figure 6 shows the measured voltage and current for the five cases when the load is a power bank. Table 2 summarises the results.

Compared to the case of a 100Ω load (Table 1), the output voltage is more or less constant at 4 V, but the current is reduced; this is due to the high input impedance of the power bank.

Figure 7 shows the measured voltage for the five cases and power when the load is a power bank. The variation of power with time follows the same trend as that of voltage.

5 Conclusions

When fixed to a backpack, a $6\text{ cm} \times 6\text{ cm}$ solar module was used to generate electric power. Voltage, current, and energy were measured from 10:30 a.m. until 4:30 p.m. Five cases were considered when the module was looking (a) east, (b) west, (c) southeast, (d) flat, and (e) north. The results showed that the output was high when the sun's rays were typical for the module. The measurements were taken when the load was 100Ω , and the electrical load was a power bank. The output voltage in the case of the power bank was nearly constant at about 4 V, but the current was reduced compared to the scenario of a 100Ω load. This was because of the high input impedance of the power bank.

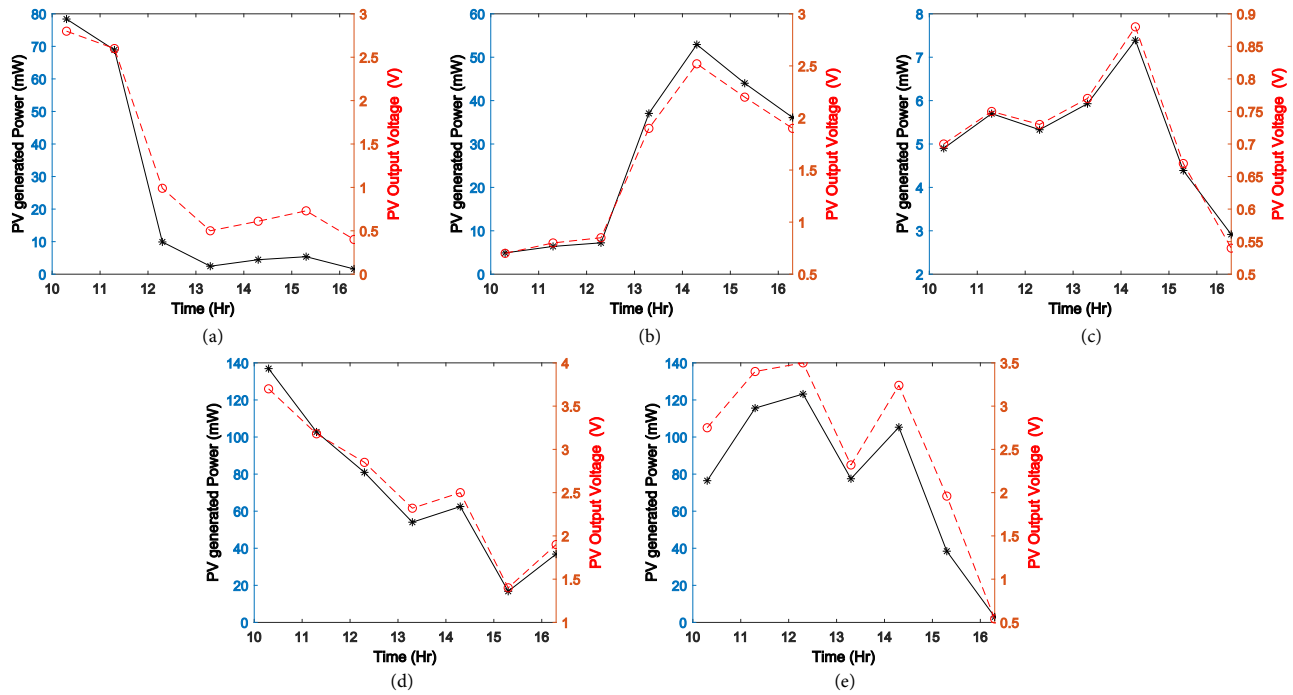


Figure 5: The measured generated voltage and power for the resistive load of 100Ω at different directions (a) east (b) west (c) southeast (d) flat (e) north.

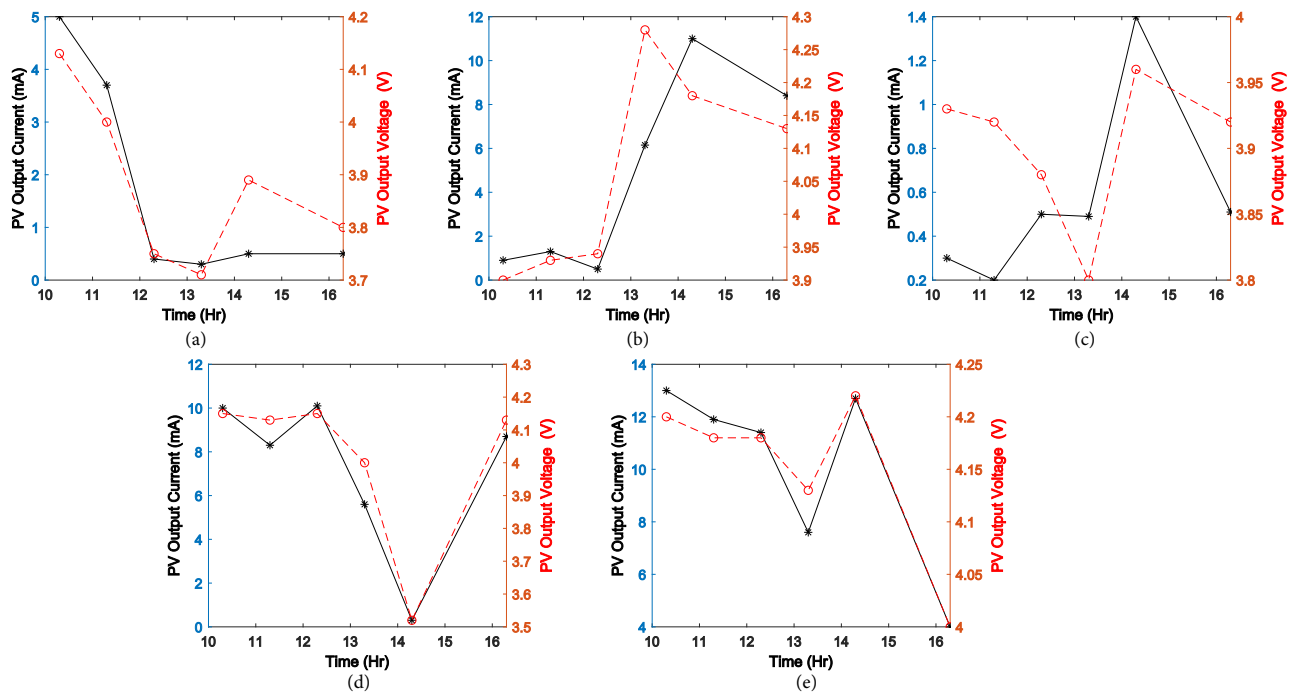
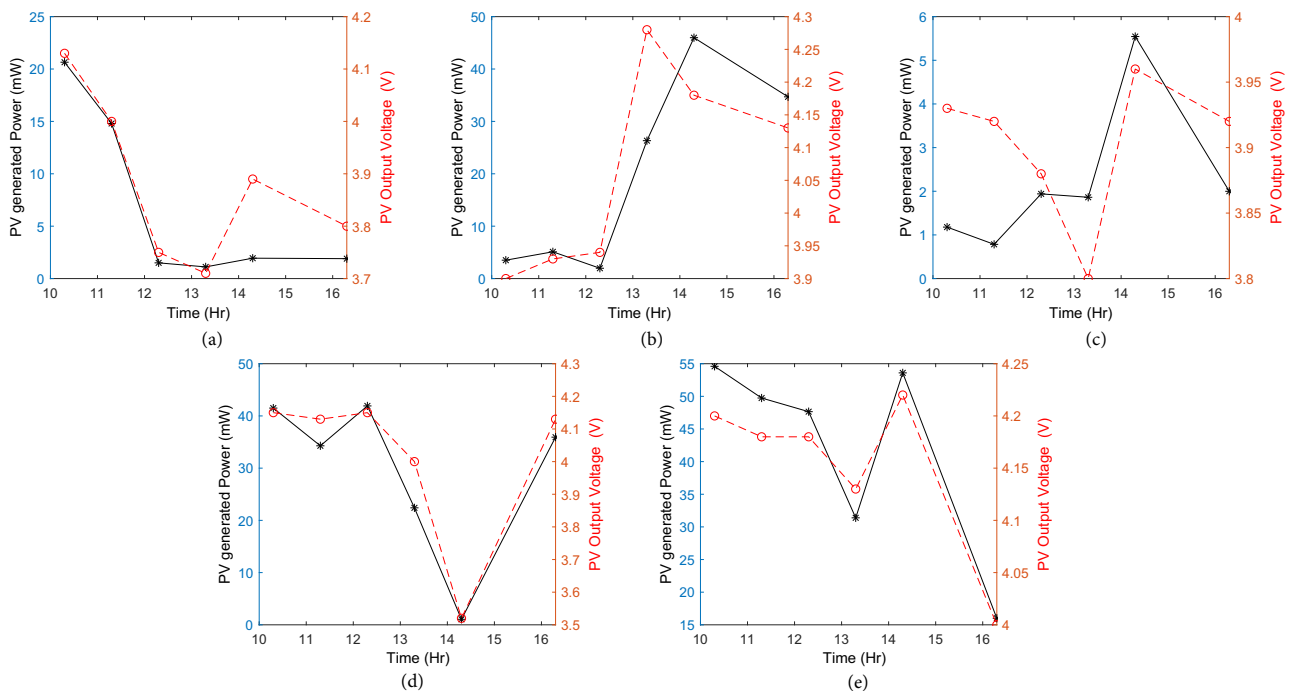


Figure 6: The measured output voltage and current for the power bank as a load at different directions (a) east (b) west (c) southeast (d) flat (e) north.

Table 2: The measured output voltage and current at different motion directions when the load is a power bank.

Direction	Voltage (V)	Current (mA)	Power (mW)	Time
East	4.1	5	22	10–12
West	4.27	11	43	2–4
Southeast	4.1	10	40	10–12
Flat	4.1	13	55	10–2
North	4	1.4	5.5	10–2

**Figure 7:** The measured output voltage and power for the power bank as a load at different directions (a) east (b) west (c) southeast (d) flat (e) north.

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References

- [1] M. H. Ahmadi, M. Ghazvini, M. Sadeghzadeh, M. A. Nazari, and M. Ghalandari, "Utilization of Hybrid Nanofluids in Solar Energy Applications: A Review," *Nano-Struct. Nano-Objects*, vol. 20, p. 100386, 2019.
- [2] O. A. Al-Shahri, F. B. Ismail, M. A. Hannan, M. H. Lipu, A. Q. Al-Shetwi, R. A. Begum, and E. Soujeri, "Solar Photovoltaic Energy Optimization Methods, Challenges and Issues: A Comprehensive Review," *J. Clean. Prod.*, vol. 284, p. 125465, 2021.
- [3] F. K. Alhousni, F. B. Ismail, P. C. Okonkwo, H. Mohamed, B. O. Okonkwo, and O. A. Al-Shahri, "A Review of PV Solar Energy System Operations and Applications in Dhofar Oman," *AIMS Energy*, vol. 10, no. 4, pp. 858–84, 2022.
- [4] Alweheshi, S., A. Abdelali, Z. Rajab, A. Khalil, and F. Mohamed. 2019. "Photovoltaic Solar Energy Applications in Libya: a Survey." In *2019 10th International Renewable Energy Congress (IREC)*, 1–6. Sousse, Tunisia: IEEE.
- [5] L. Das, F. Rubbi, K. Habib, N. Asfatti, R. Saidur, B. B. Saha, and T. Alqahtani, "State-of-the-art Ionic Liquid & Ionanofluids Incorporated with Advanced Nanomaterials for Solar Energy Applications," *J. Mol. Liq.*, vol. 336, p. 116563, 2021.
- [6] Dey, B. K., I. Khan, N. Mandal, and A. Bhattacharjee. 2016. "Mathematical Modelling and Characteristic Analysis of Solar PV Cell." In *2016 IEEE 7th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)*, 1–5. Vancouver, BC, Canada: IEEE.
- [7] M. A. Hasan and S. K. Parida, "An Overview of Solar Photovoltaic Panel Modeling Based on Analytical and Experimental Viewpoint," *Renew. Sustain. Energy Rev.*, vol. 60, pp. 75–83, 2016.

- [8] K. A. Kim, F. S. Bagci, and K. L. Dorsey, "Design Considerations for Photovoltaic Energy Harvesting in Wearable Devices," *Sci. Rep.*, vol. 12, no. 1, p. 18143, 2022.
- [9] Y. Liu, S. Zhang, S. Beirne, K. Kim, C. Qin, Y. Du, and J. Chen, "Wearable Photo-Thermo-Electrochemical Cells (PTECs) Harvesting Solar Energy," *Macromol. Rapid Commun.*, vol. 43, no. 6, p. 2200001, 2022.
- [10] S. Mekhilef, R. Saidur, and A. Safari, "A Review on Solar Energy Use in Industries," *Renew. Sustain. Energy Rev.*, vol. 15, no. 4, pp. 1777–90, 2011.
- [11] X. H. Nguyen and M. P. Nguyen, "Mathematical Modeling of Photovoltaic Cell/module/arrays with Tags in Matlab/Simulink," *Environ. Syst. Res.*, vol. 4, pp. 1–13, 2015.
- [12] A. Pérez-Montoro, M. García-Valderas, E. Olías-Ruiz, and C. López-Ongil, "Solar Energy Harvesting to Improve Capabilities of Wearable Devices," *Sensors*, vol. 22, no. 10, p. 3950, 2022.
- [13] C. Schuss and T. Rahkonen, "Solar Energy Harvesting Strategies for Portable Devices Such as Mobile Phones," in *14th Conference of Open Innovation Association FRUCT*, Espoo, Finland, IEEE, 2013, pp. 132–9.
- [14] A. V. Sutar, V. Dighe, P. Karavkar, P. Mhatre, and V. Tandel, "Solar Energy Based Mobile Charger Using Inductive Coupling Transmission," in *2020 4th International Conference on Intelligent Computing and Control Systems (ICICCS)*, Madurai, India, IEEE, 2020, pp. 995–1000.
- [15] C. Schuss, B. Eichberger, and T. Rahkonen, "Design Specifications and Guidelines for Efficient Solar Chargers of Mobile Phones," in *2014 IEEE 11th International Multi-Conference on Systems, Signals & Devices (SSD14)*, Barcelona, Spain, IEEE, 2014, pp. 1–5.
- [16] C. Sharma and A. Jain, "Solar Panel Mathematical Modelling Using Simulink," *Int. J. Eng. Res. Appl.*, vol. 4, no. 5, pp. 67–72, 2014.
- [17] Yu, B. Y., Z. H. Wang, L. Ju, C. Zhang, Z. G. Liu, L. Tao, and W. B. Lu, "Flexible and Wearable Hybrid RF and Solar Energy Harvesting System," *IEEE Trans. Antenn. Propag.*, vol. 70, no. 3, pp. 2223–2233, 2021.