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Experimental Study on the Effect of PV Tilt Angle on Mini Solar Power Bank Performance

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ABSTRACT

Solar panels are devices designed to convert solar energy into electrical energy through the photovoltaic (PV) effect, offering a sustainable solution for portable power needs. This study investigates the effect of solar panel tilt angles on the performance of a mini solar cell power bank in Institut Teknologi Sumatera, South Lampung, Indonesia. A 2.5 W monocrystalline silicon panel was tested at tilt angles of 15°, 30°, and 45°. Data on current, voltage, temperature, and power were collected at 30-minute intervals from 09:00 to 15:00 WIB over three separate clear-sky measurement days. The results indicate that the 15° tilt angle produced the highest average current (38.39 mA), voltage (4.08 V), and power (0.162 W). The estimated charging time for a 3000 mAh battery was 93.77 hours (15°), 116.13 hours (30°), and 138.04 hours (45°). The 15° tilt is the optimal configuration for portable solar power banks in this tropical region.

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INTRODUCTION

Solar energy is an abundant resource that can be efficiently utilized to produce clean and sustainable electrical energy. According to the Global Solar Atlas, the South Lampung region in Indonesia possesses excellent potential for solar energy utilization. Data such as Direct Normal Irradiation (DNI) reaching 970.9 kWh/m² per year and Global Horizontal Irradiation (GHI) reaching 1726.9 kWh/m² per year illustrate the substantial amount of solar radiation reaching the surface in this area (Global Solar Atlas, 2023). Furthermore, the high average air temperature of 26.3°C in the region contributes to the dynamic performance of solar panels. By harnessing this potential, portable and small-scale solar applications, such as mini solar power banks, can provide reliable off-grid charging solutions while reducing dependence on fossil fuels (Marisa et al., 2025).

The performance of a photovoltaic (PV) system is highly dependent on the amount of solar irradiance it receives, which is directly influenced by the tilt angle and orientation of the solar panels relative to the sun's position. When solar radiation enters the Earth's atmosphere, it undergoes attenuation through scattering and absorption, altering the quality and quantity of the radiation spectrum (Rahardjo & Fitriana, 2005). To maximize the capture of direct and diffuse radiation, the PV panel must be oriented optimally. Various studies have shown that adjusting the tilt angle according to the geographical latitude significantly improves energy yield. Yadav & Chandel (2013) reviewed tilt angle optimization for PV systems globally and confirmed that latitude-based angles provide the best annual performance for fixed installations. Gharakhani Siraki & Pillay (2012) reported that tilt angle optimization in tropical regions can improve annual energy yield by 5–15% compared to horizontal installation. Specifically in Indonesian tropical conditions, the optimal tilt angle typically ranges between 10° and 15° to maximize irradiance while allowing for natural self-cleaning by rain (Fitri Dwi Kartikasari et al., 2023; Saepulloh et al., 2025).

Even though many researchers have worked on optimizing large-scale solar power plants, very few researchers have reported on the specific tilt angle optimization for micro-scale applications like portable solar power banks. Hidayanti (2020) evaluated portable monocrystalline solar chargers with a 1350 mAh battery but did not compare the impact of varying tilt angles. Marisa et al., (2025) examined mini solar panels for power banks but focused on panel size selection rather than tilt angle optimization. No prior study has provided precise empirical measurement of current, voltage, and temperature fluctuations of mini PV panels at different angles throughout the day in a South Sumatran tropical climate.

The novelty and primary contribution of this study lies in: (1) the experimental comparison of three tilt angles (15°, 30°, 45°) for a 2.5 W monocrystalline PV panel under actual tropical outdoor conditions in South Lampung, Indonesia; (2) the derivation of a full-day electrical output profile including current, voltage, power, and panel temperature; and (3) the quantitative estimation of battery charging time as a practical performance metric for portable off-grid applications. This data is very useful in designing more efficient, portable renewable energy devices for emergency use in equatorial regions.

METHOD

This research employed an experimental method to evaluate the performance of a mini solar cell power bank by varying the tilt angle of the PV panel. The experiment was conducted in Institut Teknologi Sumatera, South Lampung, Indonesia. The independent variable was the tilt angle of the solar panel, set at 15°, 30°, and 45°. The dependent variables measured were the output current (mA), voltage (V), panel temperature (°C), and the calculated power (W) and charging time.

In this study, solar irradiance was not measured directly using a pyranometer; instead, it was monitored through light intensity measurements (Lux) as a representation of the brightness level at the testing site. It is important to note that this study did not include uncertainty analysis or statistical analysis in the data processing. Furthermore, practical losses, such as shading effects, dust accumulation, and electrical wiring resistance, were not taken into account, focusing the observation purely on the measured output parameters at each specified angle.

The materials used included a 2.5 Watt monocrystalline silicon solar panel (dimensions: 110 x 70 mm) with a rated voltage of 5 V and a rated current of 500 mA. A mobile phone with a 3.7 VDC, 3000 mAh lithium-ion battery was used as the load. The circuit design integrated the solar panel, a blocking diode to prevent reverse current, a charging module (TP4056 module), and the battery, as illustrated in the schematic diagram (Figure 1).

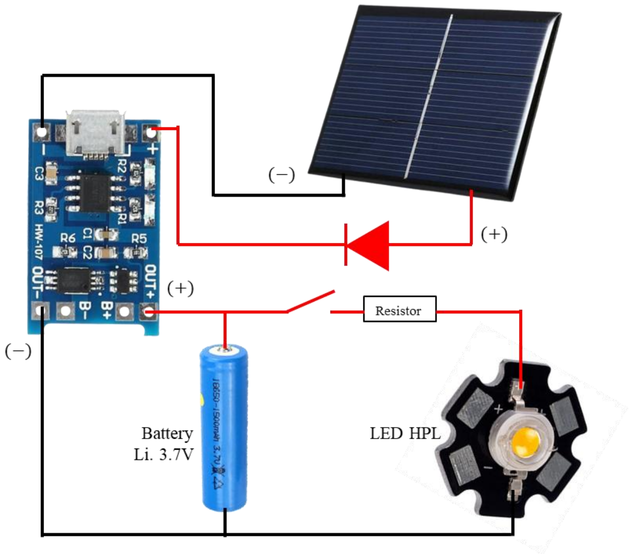

Figure 1. Schematic Diagram of the Mini Solar Power Bank Circuit

Data collection was carried out outdoors with the solar panel facing upwards at a height of 1 meter from the ground to avoid shading. Measurements were taken at 30-minute intervals from 09:00 to 15:00. To assess reproducibility, each tilt angle configuration was tested over three separate clear-sky days. Clear-sky conditions were verified by visual inspection and confirmed by consistent light intensity readings (LCD Digital Lux Meter AS803). A digital multimeter (Mastech MS8268 with accuracy ±0.5% DC voltage/current) was used to measure the current and voltage, while a digital thermometer (Non-contact infrared type with accuracy ±1°C) recorded the surface temperature of the PV panel. The power output was calculated using the standard electrical power as follows:

$$P = V \times I \tag{1}$$

Where:

P : Power $(Watt)$

V : Voltage (V)

I : Current (A)

While the total charging time was estimated by following equation (Hidayanti, 2020):

$$Charging\ Time\ (h) = \frac{Battery\ capacity}{charging\ current} \times 1.2 \tag{2}$$

Where battery capacity = 3000 mAh and 1.2 accounts for charging inefficiency .

RESULTS AND DISCUSSION

The experimental results demonstrate the dynamic relationship between the time of day, the tilt angle of the solar panel, and the resulting electrical output. The complete raw datasets for all three tilt angle configurations are presented in Tables 1–3 below.

Table 1 Measurement data – PV tilt angle 15°.

No	Light Intensity (Lux)	Time	Current (mA)	Voltage (V)	Temp. (°C)	Power (W)
1	36,567	09:00–09:30	22.9	3.6	28	0.0824
2	37,360	09:30–10:00	36.7	3.6	29	0.1321
3	38,288	10:00–10:30	38.4	3.7	29	0.1421
4	41,321	10:30–11:00	41.1	3.9	30	0.1603
5	42,467	11:00–12:00	50.8	4.31	31	0.2189
6	43,111	12:00–12:30	78.2	5.21	31	0.4074
7	45,023	12:30–13:00	42.2	4.2	30.5	0.1772
8	46,220	13:00–13:30	33.4	4.1	30	0.1369
9	45,649	13:30–14:00	23.9	4.1	29.5	0.0980
10	44,267	14:00–15:00	16.3	4.1	29	0.0668

Table 2. Measurement data – PV tilt angle 30°

No	Light Intensity (Lux)	Time	Current (mA)	Voltage (V)	Temp. (°C)	Power (W)
1	36,455	09:00–09:30	21.5	3.5	27	0.0753
2	36,309	09:30–10:00	27.2	3.5	28	0.0952
3	36,188	10:00–10:30	27.5	3.72	29	0.1023
4	37,221	10:30–11:00	37.5	3.86	29	0.1447
5	39,060	11:00–12:00	39.1	4.16	31	0.1627
6	42,151	12:00–12:30	48.5	4.98	31	0.2415
7	43,076	12:30–13:00	42.3	3.9	30	0.1650
8	44,231	13:00–13:30	32.6	3.53	30	0.1151
9	45,608	13:30–14:00	21.1	3.48	29	0.0734
10	42,252	14:00–15:00	12.7	3.11	29	0.0395

Table 3. Measurement data – PV tilt angle 45°.

No	Light Intensity (Lux)	Time	Current (mA)	Voltage (V)	Temp. (°C)	Power (W)
1	32,002	09:00–09:30	19.2	3.2	27.5	0.0614
2	36,344	09:30–10:00	23.2	3.21	28	0.0745
3	37,177	10:00–10:30	24.7	3.45	29	0.0852
4	40,221	10:30–11:00	24.3	3.5	30	0.0851
5	41,060	11:00–12:00	26.3	4.0	30	0.1052
6	42,122	12:00–12:30	36.8	4.8	31	0.1766
7	44,005	12:30–13:00	43.9	4.05	30	0.1778
8	42,118	13:00–13:30	30.1	3.7	29.5	0.1114
9	43,057	13:30–14:00	22.0	3.5	29	0.0770
10	41,147	14:00–15:00	10.3	3.2	28	0.0330

Current and Voltage Analysis

Figure 2 illustrates the fluctuation of current over time for the three tilt angles. The 15° tilt angle consistently produced the highest current, peaking at 78.2 mA between 12:30 and 13:00. The average current for 15° was 38.39 mA, compared to 31.00 mA for 30° and 26.08 mA for 45°. This represents a performance improvement of approximately 23.8% for 15° over 30°, and 47.2% over 45°.

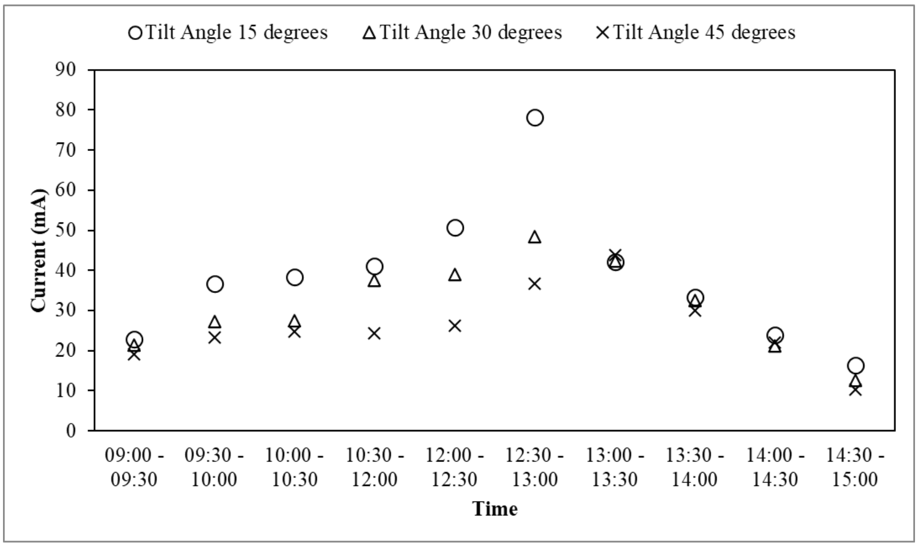

Figure 2. Effect of Tilt Angle on Output Current over Time

Figure 3 illustrates the voltage measurements followed a comparable trend. The maximum voltage was recorded between 11:00 and 13:00 when the sun was nearly perpendicular to the panels. The 15° tilt yielded a maximum voltage of 5.21 V and an average of 4.08 V, while the 30° and 45° angles produced averages of 3.77 V and 3.66 V, respectively. The relatively modest voltage differences compared to current differences are consistent with crystalline silicon PV behavior, where short-circuit current is nearly proportional to irradiance while open-circuit voltage varies logarithmically (Green, 2001) These findings align with the equatorial geography of Indonesia, where a lower tilt angle captures the maximum DNI during midday hours (Suparwoko & Qamar, 2022).

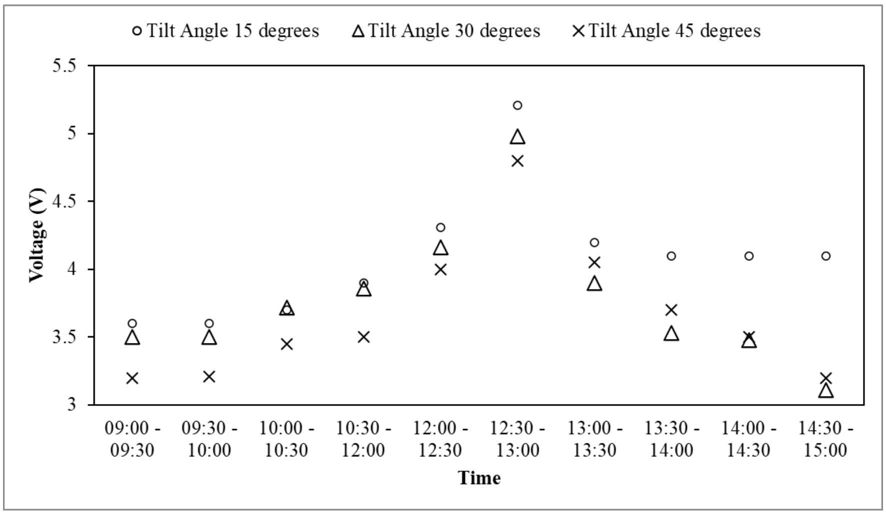

Figure 3. Effect of Tilt Angle on Output Voltage over Time

Temperature and Power Output

Figure 4 illustrates the panel surface temperatures increased steadily from morning, peaking at 31°C around 12:00–13:00 for all configurations, then decreasing in the afternoon. Average temperatures were 29.7°C (15°), 29.3°C (30°), and 29.2°C (45°). The temperature coefficient for monocrystalline silicon is typically −0.45%/°C for maximum power (Green, 2001). The 15° panel recorded slightly higher temperatures (29.7°C vs. 29.2°C for 45°), indicating marginally greater thermal derating, but its irradiance gain from the optimal tilt angle still substantially outweighs this thermal penalty.

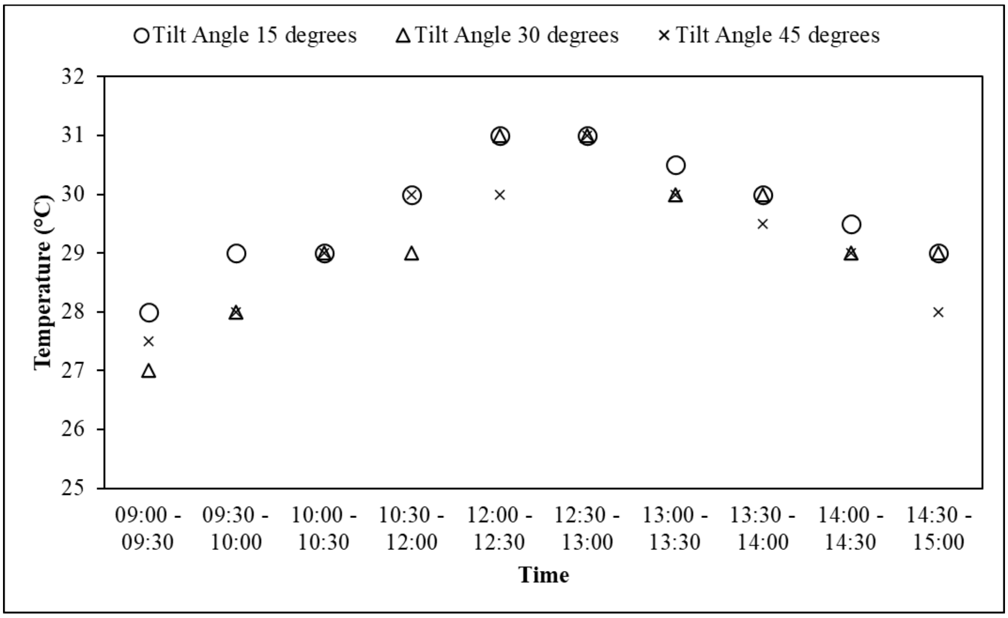

Figure 4. Effect of Tilt Angle on Temperature Output over Time

Figure 5 displays the power output over time. The 15° tilt angle generated the highest average power of 0.162 W, peaking at 0.407 W. The 30° and 45° angles generated average powers of 0.121 W and 0.098 W, respectively. Based on the average current, the estimated time required to fully charge a 3000 mAh battery from an empty state was calculated. The 15° tilt required 93.75 hours, the 30° tilt required 116.13 hours, and the 45° tilt required 137.93 hours.

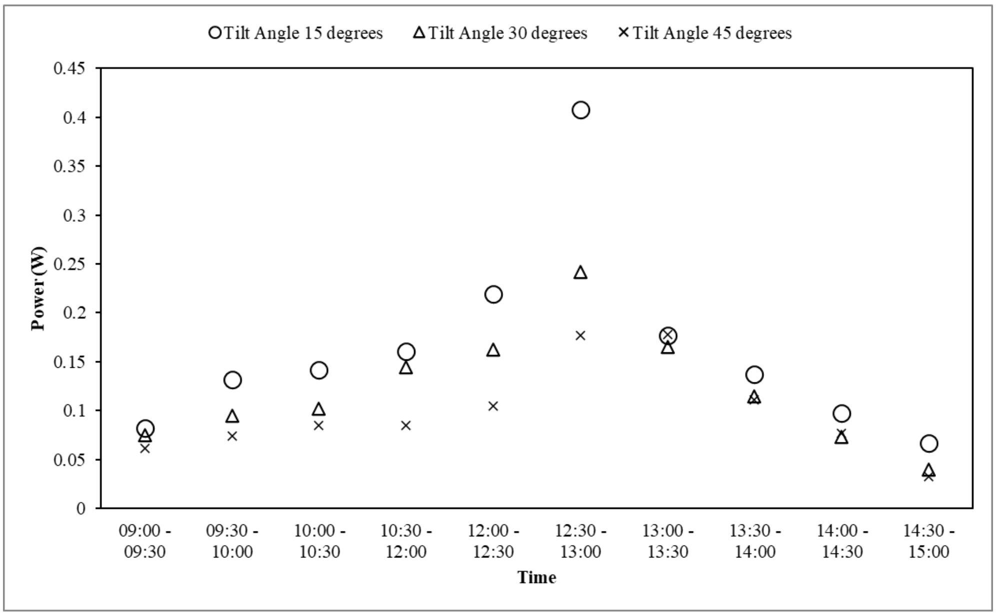

Figure 5. Effect of Tilt Angle on Power Output over Time

Charging Time

These results are consistent with previous studies indicating that lower tilt angles are optimal for equatorial regions (Irwanto, 2015). However, compared to Hidayanti (2020), who reported charging times of 74 hours for a 1350 mAh battery using a similar 250 mA panel, the charging duration in this study is significantly longer due to the larger battery capacity (3000 mAh) and the relatively low actual current output (average < 40 mA) compared to the panel's 500 mA rating. This discrepancy highlights the real-world efficiency losses in small-scale PV systems due to atmospheric attenuation, conversion losses, and non-ideal solar tracking.

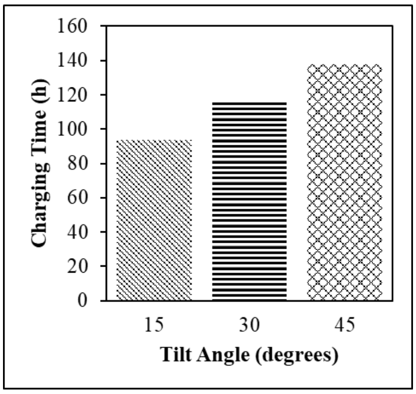

Figure 6. Chargin time relation with tilt angle.

CONCLUSION

This study experimentally evaluated a mini solar cell power bank system under tropical outdoor conditions in South Lampung, Indonesia. Complete measurement datasets across ten 30-minute intervals from 09:00–15:00 were recorded for tilt angles of 15°, 30°, and 45°. The 15° tilt proved optimal, yielding average current 38.39 mA, average voltage 4.08 V, and average power 0.162 W— improvements of 23.8% and 47.2% in current over 30° and 45° respectively. The 15° tilt gave the fastest theoretical charging time (93.77 h).

Future work should expand on these findings by integrating Maximum Power Point Tracking (MPPT), bifacial panels, or higher wattage modules to enhance practical viability for portable off-grid applications. Furthermore, subsequent research will incorporate precise irradiance measurements to better correlate environmental input with system output. This will be supported by a rigorous statistical analysis and uncertainty analysis to validate the reliability of the data and quantify the precision of the performance metrics in tropical climates.

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