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Investigation an Effect of Tilt Angle and Water Cooling on Performance of a Photovoltaic Module of a Solar-Powered Vehicle Charging Station

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A B S T R A C T

Recently, the use of electric vehicle increases significantly worldwide including in Indonesia. However, this trend is in contrast with availability of an electric vehicle charging station. Since Indonesia has a huge solar energy potential, it is possible to build a solar powered electric charging station. Various parameters that affect the performance of the solar panel have to be considered. The present work is performed into two parts, i.e. the first part is investigation of performance of the photovoltaic (PV) panel at tilt angle of 5°, 10°, 15°, 20°, and 25° and the second part is the investigation of performance of the PV panel without and with water cooling at optimum tilt angle obtained from the first part. Data collection is performed from 9 am to 2 pm for 5 days. The results show that the optimum tilt angle is found to be 20° with maximum conversion efficiency of 21.02%. Meanwhile, the water spray cooling of the PV module's surface can improve output power at the rate of 9.1%. The scientific innovation of the present work is the development of electric bicycle charging station with energy source from solar energy which is renewable and clean energy.

1. Introduction

Since depletion of fossil fuel and global warming increasing in last decade, many countries targeted massive use of renewable energy source. Solar energy, one of many renewables energies, has been utilized worldwide for various purposes, i.e. heating, cooling, and power generation [1-3]. Further, solar energy has been also used for emergency power supply for NICU at hospital in Iran [4]. The solar energy also has a potential for providing sustainable energy for natural disaster area [5].

Solar energy was emerging as beneficial renewable energy sources [6,7]. Photovoltaic panels

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harness solar energy to generate electricity, eliminating the need for fossil fuels and reducing greenhouse gas emissions [8,9]. Compare with other renewable energy systems, solar energy system is more proven technology which marking a pivotal shift in global power production technologies [10,11]. Solar electricity generation systems have some merits, such as energy-regeneration, cleanliness, no pollution, and safety [12]. However, preliminary work has to be performed before developing solar energy conversion system in order to obtain optimum parameter design [13], for example utilization of GIS software to figure out the strong solar radiation potential at specific area [14]. Numerical analysis is also important in designing energy conversion system [15].

Recently, the use of electric vehicle increases significantly worldwide, including in Indonesia, as consequent of the transition to net zero emission target [16, 17]. According to Akomea-Frimpong *et al.*, 2025 [18], global electric vehicle purchase rate about 5.3% year on year. Work performed by Li et al., 2025 [19] indicated that replacing internal combustion engine vehicles (ICEVs) with EVs could improve roadside air quality and reduce CO_2 emissions. Since the electric power used to recharge the electric vehicle generated from fossil fuel-based power plant, hence the use of electric vehicle not yet 100% carbon footprint free. Thus, it is urge to use renewable energy source, i.e. solar energy to power an electric vehicle charging station.

Indonesia has almost 208 GW solar energy potential [20]. Compared with other renewable energies, the amount of solar energy is the highest among others as shown in Table 1. Indonesia received average solar intensity about 4.8 kW/m^2/day. This amount is very good potential to be used as solar powered charging station.

Table 1. Indonesia's renewable energy potential [20]

No	Renewable energy	Potential (GW)
1	Bio energy	32.654
2	Wind energy	60.647
3	Solar energy	207.898
4	Hydro energy	75.000
5	Geothermal energy	25.800

Beside solar irradiance, other parameters such as orientation, tilt angle, and surface temperature of the PV module also can affect performance of the PV module [21]. Kumar *et al.,* 2011 [22] stated that PV cell orientation and tilt angle have more effect on the performance of the PV module. Figure 1 shows the schematic diagram of the tilt angle of the PV module. Solar irradiation from the sky has to component of the direct irradiation and the diffuse irradiation [23]. The tilt angle (β) is an angle between PV module and horizontal base plain.

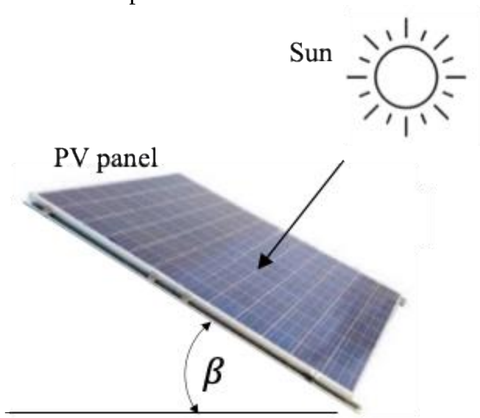

Figure 1. Definition of tilt angle

Many works on tilt angle optimization have been conducted to obtain maximum possible peak power output. It can be stated that the optimum tilt angle is depended on the location where the PV module is installed [24]. Alzahrani *et al.*, 2025 [25] obtained optimum of 25° tilt angle at Jeddah city. Al-Sayyab *et al.*, 2019 [26] predicted the optimum tilt angle of 28° using theoretical and experimental investigation at Basra city. Kallioğlu *et al.*, 2024 [27] found the optimum tilt angle of 31.33° at Ankara province. Meanwhile, Handoyo *et al.*, 2013 [28] observed the optimum tilt angle of 36°-39.4° at Surabaya city, Indonesia.

Typically, PV modules convert only approximately 20% of the solar irradiance into electricity, and the rest is converted into heat [29]. Increasing temperature of the PV module might reduce degree of its conversion efficiency [30]. Beside temperature of PV panel, temperature coefficient might also affect the performance of PV technologies [31]. Cooling of the PV surface is required to maintenance low surface temperature. One of various cooling techniques have been adopted for PV is water cooling. The use of water cooling can increase conversion efficiency of the PV module. Efficiency of the mono- crystalline PV module increased from 2.91 % to 12.76 % for the non- cooled and cooled panels [32]. Mostakim *et al.*, 2024 [33] observed PV panel efficiency enhancement up to 16.78 %, at water flow rate of 1.56 L/min. Water injection cooling resulted in an energy output growth [34]. The use of water-cooled PV panels is an attractive and feasible option for a short-term and long-term efficiency improvement with great impact on the expansion and durability of PV power plants [35].

Many electric vehicle charging stations have been built worldwide, but mostly of those stations in large scale and powered by conventional electric grid network. Limited electric bicycle charging station in small scale and powered by solar energy has been reported. This gap in research innovation has to be encountered. Thus, the effect of tilt angle and water spray cooling on performance of a 100 Wp PV panel is investigated in the present work. This work is as a part of optimization work in developing solar energy powered electric vehicle charging station. The performance, in term of output current and voltage, and conversion efficiency, of the PV module is evaluated at tilt angle of 5°, 10°, 15°, 20°, and 25°. These tilt angles are selected in the present work based on the previous work performed by Handoyo *et al*., 2013 [28] in the same island with the present work. They investigated tilt angles of 0 - 40°, hence the selection of tilt angles 5°, 10°, 15°, 20°, and 25° in the present work are acceptable. The performance of the PV module is also figured out without cooling and with water spray cooling. Although many works in solar energy have been reported so far, but limited works have been performed on solar powered electrical bicycle charging station

2. Materials and Methods

Figure 2 presents schematic diagram of the experimental setup. The setup consists of a 100 Wp poly-crystalline PV panel, a maximum power point tracker (MPPT), a battery, water tank, a pump, and water spray nozzle. The model of GH100P-18 polycrystalline PV panel is used in the present work with detail specification is given in Table 2.

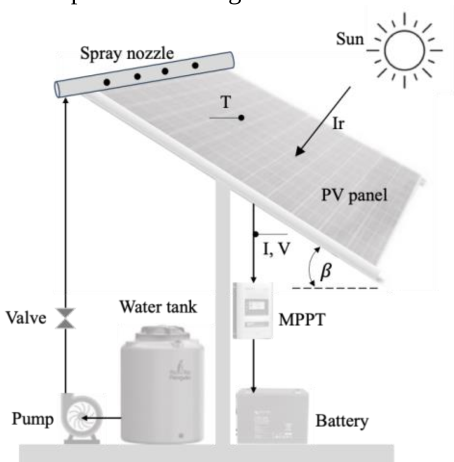

Figure 2. Experimental setup

Table 2. Specification of the PV panel

Polycrystalline PV panel	**Specification**
Rated maximum power (Pm)	100 W
Voltage at P_{max} (V_{mp})	17 V
Current at P_{max} (I_{mp})	5.89 A
Open-circuit voltage (V_{oc})	22.0 V
Short-circuit current (I_{sc})	6.08 A
Normal operating cell temp.	47±2℃
Dimension	1020×670×30 mm
Panel surface area (A)	0.6834 m^2

The PV panel converts solar irradiation into electric energy. The electric energy is stored in the battery. MPPT is used to control the voltage and current to the battery. Meanwhile, PV panel cooling system consists of a water tank, a pump, and spray nozzles. Water in the tank is pumped to the spray nozzles to generate intermittent water spray on the surface of the PV panel.

Experimental work is conducted at Energy Conversion Laboratory of Universitas AKPRIND Indonesia located in the latitude 7° 15’-49’ of the South with an average solar radiation about 4 $kWh/m^2/day$. The experimental work is divided into two parts. The first part is investigation of performance of the PV panel at tilt angle of 5°, 10°, 15°, 20°, and 25° and the second part is investigation of the performance without and with water cooling at optimum tilt angle obtained from the first part. Data collection is performed from 9 am to 2 pm for 5 days. The data taken are solar irradiance (Ir), surface temperature of the panel (T), output current of the panel (I), and output voltage of the panel (V). The output power and conversion efficiency of the panel is calculated using Eq. (1) and Eq. (2) [36].

$$P_{out} = V \times I \tag{1}$$

$$\eta = \frac{P_{out}}{A_{pv} \times I_r} \tag{2}$$

where A_{pv} is the PV area, I_r is the solar irradiance. According to Aly *et al.*, 2019 [29], it is only 20% of solar irradiance is converted into electric energy in the PV module. Taken into account surface area of the panel from the Table 1, the efficiency of the PV panel can be calculated using Eq. (3)

$$\eta = 0.2 \times \frac{P_{out}}{A_{pv} \times I_r} \tag{3}$$

3. Results and Discussion

Figure 3 displays solar irradiance during 5 days observation, day 1 for 5° tilt angle, day 2 for 10° tilt angle, day 3 for 15° tilt angle, day 4 for 20° tilt angle, and day 5 for 25° tilt angle. The data collection is done from 9 am to 2 pm. Due to varying weather condition during those days, the solar irradiance fluctuates every hour and the values are different for each day. The average value of solar irradiation in each day is given in Figure 4. It can be seen the highest solar irradiation occurs at day 4 (the tilt angle of 20°).

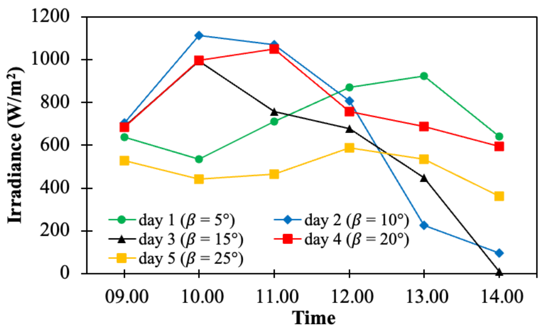

Figure 3. Solar irradiance during 5 days experiment

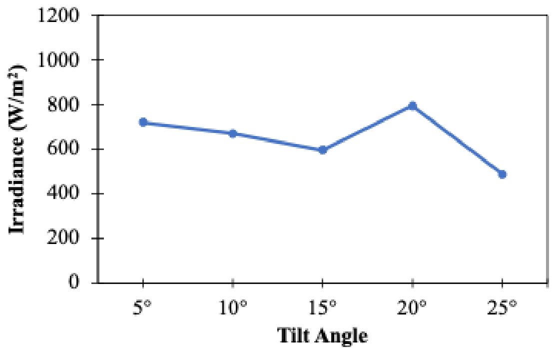

Figure 4. Average solar irradiance

Figure 5 shows an average output current and output voltage of the PV module at tilt angle of 5°, 10°, 15°, 20°, and 25°. The graph in Figure 5 cannot be used to analyse the optimum tilt angle in the present work since the solar irradiance to the surface is differ for each tilt angle. However, the graph reveals the trend of the output current and the output voltage. The voltage is more stable than the current at various tilt angles. The voltage ranges from 13.57 to 15.24 Volt. Meanwhile, the output current start from 0.56 Ampere at tilt angle of 25° till 1.50 Ampere at tilt angle of 20°.

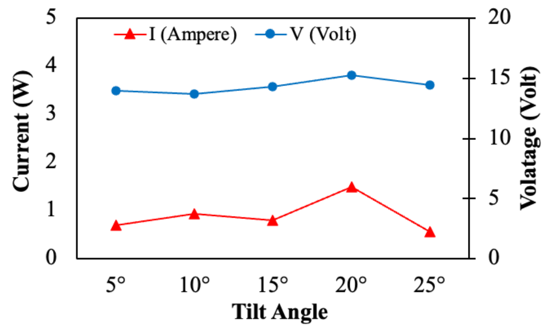

Figure 5. Output current and voltage

Optimum tilt angle is analyzed using Eq. (2) which is the ratio of output power to the input power (solar irradiance conversion efficiency) of the PV module. The power output and conversion efficiency are plotted in Figure 6. It can be stated that the optimum tilt angle in present work is 20° tilt angle facing north. The highest conversion efficiency at tilt angle of 20° is 21.02% and the lowest conversion efficiency is 9.95% at tilt angle of 5°. The highest efficiency occurs at tilt angle of 20° is due to the maximum output power can be generated by the PV module. The optimum tilt angle in present will work will differ with that different location. Besides location, variation of global direct irradiance may impact the optimum tilt angle [37]. In order to maintain the performance of PV panel, Sameera *at al.*, 2024 [21] suggested that solar panels should change the tilt angle monthly or seasonally for better utilization of solar energy. To obtain the best tilt angle of the PV panel, the Schwartz's model can be adopted with high accuracy [12].

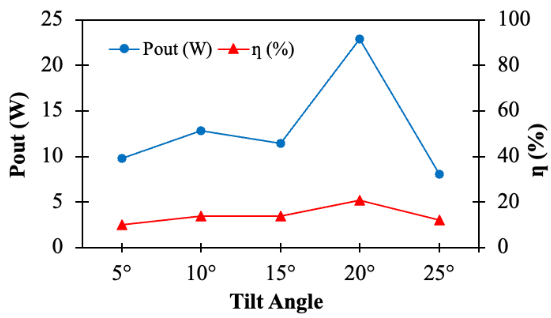

Figure 6. Output power and conversion efficiency

Meanwhile, Figure 7 displays an effect of water spray cooling on output power of the PV panel at tilt angle of 20°. The water flow rate is setup at 5 lpm which intermittent spray every 20 minute for 60 second. The results show that the cooling of the PV surface able to increase output power, from 8.10 W to 8.83 W, without cooling and with water cooling. The use of intermittent water spray enhances output power of 9.1%. However, this value is lower than the value obtained by Mostakim *et al.*, 2024 [33], Chanphavong *et al.*, 2022 [32], Chala, *et al.*, 2024 [34], and Zubeer & Ali, 2021 [38] as compared in Figure 8. This indicates the cooling is less effective in the present work, since the surface temperature of the panel is still under the normal operating temperature of the panel, i.e. 47±2℃ (See Table 2).

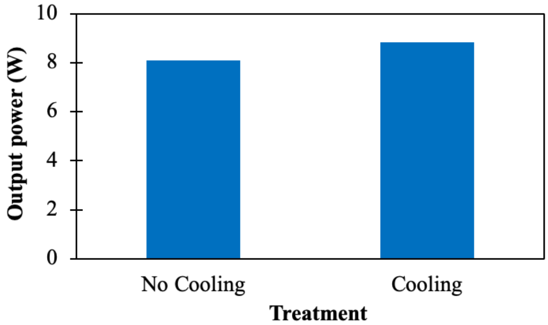

Figure 7. Cooling effect on output power

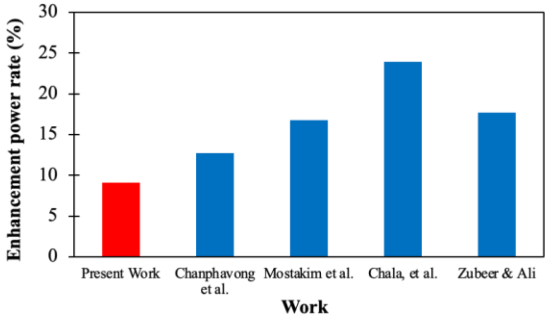

Figure 8. Enhancement of power rate

The optimum of tilt angle of 20° and cooling water flow rate of 5 lpm obtained in the present work can be adopted in other area. However, the latitude of the site, solar radiation, and watt peak of the solar panel have to be taken account in developing solar powered electrical bicycle charging station in other places.

4. Conclusions

The use of electric vehicle increases significantly worldwide including in Indonesia. However, this trend is in contrast with availability of an electric vehicle charging station. Mostly of those existing charging stations use electric energy which generated from coal power plant which is non-renewable and high pollutant risk energy conversion system. In order to encounter this problem, the electric bicycle charging station powered with solar energy is developed and test in the present work. The performance of the station in terms of output power and conversion efficiency is investigated at various tilt angles (5°, 10°, 15°, 20°, and 25°). The present work also investigates the effect of PV panel cooling on the performance of the station. The experimental work is conducted at Energy Conversion Laboratory of Universitas AKPRIND Indonesia. Data collection of solar irradiance (Ir), surface temperature of the panel (T), output current of the panel (I), and output voltage of the panel (V) are collected within 5 days from 9 am to 2 pm. The data are averaged to analyse the output power and conversion energy of the station. The main results are:

- The renewable and eco-friendly solar powered electric bicycle is successfully developed in the present work.
- Tilt angle affects the performance of the PV module. Optimum tilt angle of 20° is obtained with maximum conversion efficiency of 21.02%. Obviously, the value will vary depend on the location
- The performance of the PV module can also be improved by cooling of PV surface. Intermittent water spray cooling with flow rate of 5 lpm can improved output power at the rate of 9.1%.
- For future work, the optimum tilt angle of 20° and intermittent water spray cooling of the PV panel at the rate of 5 lpm can be adopted for developing large scale solar power electric vehicle charging station with consideration of the latitude, solar irradiation, watt peak of the solar panel.

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Nomenclature

A_{pv}	Panel's surface area (m^2)
I_{mp}	Current at maximum power (A)
I_{sc}	Short-circuit current (A)
P_m	Rated maximum power (W)
P_{out}	Actual power output (W)
T	Temperature (°C)
V_{mp}	Voltage at maximum power (V)
V_{oc}	Open-circuit voltage (V)
β	Tilt angle (°)
η	Efficiency (%)

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