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PREDICTION OF THE OPTIMUM PHOTOVOLTAIC OUTPUT BASED ON CELL TEMPERATURE AND SOLAR IRRADIANCE

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ABSTRACT

Energy-harvesting photovoltaic (PV) systems are common, but due to the challenges in managing the output, they raise serious difficulties. Climate variables have an impact on the uneven output performance of PV panels. The sunlight and the surrounding environment are unlimited making it challenging to estimate a PV panel system's output of electricity. Not only that, The PV panel will only provide power in parallel with its rated capacity under the Standard Test Condition (STC). STC requires 1000 Watts of sun energy per meter square of solar irradiance and cell temperature of 25 degrees Celsius. Therefore, the changing weather, which will impact the output power, requires prediction. Since the PV panel output will not generate according to its rating, PV power generation predictions requiring calculations of elements such as weather, sun hours, and temperature play a significant role. Hence, this research is related to the prediction of the optimum photovoltaic output based on cell temperature and local solar irradiation. The novelty of this research is all of the surrounding parameters used to predict the PV output are focused on the local area in Batu Pahat, Johor where the UTHM campus is located.

Keywords: photovoltaic, solar panel, renewable energy, prediction power output.

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1. INTRODUCTION

Renewable energy sources are referred to as clean energy sources and they are highly essential since they are ecologically friendly. Malaysia now generates around 2% of its energy from renewable sources, with a goal of reaching 20% penetration by 2025. Natural gas and coal constitute the majority of Malaysia's current energy mix [1]. As a result, this issue encourages a country to establish a more sustainable energy infrastructure in order to accommodate expansion. Renewable energy resources are increasing in popularity as they improve the efficiency of producing electricity [2]. In Malaysia, renewable energy sources include wind, sun, biomass, and tidal wave. This energy, however, is not fully utilized. Renewable energy technologies are attempts at sustainable development that help to minimize reliance on fossil fuels while also potentially reducing the consequences of climate change [3]-[6]. Even though energy may be supplied from several sources, fossil fuels currently provide the majority of the energy needed to fulfill the power needs. As a result, the relatively constant supply of fossil fuels will soon be interrupted. As a result, when traditional dependency on fossil fuels is said to have resulted in carbon dioxide emissions, greenhouse gas (GHG) concerns, and environmental damage, according to the increased awareness of a clean environment [7].

Photovoltaic energy is the most essential clean, renewable energy source, having the greatest ability to resolve the world's energy concerns. Along with its low cost and great efficiency, PV are built of silicon or other materials that convert sunlight into energy directly [8][9]. Due to expected cost reductions in PV technology, the use of PV power production systems will become more widely spread in the future [10]. PV power is generated based on the time, location, and surrounding climate conditions. Malaysia is located in a tropical climate zone with considerable rainfall and dry days on an annual basis due to the local tropical wet season. The PV panel will only provide power in parallel with its rated capacity under the Standard Test Condition (STC). STC requires 1000 Watts of sun energy per meter square of solar irradiance and a temperature of 25 degrees Celsius. Therefore, the changing weather, which will impact the output power, requires prediction. Since the solar panel output will not generate according to its rating, solar power generation predictions using computational methods requiring calculations of elements such as weather, sun hours and temperature play a significant role.

2. LITERATURE REVIEW

2.1 Photovoltaic Panel (PV)

Solar panels, often referred to as PV panels, harness and convert solar energy into electrical power. The term 'PV' in solar panels denotes 'photovoltaic', indicating that these panels comprise multiple photovoltaic cells linked together. These cells consist of semiconductor materials, with silicon being the most used. Due to the relatively low electrical output of individual cells, they are assembled in series and parallel arrangements to achieve the necessary current and voltage. These cells are usually encased within a glass layer and a plastic sheet, collectively forming what is typically recognized as a "panel" [11]. When sunlight hits the cells, it generates an

electric field, leading to the production of electrical energy. The intensity of the sun's rays directly influences the amount of electricity produced, with brighter sunlight yielding more power. Importantly, these cells can function without direct sunlight and are capable of generating electricity even on overcast days. The composition of photovoltaic cells includes various elements such as the photovoltaic panels themselves, inverters, electrical connections, and stable mechanical structures. These mechanical structures are designed to position the solar panels at an optimal angle, maximizing their efficiency throughout the day [12].

2.2 Electrical Performance of PV Panel

The electrical outputs of PV panels will vary since the PV modules will be exposed to Real Operating Conditions (ROC) that differ significantly from STC. STC is the global standard for PV panel reference ratings and parameters. PV panels are STC-rated at 1000 W/m2 of solar radiation and 25 degrees Celsius of cell temperature [13]. Hence, both parameters will be included in this research in order to predict power output with more precision. The environmental temperature is the temperature of the surroundings in which the PV system is installed. Depending on the geographic area, the average temperature may range from 25.6 ^{0}C to 27.8 ^{0}C and the daily solar irradiance or the intensity of sunlight can range between 400 Wm-2 and 600 Wm-2. These two major parameters will be the main elements in predicting the power output of PV panels.

3. METHODOLOGY

3.1 PV Module Datasheet

The solar PV panel utilized for the development of the prototype model in this research is considered to be an 18W aluminum substrate mono solar panel as in Figure-1. The specifications of solar panels are outlined in Table-1.

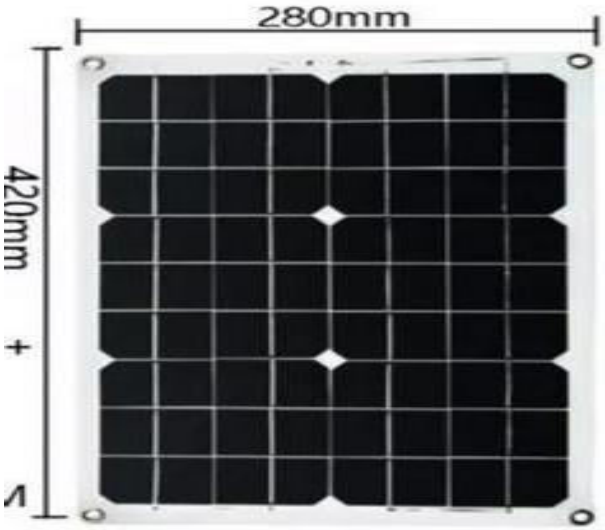

Figure-1. The PV solar panel.

Table-1. Datasheet of PV solar panel.

Features	Specification
Power	18W ± 5%
Size	420 x 280 x 2.5mm
DC Output	12V / 1.5A
USB Output	5V / 1.7A
Type	Mono Solar Panel
Material	Aluminum Substrate

3.2 Cell Temperature (T_{cell})

The temperature of a PV panel's cells is a crucial factor. This is due to the fact that both output power and efficiency are temperature highly perceptive. At the research site, Universiti Tun Hussein Onn Malaysia, the PV cells produce the actual data temperature. In order to compute for PV output portrayal, temperature data are collected three times a day at 9 a.m., 12 p.m., and 5 p.m. using a digital thermometer in Figure-2.

Figure-2. Digital thermometer

3.3 Solar Irradiance (G)

The solar power meter will provide the daily solar irradiance, as shown in Figure=3, which is being used as an input for the computational method's power output prediction. The solar power meter is placed next to the solar panel and the measuring process is completed by monitoring until the value reaches the maximum static level.

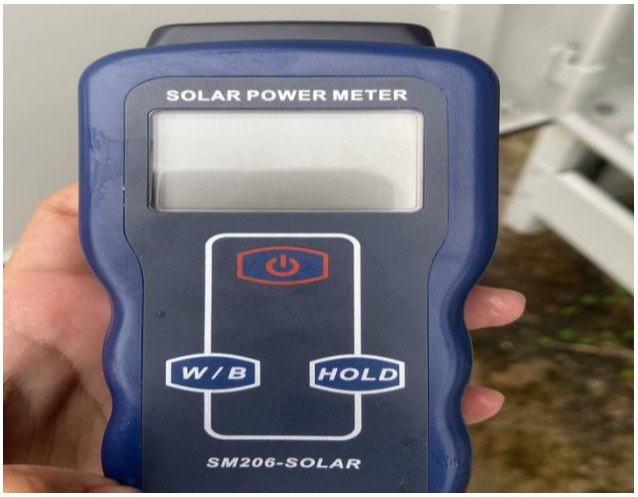

Figure-3. Solar power meter.

3.4 Prediction Power Output

The ambient temperature and solar irradiation of the area must be included when predicting power output. Furthermore, the datasheet's rated power of 450W is important for calculating predicted output power. The cell temperature must be estimated in the first step using Equation (1) [14]. The derating factor related to the temperature impact is then determined using Equation (2) [14]. Power output prediction was achieved by considering all derating factors and multiplying them by the power rating from the datasheet, as indicated in Equation (3) [14].

Cell or module temperature at ROC,

$$T_{cell} = T_{amb} + \left[\left(\frac{NOCT - 20\ deg\ C}{800\ W_{m-2}}\right) \times G\right] \quad (1)$$

Where

T_{amb} is ambient temperature (^{o}C)
NOCT is Nominal Operating Cell Temperature (^{o}C)
G is solar irradiance

Derating factor of power due to cell temperature effect,

$$k_{tem\_p} = 1 + \left[\left(\frac{a}{100\%}\right) \times (T_{cell} - T_{stc})\right] \quad (2)$$

Thus, power output for Real Operating Condition (ROC) is

$$P_{roc} = P_{stc} \times k_{power_{deration}} = P_{stc} \times k_{mm} \times k_{tem\_p} \times k_g \times k_{dirt} \times k_{age} \quad (3)$$

Peak sun factor, $kg = \frac{G}{1000}$ (4)

Where

α is temperature coefficient of power (% per ^{o}C)
T_{stc} is temperature at Standard Test Condition (STC)
$k_{power\_deration}$ is the total de-rating factors related to power
k_{mm} is a de-rating factor due to module mismatch of power [15]
kg is the peak sun factor
k_{dirt} is a de-rating factor due to dirt [15]
k_{age} is a de-rating factor due to aging [15]

Temperature for the surroundings and solar irradiation are the important input parameters used to calculate the output power of a PV panel analysis of data collected. Furthermore, derating factors must be considered in the prediction to provide a more precise outcome. This is because certain conditions are always available in PV panels while they are in use.

4. RESULT AND DISCUSSIONS

Graphs will be used to show daily and monthly power output. All graphs resulting from data collecting have been shown for this sub-topic between June and October 2023.

4.1 Total of daily PV Power Output

Total daily PV power output has been calculated using equation (1) until (4) based on parameters that have been collected from the PV solar panel. As in Figure 4, the highest power output was anticipated to be 15.177W on June 6, 2023, with the lowest power output predicted to be 14.835W on June 19, 2023. This month's average power output is 14.977W.

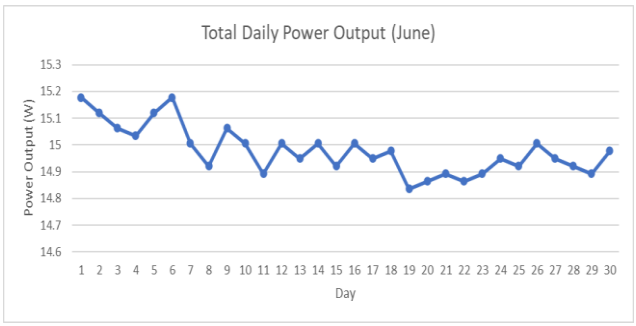

Figure-4. Total daily power output prediction for June.

Figure-5 shows the pattern of daily power output prediction for February. It can be seen that highest power output was on 1st July 2023 with 15.12W while the lowest power output was predicted to be on day 25 with 14.835W. Monthly average power output for this month is 14.948W.

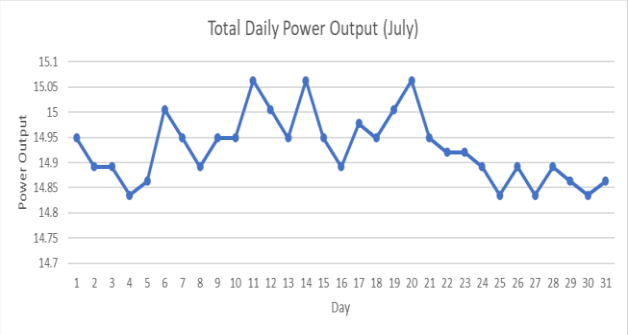

Figure-5. Total daily power output prediction for July.

Figure-6 illustrates the daily power output prediction pattern for August. The highest power output was on day 18 and 21 with 15.063W, while the lowest power output was forecasted on August 22, 2023 with 14.778W. This month's average power output is 14.945W.

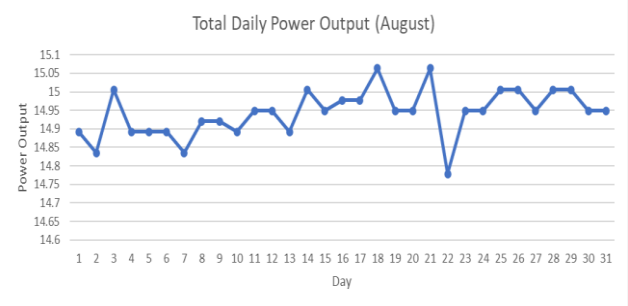

Figure-6. Total daily power output prediction for August.

Figure-7 shows the pattern of daily power output prediction for April. It can be seen that highest power output was on 24th September 2022 with 15.063W while the lowest power output was predicted to be on the first day and day 16 with 14.807W. Monthly average power output for this month is 14.922W.

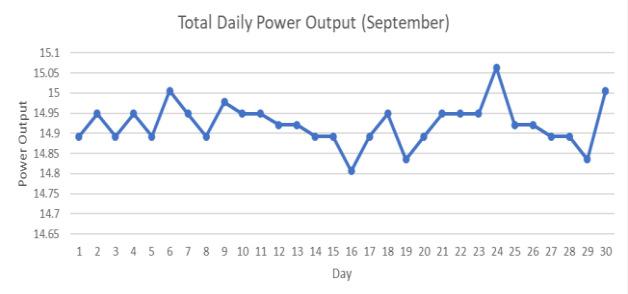

Figure-7. Total daily power output prediction for September.

Figure-8 shows the pattern of daily power output prediction for October. It can be seen that the highest power output was on day 28 with 15.006W while the lowest power output was predicted to be on 6th May 2021 with 14.721W. The monthly average power output for this month is 14.887W.

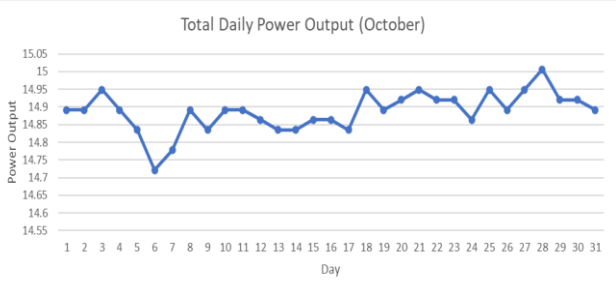

Figure-8. Total daily power output prediction for October.

4.2 Total Average of Monthly PV Power Output

In order to improve the findings, overall power output prediction was also conducted. Figure-9 illustrates the overall monthly average PV power output from June to October of the year 2023. The highest overall power output was 14.977W in June. This is due to Malaysia is dominated by a Tropical Wet climate, which may result in both scorching temperatures and tropical humidity. It is warm to hot, due to the lesser of rain in June. While the lowest average power output of 14.887W was predicted for October since a cloudy environment may reduce the effectiveness of solar panels by allowing less sunlight to fall on them.

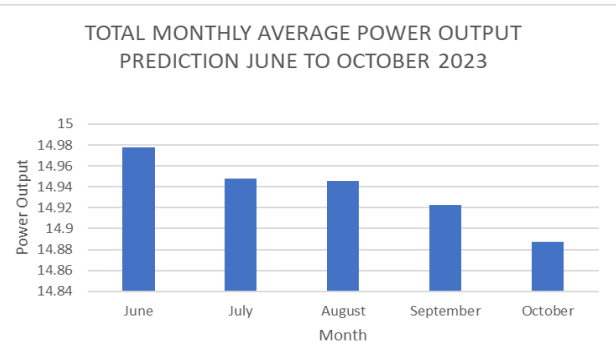

Figure-9. Total monthly average power output from June to October.

According to the findings, high temperatures do not result in a huge amount of solar radiation and significant power output. This is because, according to the calculated average temperatures, ambient temperature, and sun irradiation influenced the power output of the PV solar panel. Not only that, de-rating factors also resulted in a more exact and realistic estimate. As a result, the graphs, as stated, are the outcomes of findings those potential parameters into account.

5. CONCLUSIONS

To conclude what has been said thus far, the PV module system will be likely to depend on environmental parameters such as temperature, solar irradiation, and de-rating factors for dirt, age, and so on. This paper presents the real power output of a PV module that will be different from what would be indicated on the datasheet. As a result, it is one of the main causes why predicting PV

power output is essential, specifically when developing a PV system. The result shows that the highest average power output was in June with 14.977W followed by the lowest average power output in October with 14.887W. The prediction of the electrical power supplied by the PV panel is crucial since the PV panel can only deliver rated output power under STC. As a result, it is reasonable to forecast that the potential to predict PV panel electrical power output can assist engineering students, PV engineers, technicians, or designers in designing PV systems.

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